The 2024

EPA Automotive Trends Report
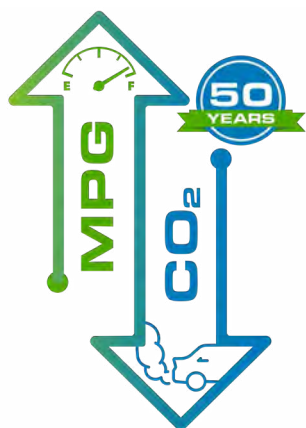
Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975

November 25, 2024

This year marks the 50th anniversary of the U.S. Environmental Protection Agency's Automotive Trends Report. This report, which provides the public unparalleled insight into the automotive industry, exemplifies not only the important work that the EPA is doing today, but also the long and rich history of the agency's commitment to science, data and transparency.

The EPA was founded with strong bipartisan support to protect our environment and public health. The EPA's partnership with the automotive industry was established from the very beginning, as the Clean Air Act of 1970 tasked the fledgling agency with the ambitious goal of reducing car pollution. In the years that followed, the EPA's emissions standards have catalyzed widespread use of new, clean technologies; eliminated lead in gasoline; reduced evaporative emissions from vehicles; and ultimately led to an impressive 99 percent reduction of common vehicle-tailpipe pollutants, such as hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter. These improvements have made direct impacts on our air quality, improved people's health and saved lives.

Through all the incredible change and innovation that has taken place in the auto industry since 1975, the Trends Report has been there to provide data, insight and transparency to the American public. The EPA has been gathering and maintaining data that covers every new light-duty vehicle produced for sale in the United States since model year 1975, and this unique dataset forms the foundation of this annual resource. As with each iteration, this edition adds new analysis and more data, including new layers of transparency through its online companion data tools. The report also provides a detailed look at how automotive manufacturers are doing under the EPA's current light-duty greenhouse gas standards, providing critical transparency on this important program. By understanding our history and by setting a common baseline for where we are today, the Trends Report is part of the backbone of what the EPA and the automotive industry have accomplished and will be able to accomplish in the future.

I am proud to introduce the 50th anniversary EPA Automotive Trends Report. This report continues to be a critical way that the EPA delivers on its mission to protect human health and the environment for more than half a century and counting. Congratulations to the incredible career team at the EPA who have made this report possible. I hope that everyone who relies on this authoritative report finds it as insightful and informative as ever.

Michael S. Regan

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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.

Since 1975, EPA has collected data on every new light-duty vehicle model sold in the United States 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 the following:

- This edition of the report is the 50th anniversary of the report and now contains data spanning 50 years of automotive history. The report has continually evolved since its inception, with this edition adding or updating many figures and analysis to better explore recent industry electrification trends.

- In March 2024, EPA finalized revised light-duty GHG standards for model year 2027-2032, and in 2024 NHTSA subsequently published revised fuel economy standards for model years 2027-2031. This report has been updated to reflect these changes wherever relevant.

- EPA has also updated the data available on the report webpage to provide more details on the data used for this report. The report data webpage can be found here: https://www.epa.gov/automotive-trends/explore-automotive-trends-data.
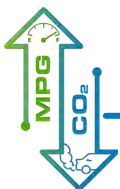
B. Manufacturers in this Report

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 2023 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 volume. These manufacturers produced at least 150,000 vehicles each in the 2023 model year and accounted for more than 97% 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 2023, including their associated makes, and their categorization for this report. Only vehicle brands produced in model year 2023 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.
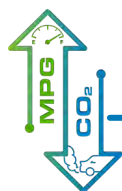
Table 1.1. Model Year 2023 Manufacturer Definitions

	Manufacturer	Makes in the U.S. Market
Large Manufacturers	BMW	BMW, Mini, Rolls Royce
	Ford	Ford, Lincoln, Roush, Shelby
	General Motors (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	Fisker	Fisker
	Jaguar Land Rover	Jaguar, Land Rover
	Lucid	Lucid
	Mitsubishi	Mitsubishi
	Rivian	Rivian
	Volvo	Lotus, Polestar, Volvo
	Aston Martin*	Aston Martin
	Ferrari*	Ferrari
	McLaren*	McLaren

* Small Volume Manufacturers

C.   Fuel Economy and CO_2 Metrics in this Report

All data in this report for model years 1975 through 2023 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 2024, which are **preliminary** and are based on data, including projected production volumes, provided to EPA by automakers prior to releasing vehicles for sale to the public. 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
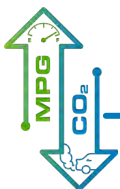
future model years, and past performance does not necessarily predict future industry trends.
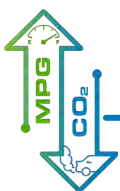
The carbon dioxide (CO_2) emissions and fuel economy data in this report fall into one of two categories based on the purpose of the data and the subsequent required emissions test procedures. The first category is **compliance** data, which is measured using laboratory tests required by law for CAFE 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 generally should not be compared to the real-world CO_2 data presented elsewhere in this report. For a more detailed discussion of the fuel economy and

CO_2 data used in this report, including the differences between real-world and compliance data, see Appendices C and D.

D. Other Sources of Data

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.

Additional detailed vehicle data is available on www.fueleconomy.gov, which is a web resource that helps consumers make informed fuel economy choices when purchasing a vehicle and achieve the best fuel economy possible from the vehicle they own. EPA supplies the underlying data, much of which can be downloaded at https://fueleconomy.gov/feg/download.shtml.

In addition, EPA's Green Vehicle Guide is an accessible, transportation-focused website that provides information, data, and tools on greener options for moving goods and people.

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/home.
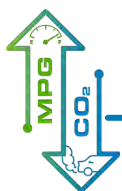
2. Fleetwide Trends Overview

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 2023 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

The downward trend for the average new vehicle real-world CO_2 emission rate continued in model year 2023. The average model year 2023 vehicle produced 319 grams per mile (g/mi) of CO_2, which is 18 g/mi less than the previous model year, and the lowest emission rate on record. Real-world fuel economy increased by 1.1 mpg to a record high 27.1mpg.[1] The trends in CO_2 emissions and fuel economy since 1975 are shown in Figure 2.1.

Many factors are responsible for decreasing new vehicle CO2 emissions, including increased production of a wide range of technologies. This includes increased production of battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) which have noticeably influenced the overall trends. Without BEVs and PHEVs, the average new

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

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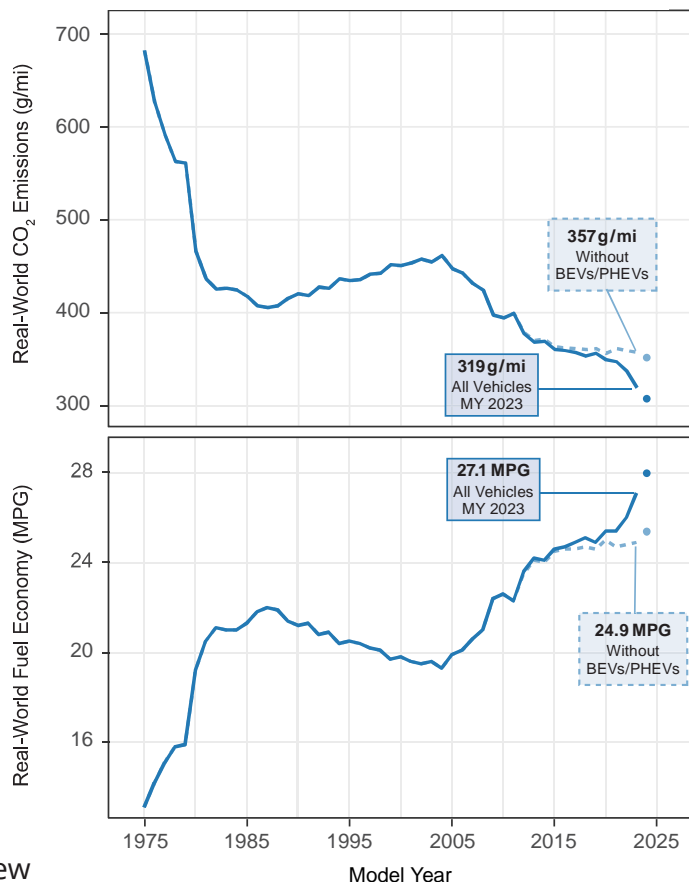
[1] EPA generally uses unrounded values to calculate values in the text, figures, and tables in this report. This approach results in the most accurate data but may lead to small apparent discrepancies due to rounding.
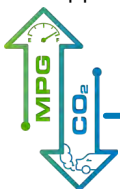
vehicle real-world CO_2 emission rate was 37 g/mi higher, and the year over year improvement in model year 2023 was only 1.4 g/mi.

Preliminary data suggest that the average new vehicle CO_2 emission rate and fuel economy will continue to improve in model year 2024, and that the impact of BEVs and PHEVs will continue to grow. The preliminary model year 2024 data are based on production estimates provided to EPA by manufacturers months before the vehicles go on sale. The data are a useful indicator, however there is always uncertainty associated with such projections, and we caution the reader against focusing only on these data. Projected data are shown in Figure 2.1 as a dot because the values are based on manufacturer projections rather than final data.

While the most recent annual changes often receive the most public attention, the greatest value of the Trends database is to document long-term trends. The magnitude of changes in annual CO_2 emissions and fuel economy tend to be small relative to longer, multi-year trends. Figure 2.2 shows fleetwide estimated real-world CO_2 emissions and fuel economy for model years 1975–2023. 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.

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. BEVs, 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). The fuel economy of BEVs, in mpge, is included in the fleet average shown in Figure 2.2 and elsewhere in this report. If electric vehicles continue to capture a larger market share, the overall relationship between fuel economy and tailpipe CO_2 emissions will change.
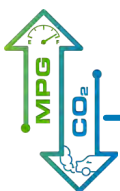
Figure 2.2. Trends in Fuel Economy and CO_2 Emissions Since Model Year 1975
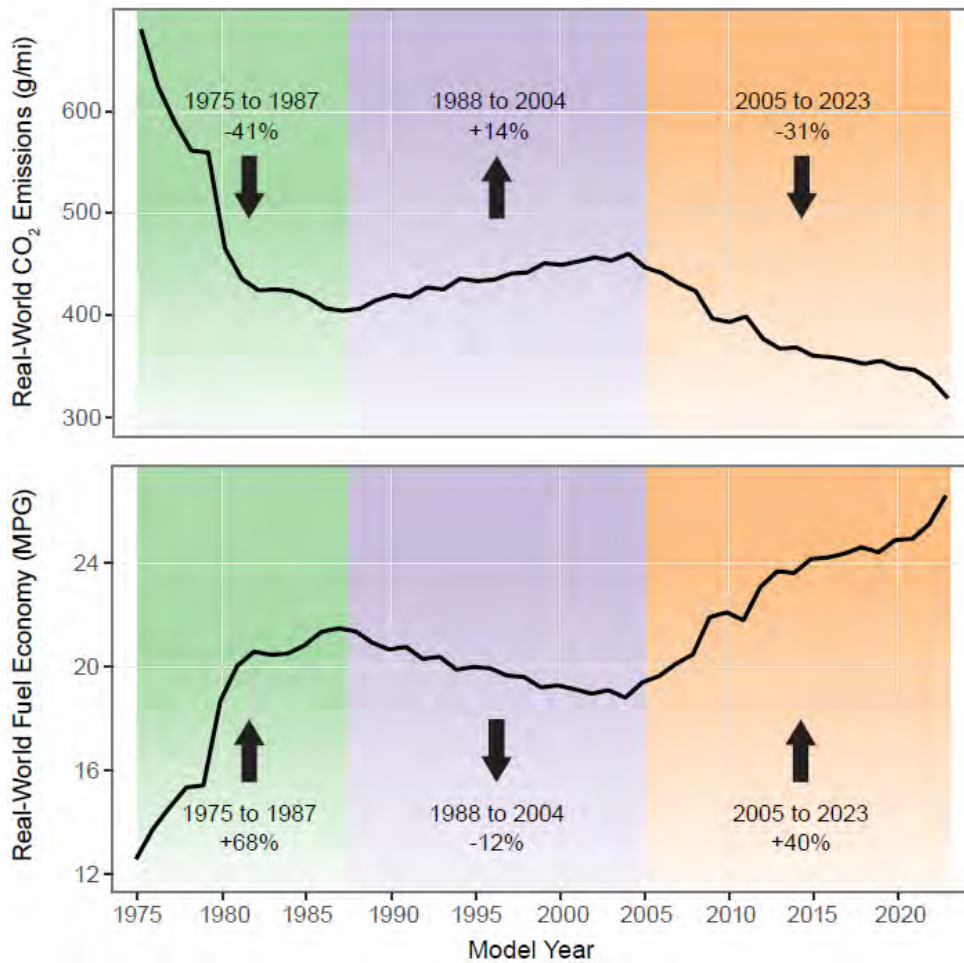
Another way to look at CO_2 emissions over time is to examine how the distribution of new vehicle emission rates have changed. Figure 2.3 shows the distribution of real-world tailpipe CO_2 emissions for all vehicles produced within each model year. Half of the vehicles produced each year are clustered 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 battery 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. The introduction of zero tailpipe emission BEVs in model year 2011 and their growth past 5% market share in model year 2022 are both visible in Figure 2.3.
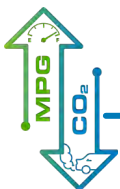
Figure 2.3. Distribution of New Vehicle CO2 Emissions by Model Year[2]
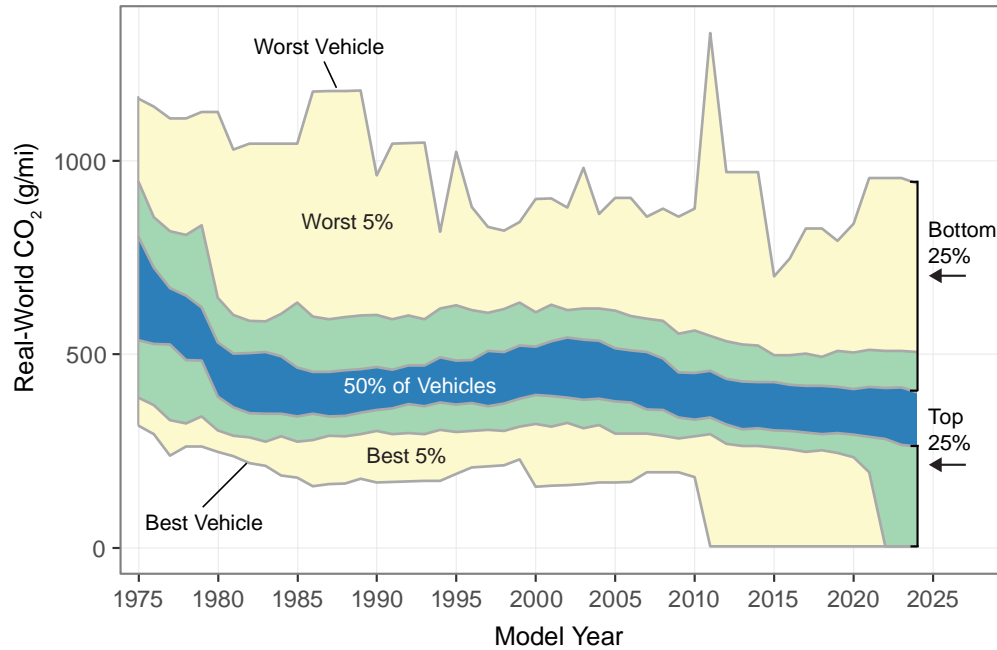
It is important to note that the methodology used in this report for calculating estimated real-world fuel economy and CO_2 emission values has changed over time to reflect changing vehicle technology and operation. For example, the estimated real-world fuel economy for a 1980s vehicle is somewhat higher 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.

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[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.
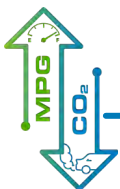
B. Production Trends

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 January 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 discrepancies 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 on average roughly 0.4% 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, economic conditions 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 as well as vehicle production and supply chains. Figure 2.4 shows the production trends by model year for model years 1975 to 2023. Model year 2023 production was 14,196,404 vehicles.

Figure 2.4. New Vehicle Production by Model Year
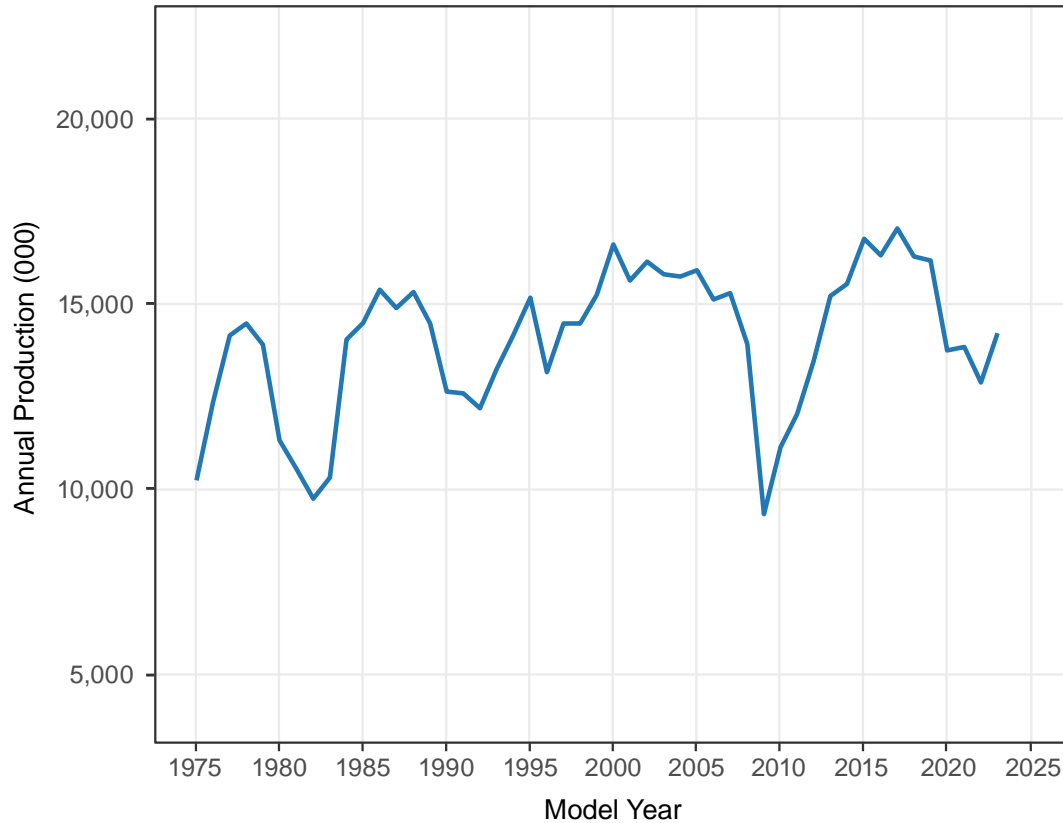
C. Manufacturer Fuel Economy and CO_2 Emissions

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.

Over the last five years, as shown in Figure 2.5, nine of the fourteen largest manufacturers selling vehicles in the U.S. decreased new vehicle estimated real-world CO_2 emission rates. Tesla was unchanged because their all-electric fleet produces no tailpipe CO_2 emissions. Between model years 2018 and 2023, Mercedes achieved the largest reduction in CO_2
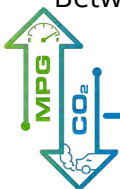
emissions at 73 g/mi. Volkswagen (VW) achieved the second largest reduction in overall CO_2 tailpipe emissions, at 44 g/mi, and BMW had the third largest reduction in overall CO_2 tailpipe emissions at 34 g/mi. Ford, Hyundai, Kia, Nissan, Stellantis, and Toyota also achieved overall emission reductions.

Four manufacturers increased new vehicle CO2 emission rates between model years 2018 and 2023 (Honda, Mazda, GM, and Subaru). Honda had the largest increase at 18 g/mi. Mazda had the second largest increase at 12 g/mi, and General Motors (GM) had the third largest increase at 11 g/mi.

For model year 2023 alone, Tesla's all-electric fleet had the lowest tailpipe CO_2 emissions of all large manufacturers at 0 g/mi. Tesla was followed by Kia at 289 g/mi, Hyundai at 292 g/mi, and Mecedes at 304 g/mi. At 402 g/mi, Stellantis had the highest new vehicle average CO_2 emissions and lowest fuel economy of the large manufacturers in model year 2023, followed by GM at 396 g/mi and Ford at 374g/mi. Tesla also had the highest overall fuel economy, followed by Kia, Hyundai, and Nissan.

Figure 2.5 is organized according to increasing fuel economy values, but the order would change if based on CO_2 emission rates. This is due the fact that BEVs and PHEVs have a different relationship between tailpipe emissions and fuel economy than other vehicles, and different rates of adoption of BEVs and PHEVs between manufacturers.

For vehicles powered only with gasoline, fuel economy and tailpipe CO_2 emissions are related via a straightforward inverse relationship where increasing fuel economy decreases CO_2 emissions. However, the relationship between fuel economy and tailpipe CO_2 emissions is different for PHEVs, which use electricity in addition to gasoline, and EVs, which use only electricity. For PHEVs and BEVs, the electricity used by the vehicle results in 0 g/mi of tailpipe CO_2 emissions. However, the overall efficiency of PHEVs and BEVs is reported in terms of mpge, or miles-per-gallon-of-gasoline-equivalent, which is a measure of the total energy the vehicle uses, in terms of the amount of energy in a gallon of gasoline. Therefore, the relationship between mpge and tailpipe CO_2 emission is not the same for PHEVs and BEVs as it is for gasoline vehicles.

As a result, manufacturers who produce more BEVs and PHEVs will have lower CO_2 emissions relative to their fuel economy than other manufacturers that produce fewer BEVs and PHEVs. For example, in model year 2023 BMW and Mazda had the same average fuel economy of 27.6 mpge, but BMW, which produced both BEVS and PHEVs, has a lower average CO_2 rate than Mazda, which did not produce BEVs or PHEVs.

Figure 2.5. Changes in Estimated Real-World Fuel Economy and CO₂ Emissions by Manufacturer

Fuel Economy (MPG), 2018 − 2023

Manufacturer	2018	2023
Tesla	113.7	120.6
Kia	27.8	30.4
Hyundai	28.6	29.8
Nissan	27.1	28.9
Subaru	28.4	28.7
Honda	28.3	30.0
BMW	26.0	27.6
Mazda	27.6	28.7
Toyota	25.5	27.5
Mercedes	23.5	27.5
VW	24.6	27.0
Ford	22.4	23.2
GM	22.4	23.0
Stellantis	21.7	21.8
All Manufacturers	**25.1**	**27.1**

CO₂ Emissions (g/mi), 2018 − 2023

Manufacturer	2018	2023
Tesla		0
Kia	319	289
Hyundai	311	292
Nissan	327	305
Subaru	310	311
Honda	296	314
BMW	339	305
Mazda	310	322
Toyota	348	322
Mercedes	377	304
VW	361	317
Ford	397	374
GM	386	396
Stellantis	409	402
All Manufacturers	**353**	**319**

Table 2.1. Production, Estimated Real-World CO2, and Fuel Economy for Model Year 1975–2024

Model Year	Production (000)	Real-World CO_2 (g/mi)	Real-World FE (MPG)	Model Year	Production (000)	Real-World CO_2 (g/mi)	Real-World FE (MPG)
1975	10,224	681	13.1	2000	16,571	450	19.8
1976	12,334	625	14.2	2001	15,605	453	19.6
1977	14,123	590	15.1	2002	16,115	457	19.5
1978	14,448	562	15.8	2003	15,773	454	19.6
1979	13,882	560	15.9	2004	15,709	461	19.3
1980	11,306	466	19.2	2005	15,892	447	19.9
1981	10,554	436	20.5	2006	15,104	442	20.1
1982	9,732	425	21.1	2007	15,276	431	20.6
1983	10,302	426	21.0	2008	13,898	424	21.0
1984	14,020	424	21.0	2009	9,316	397	22.4
1985	14,460	417	21.3	2010	11,116	394	22.6
1986	15,365	407	21.8	2011	12,018	399	22.3
1987	14,865	405	22.0	2012	13,449	377	23.6
1988	15,295	407	21.9	2013	15,198	368	24.2
1989	14,453	415	21.4	2014	15,512	369	24.1
1990	12,615	420	21.2	2015	16,739	360	24.6
1991	12,573	418	21.3	2016	16,278	359	24.7
1992	12,172	427	20.8	2017	17,016	357	24.9
1993	13,211	426	20.9	2018	16,260	353	25.1
1994	14,125	436	20.4	2019	16,139	356	24.9
1995	15,145	434	20.5	2020	13,721	349	25.4
1996	13,144	435	20.4	2021	13,812	347	25.4
1997	14,458	441	20.2	2022	12,860	337	26.0
1998	14,456	442	20.1	2023	14,196	319	27.1
1999	15,215	451	19.7	2024 (prelim)		305	28.0

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
2010	Hyundai	Mercedes	Honda FCX	60.2	FCEV	Smart Fortwo	36.8
2015	Mazda	Stellantis	BMW i3	121.3	BEV	Mitsubishi Mirage	39.5
2016	Mazda	Stellantis	BMW i3	121.3	BEV	Mazda 2	37.1
2017	Honda	Stellantis	Hyundai Ioniq	132.6	BEV	Mitsubishi Mirage	41.5
2018	Tesla	Stellantis	Hyundai Ioniq	132.6	BEV	Mitsubishi Mirage	41.5
2019	Tesla	Stellantis	Hyundai Ioniq	132.6	BEV	Mitsubishi Mirage	41.6
2020	Tesla	Stellantis	Tesla Model 3	138.6	BEV	Mitsubishi Mirage	41.6
2021	Tesla	Stellantis	Tesla Model 3	139.1	BEV	Mitsubishi Mirage	41.6
2022	Tesla	Stellantis	Lucid Air G	131.4	BEV	Mitsubishi Mirage	41.6
2023	Tesla	Stellantis	Lucid Air AWD	140.3	BEV	Mitsubishi Mirage	41.6
2024 (prelim)	Tesla	Stellantis	Hyundai Ioniq 6	137.0	BEV	Mitsubishi Mirage	40.0

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[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.
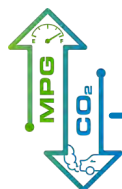
Table 2.3. Manufacturer Estimated Real-World Fuel Economy and CO_2 Emissions for Model Year 2022–2024

Manufacturer	MY 2022 Final Real-World FE (mpg)	MY 2022 Final Real-World CO_2 (g/mi)	MY 2023 Final Real-World FE (mpg)	MY 2023 Final FE Change from MY 2022 (mpg)	MY 2023 Final Real-World CO_2 (g/mi)	MY 2023 Final CO_2 Change from MY 2022 (g/mi)	MY 2024 Preliminary Real-World FE (mpg)	MY 2024 Preliminary Real-World CO_2 (g/mi)
BMW	25.3	344	27.6	2.3	305	-39	29.1	285
Ford	23.1	380	23.2	0.1	374	-6	23.8	365
GM	22.0	406	22.4	0.4	396	-9	23.9	366
Honda	28.7	309	28.3	-0.4	314	4.4	29.8	296
Hyundai	29.1	302	29.8	0.7	292	-11	30.0	286
Kia	28.6	306	30.4	1.7	289	-17	29.6	289
Mazda	27.0	328	27.6	0.5	322	-6	27.8	319
Mercedes	23.7	372	27.5	3.7	304	-68	30.2	268
Nissan	27.4	322	28.9	1.4	305	-17	28.6	306
Stellantis	21.3	415	21.8	0.5	402	-13	23.3	360
Subaru	27.9	318	28.4	0.4	311	-7	28.0	316
Tesla	119.3	0	120.6	1.3	0	0	117.4	0
Toyota	27.8	319	27.5	-0.3	322	2	28.3	310
VW	26.1	333	27.0	1.0	317	-16	27.9	305
All Manufacturers	**26.0**	**337**	**27.1**	**1.1**	**319**	**-18**	**28.0**	**305**

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 can 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 have a gross vehicle weight rating[6] (GVWR) of more than 6,000 pounds or have four-wheel drive and meet various off-road requirements, such as ground clearance, can also qualify as light trucks. Vehicles that do not meet these requirements are considered cars. For more information on car and truck regulatory definitions, see Appendix F.

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

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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 rating is the combined weight of the vehicle, passengers, and cargo of a fully loaded vehicle.
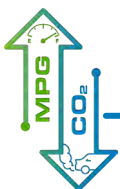
report uses the current regulatory car and truck definitions, and these changes have been propagated back throughout the historical data.
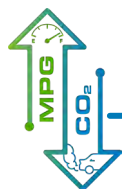
This report further separates the car and truck regulatory classes into five vehicle type categories based on their body style classifications under the fuel economy labeling program. The regulatory car class is divided into two vehicle types: sedan/wagon and car SUV. The sedan/wagon vehicle type includes mini-compact, 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
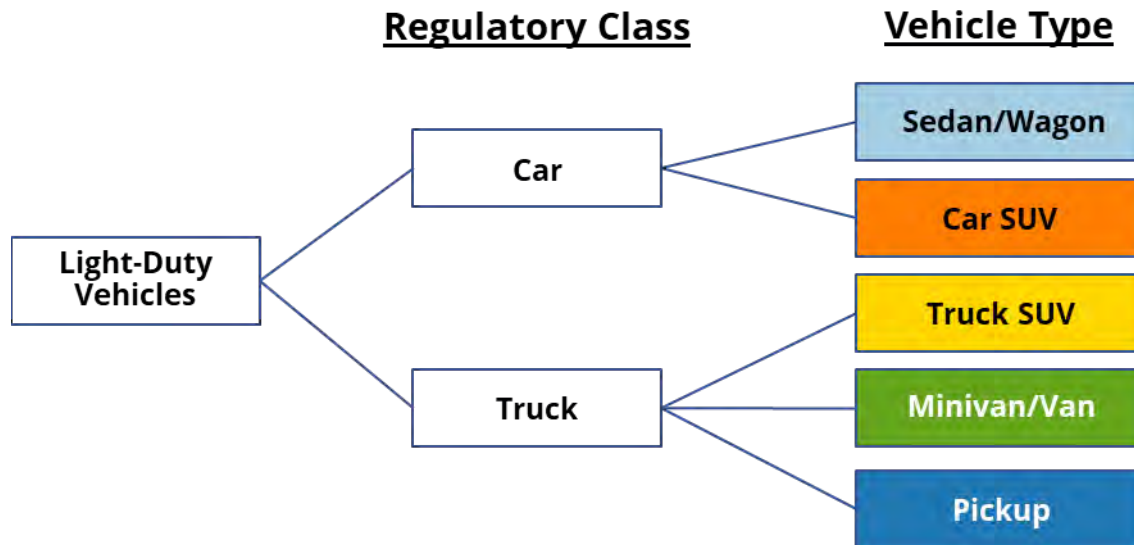
Fuel Economy and CO_2 by Vehicle Type

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
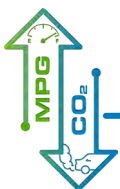
vehicle type towards a combination of truck SUVs, car SUVs, and pickups. Sedan/wagons were the dominant vehicle type in 1975, when more than 80% of vehicles produced were sedan/wagons. Since then, their production share has generally been falling, and with a market share of only 25% in model year 2023, sedans/wagons now hold less than a third 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 2023, both car and truck SUVs increased market share, to their highest combined percentage of market share. Truck SUV production share reached 45%, while Car SUV production share reached 12%. 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 15% of the market in model year 2023. Minivan/vans captured less than 5% of the market in 1975, increased to 11% in model year 1995 but have fallen since to less than 3% of vehicle production in recent years. The projected 2024 data shows a vehicle type distribution that is similar to model year 2023.

Figure 3.2. Production Share and Estimated Real-World CO_2 Emissions
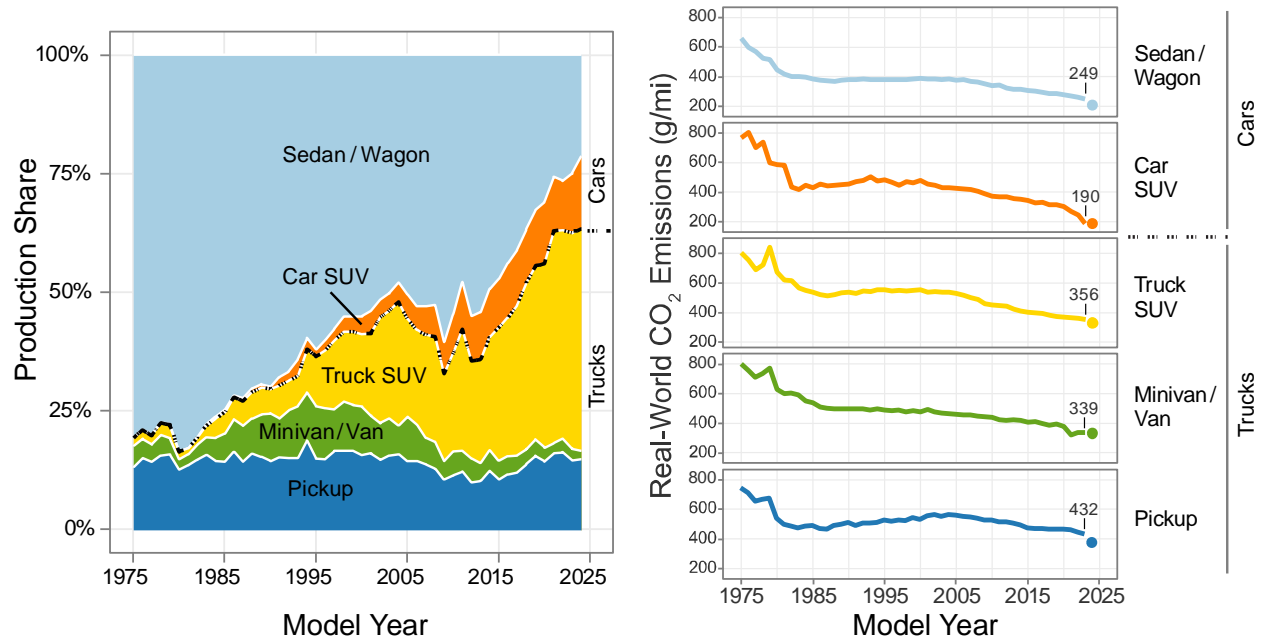
The truck regulatory class (including pickups, minivan/vans, and truck SUVs) fell slightly in the model year 2023, for the first time in twelve years. However, the overall truck production share remained near an all-time high of 62%. Trucks are projected to increase

overall production share slightly in 2024. 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, also shows estimated CO_2 emissions for each vehicle type since 1975. In model year 2023, compared to model year 2022, the four largest vehicle types continued their trends of reduced CO_2 emissions and increased fuel economy. Minivan/vans, which accounted for less than 3% of new vehicle production in model year 2023, had CO_2 emissions that were unchanged. Most notable is the 60 g/mi, or 24%, reduction, in the average new vehicle real-world CO_2 emissions within car SUVs. This improvement in CO_2 emissions stems from the influx of BEVs within car SUVs, with BEVs now accounting for 36% of all MY 2023 car SUVs. The car SUV vehicle type now has the lowest average new vehicle CO_2 emissions. In the preliminary model year 2024 data (shown as a dot on Figure 3.2), all vehicle types except Car SUV are expected to improve CO_2 emissions from model year 2023, while car SUV CO_2 emissions are projected to remain the same.

In terms of fuel economy, car SUVs increased fuel economy by 7.2 mpg, to become the vehicle type with the highest fuel economy. Sedan/wagons increased fuel economy by 0.9 mpg, pickups increased by 0.5 mpg, and truck SUVs increased by 0.4 mpg, while minivans/vans decreased by 0.1 mpg. Four of the five vehicle types, pickups being the exception, now achieve fuel economy more than double what they achieved in 1975. Four of the five vehicle types are also expected to improve fuel economy further based on preliminary model year 2024 data, with only car SUVs declining slightly.

Overall fuel economy and CO_2 emissions trends depend on the trends within the five vehicle types, but also on the market share of each of the vehicle types. Since 1975, the market has shifted dramatically away from sedan/wagons and towards truck SUVs and car SUVs. Until recently, the sedan/wagon vehicle type was the most efficient, so the market shifts toward other vehicle types with lower fuel economy and higher CO_2 emissions offset some of the fleetwide benefits that otherwise would have been achieved from the improvements within each vehicle type. However, the growth of electric vehicles, particularly within the car SUV vehicle type, is changing the relationship between vehicle types and overall average new vehicle real-world CO_2 emissions.

The model year 2023 production breakdown by vehicle type for each manufacturer is shown in Figure 3.3. There are clear variations in production distribution by manufacturer. BMW had the highest production of sedan/wagons at 47%, Tesla had the highest percentage of car SUVs at 55%, Mazda had the highest percentage of truck SUVs at 89%, Ford had the highest percentage of pickups at 44%, and Stellantis had the highest
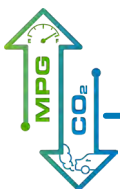
percentage of minivan/vans at 10%. The distribution of production between vehicle types remained similar between model year 2022 and 2023. Nissan, Tesla, and VW each decreased sedan/wagon production by more than 10 percentage points, moving production towards a combination of car and truck SUVs. GM increased their pickup production share by 12 percentage points, while decreasing the percentage of truck SUVs. All other vehicle type production shifts within each manufacturer were less than 10 percentage points.

Figure 3.3. Vehicle Type Distribution by Manufacturer for Model Year 2023
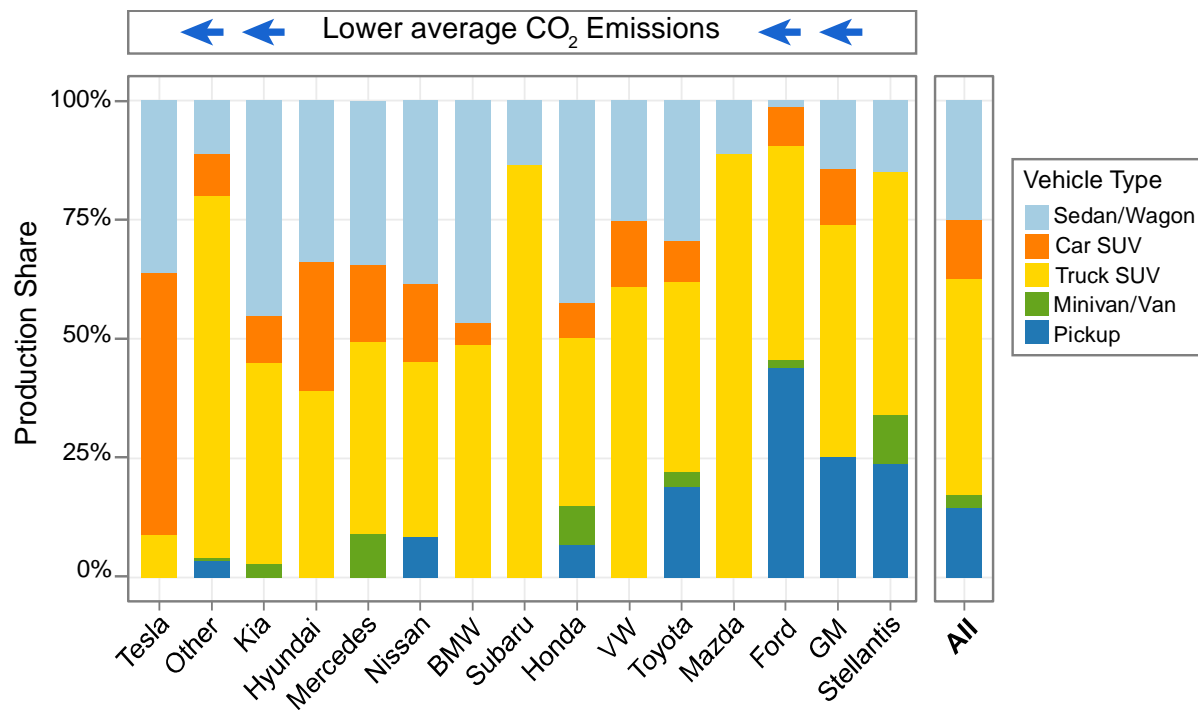
For some manufacturers, changes in the mix of vehicle types they produce has also led to a significant impact on their overall new vehicle CO_2 emissions and fuel economy. As shown in Figure 2.5, Honda had the largest increase in average CO_2 emission over the last five years, at 18 g/mi. The increase in emissions for Honda was due to a shift in production towards truck SUVs and pickups along with increases in the emission rates within both of those vehicle types compared to model year 2018. Mazda had the second largest increase at 12 g/mi, due entirely to a shift from 36% to 89% truck SUV production.

SUV Classification

Since 1975, the production share of SUVs in the United States has increased in all but 10 years, and now accounts for 58% 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 GVWR 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 trend of particular interest is the classification of SUVs as either car SUVs or truck SUVs.

This report does not track GVWR, 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. Heavier vehicles were excluded, as these vehicles generally exceed 6,000 pounds GVWR 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 72% in model year 2023, which is the highest percentage of production since at least model year 2000. Model year 2024 data is projected to have a slightly lower ratio of truck SUVs.

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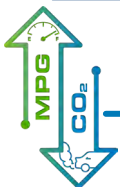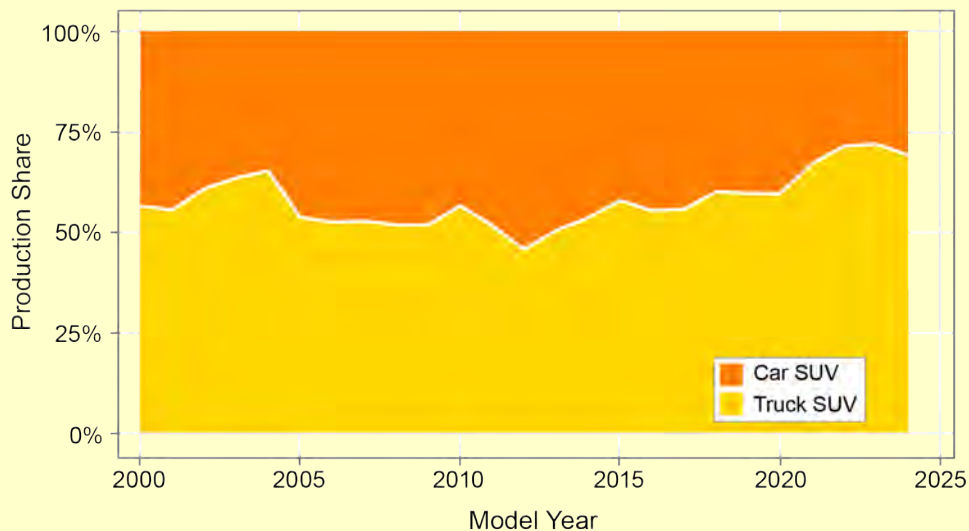
B. Vehicle Weight

Vehicle weight is a fundamental vehicle attribute and an important metric for analysis 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. Among battery electric vehicles (BEVs), increased weight will likely decrease the overall efficiency of the vehicle, measured either in kilowatt-hours per 100 miles or miles per gallon of gasoline equivalent (mpge). However, it will not increase tailpipe CO_2 emissions, since BEVs 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.

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 2023 was about 6% above 2004 and is currently at the highest point on record, at 4,371 pounds. Preliminary model year 2024 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. In contrast, for model year

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[7] Vehicle curb weight is the weight of an empty, unloaded vehicle.
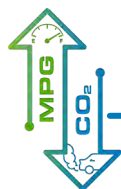
2023, the difference between the heaviest and lightest vehicle types was about 1,535 pounds, or about 35% of the average new vehicle weight. In 1975, the average new sedan/wagon outweighed the average new pickup by about 45 pounds, but the different weight trends over time for each of these vehicle types led to a very different result in model year 2023, with the average new pickup outweighing the average new sedan/wagon by about 1,535 pounds. Pickups are below their model year 2014 high of 5,485 pounds per vehicle, due in part to vehicle redesigns of popular truck models and the use of weight saving designs, such as aluminum bodies. However other trends, such as the growth in battery electric vehicles (BEVs), appears to be pushing vehicle weights back up.

Figure 3.5. Average New Vehicle Weight by Vehicle Type
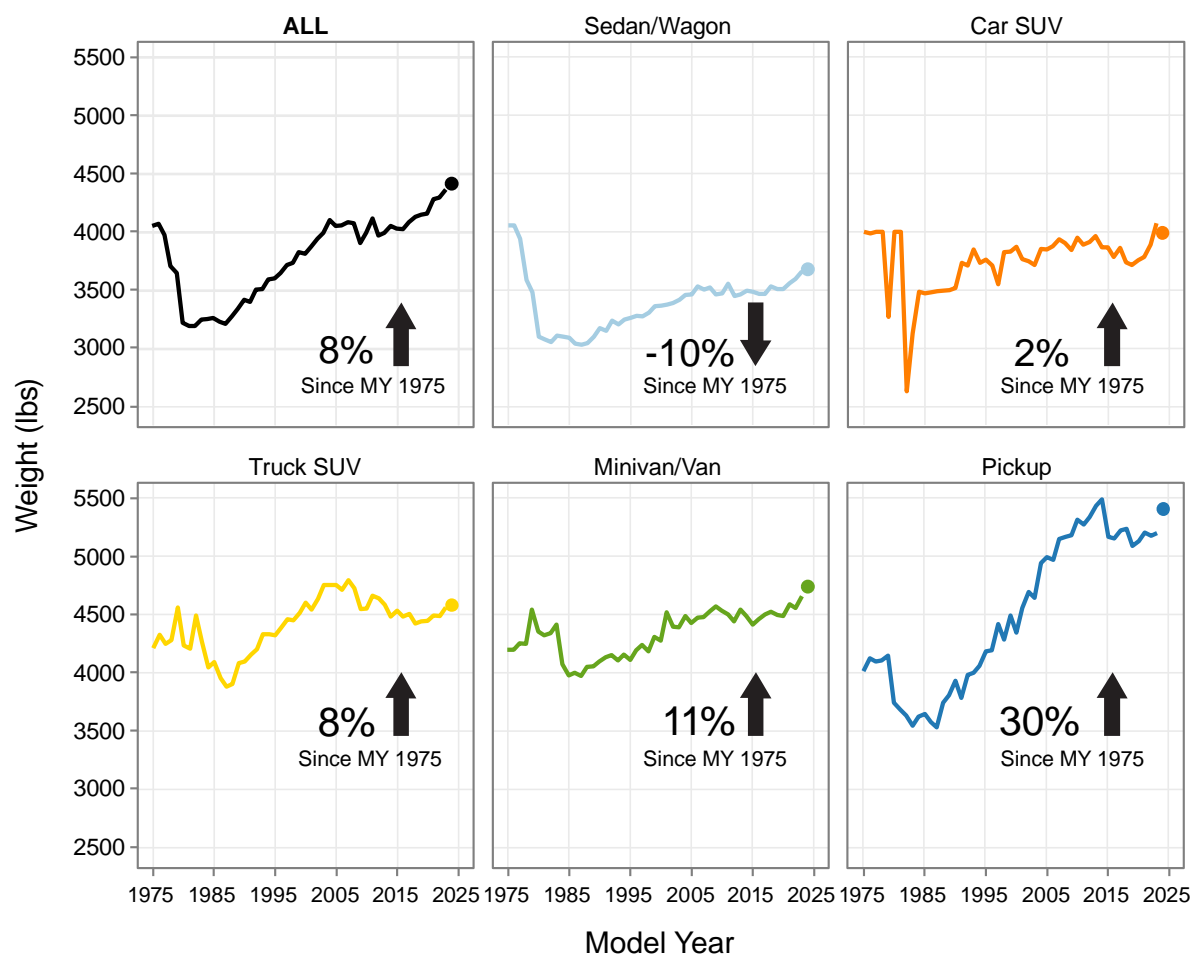
Figure 3.6 shows the annual production share of different inertia weight classes for new vehicles since model year 1975. In model year 1975, there were significant sales in all weight classes from <2,750 pounds to 5,500 pounds. In the early 1980s, the largest vehicles
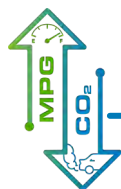
disappeared from the market, and light cars <2,750 pounds inertia weight briefly captured more than 25% of the market. Since then, cars in the <2,750-pound inertia weight class have all but disappeared, and the market has moved towards heavier vehicles. Interestingly, the heaviest vehicles in model year 1975 were mostly large cars, whereas the heaviest vehicles today are largely pickups and truck SUVs.

Figure 3.6. Inertia Weight Class Distribution by Model Year
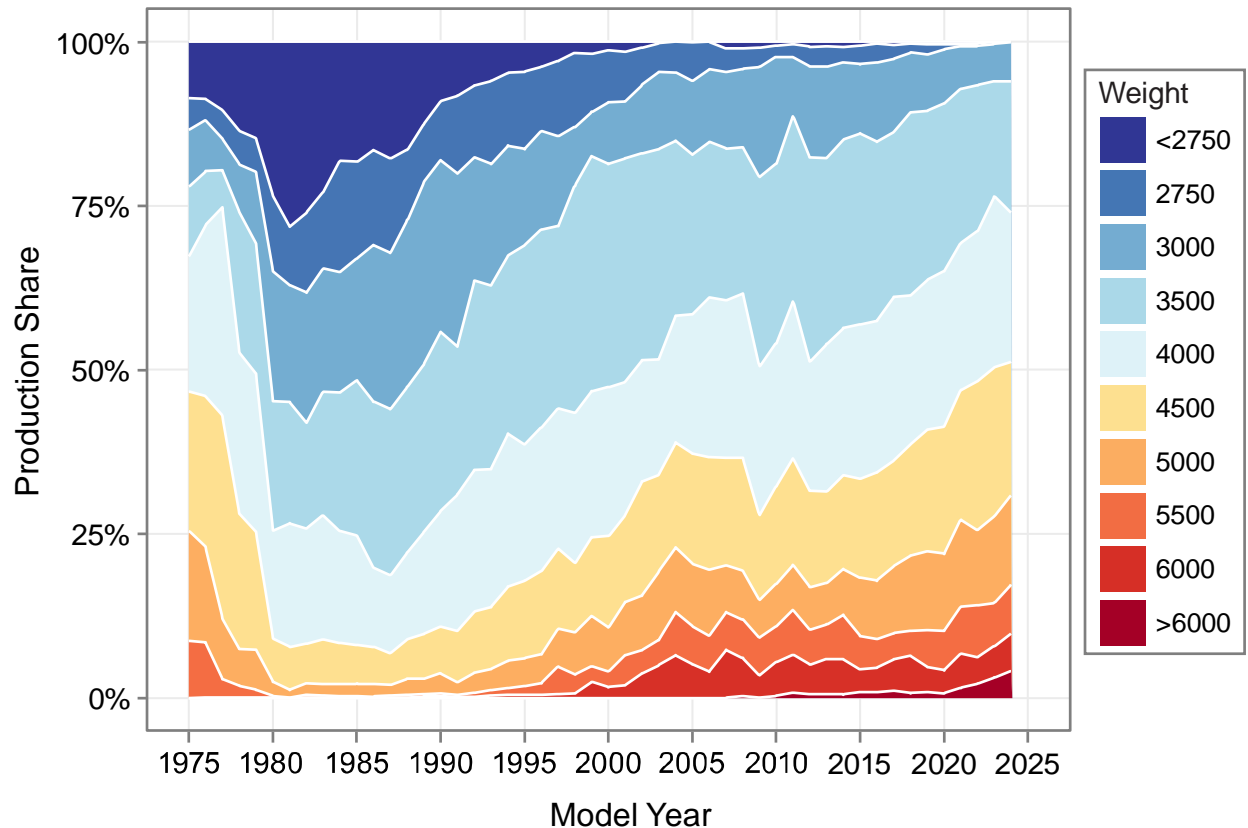
Vehicle Weight and Technology

In addition to the changes in vehicle type, the changing powertrain technologies used in recent model years have also impacted typical vehicle weight. For example, BEVs require a battery that can store enough energy to propel the vehicle over the design range of the vehicle, which for many current BEVs is more than 300 miles. The large battery required to hold that amount of energy increases the weight of the vehicle, often making it heavier than an equivalent internal combustion engine vehicle.

Figure 3.7 shows the average weight, by vehicle type, of internal combustion engine (ICE) vehicles (including those with stop/start, but not hybrids or PHEVs) compared to BEVs and PHEVs. The average of all vehicles within each vehicle type (including hybrids, PHEVs, and FCEVs) is also shown as a solid black bar. For each vehicle type, BEVs and PHEVs are heavier than their ICE counterparts. BEVs and PHEVs appear to be increasing the overall weight within each vehicle type, with the magnitude of the impact dependent on the uptake of BEVs and PHEVs within each vehicle type.

Overall vehicle weight has generally been trending upwards for several decades, as shown in Figure 3.5. This trend has driven by many factors, including market shifts between vehicle types. The weight difference between ICE vehicles and BEV/PHEV vehicles shown for most vehicle types in Figure 3.7 is comparable to the difference in weight between ICE sedan/wagons and ICE truck SUVs. Overall vehicle production has by and large been moving away from sedan/wagons towards truck SUVs, as shown in Figure 3.2, for decades. This market shift over time has, to date, had much more of an impact on overall new vehicle average weight than the recent emergence of BEVs and PHEVs.

It is also important to note that even within vehicle types shown in Figure 3.7, the BEVs and PHEVs available may not be exactly comparable to the ICE vehicles. For example, the only electric vehicle pickup trucks are large full-sized pickups, while the ICE category includes some smaller pickup trucks. This difference is likely increasing the weight difference shown for pickups in Figure 3.7.
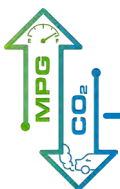
Figure 3.7. Average New Vehicle Weight by Vehicle Type and Powertrain
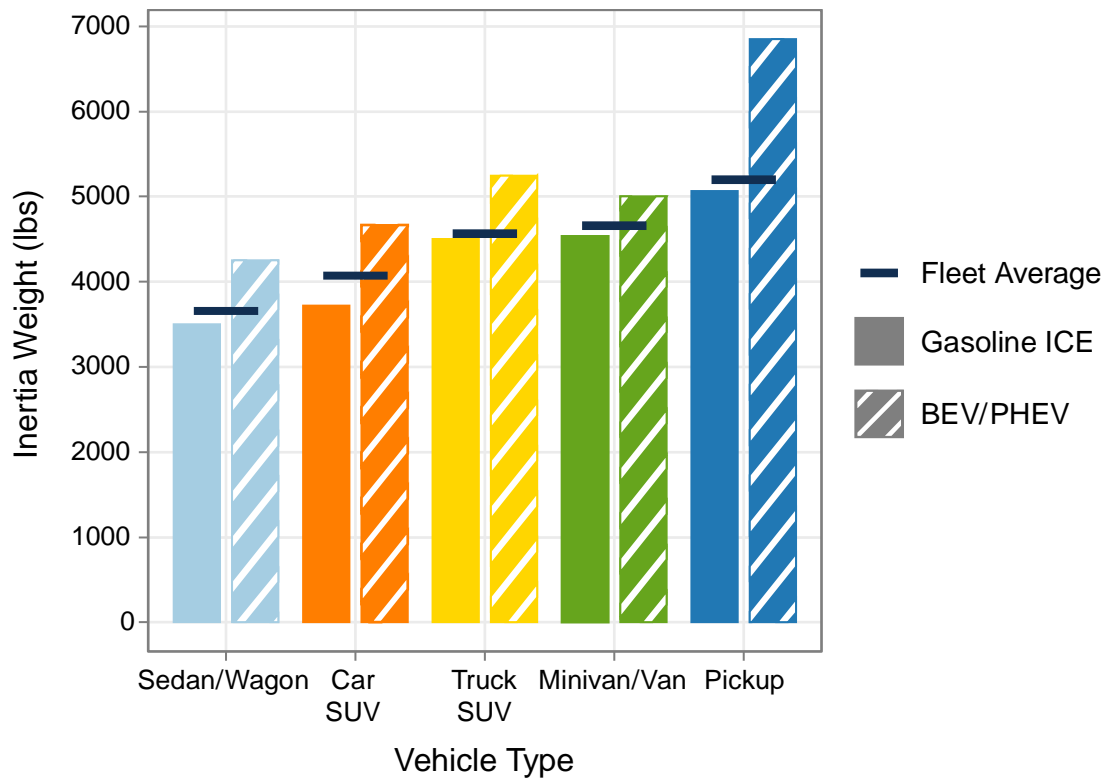
Vehicle Weight and CO_2 Emissions

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. Figure 3.8 shows estimated real-world CO_2 emissions and fuel economy as a function of vehicle inertia weight for several model year 2023 technologies. Increased weight correlates to lower fuel economy and higher CO_2 emissions for ICE and hybrid technologies and may also correlate for PHEVs. For BEVs, weight does not impact tailpipe emissions, since all BEVs have zero tailpipe emissions, however increasing BEV weight likely correlates to reduced vehicle efficiency, as measure in miles per gallon of gasoline equivalent (mpge). Limited data did not allow for trendlines in Figure 3.8 for PHEV and BEV data.

Figure 3.8. Relationship of Inertia Weight and CO_2 Emissions
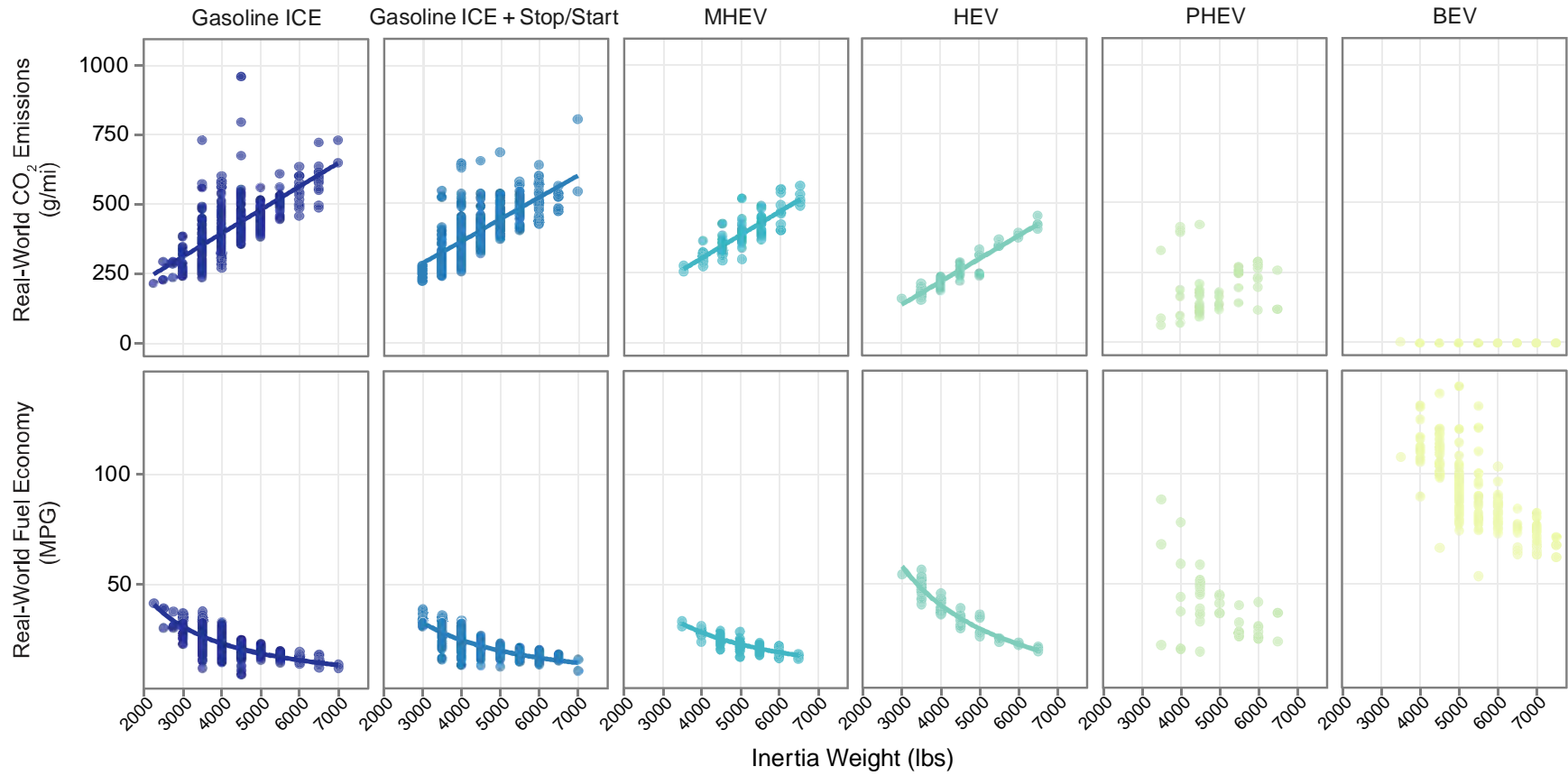
C. Vehicle Power

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 2023 produced 94% more power than a new vehicle in model year 1975, and 160% more power than an average new vehicle in model year 1981. The average new vehicle horsepower is at a record high, increasing from 259 hp in model year 2022 to 266 hp in model year 2023. The preliminary value for model year 2024 is 267 hp, which would be another record-high for horsepower.

Electric motors provide power differently than internal combustion engines. For example, internal combustion engines need to achieve a high rotation speed (rotations per minute, or RPM) before they can achieve maximum horsepower. In addition, many BEVs have high hp ratings due to the large amount of power electric motors can generate. Determining the overall vehicle horsepower for BEVs can be complicated for vehicles that have more than one electric motor, depending on how the multiple motors are integrated. PHEVs, which have an internal combustion engine, at least one motor, and complicated control strategies, can be even more difficult to assess. Therefore, horsepower values for the increasing number of BEVs and PHEVs 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 3.9. Horsepower for sedan/wagons increased 69% between model year 1975 and 2023, 139% for car SUVs, 77% for truck SUVs, 72% for minivan/vans, and 141% 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.
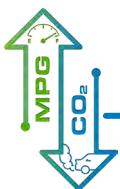
Figure 3.9. Average New Vehicle Horsepower by Vehicle Type
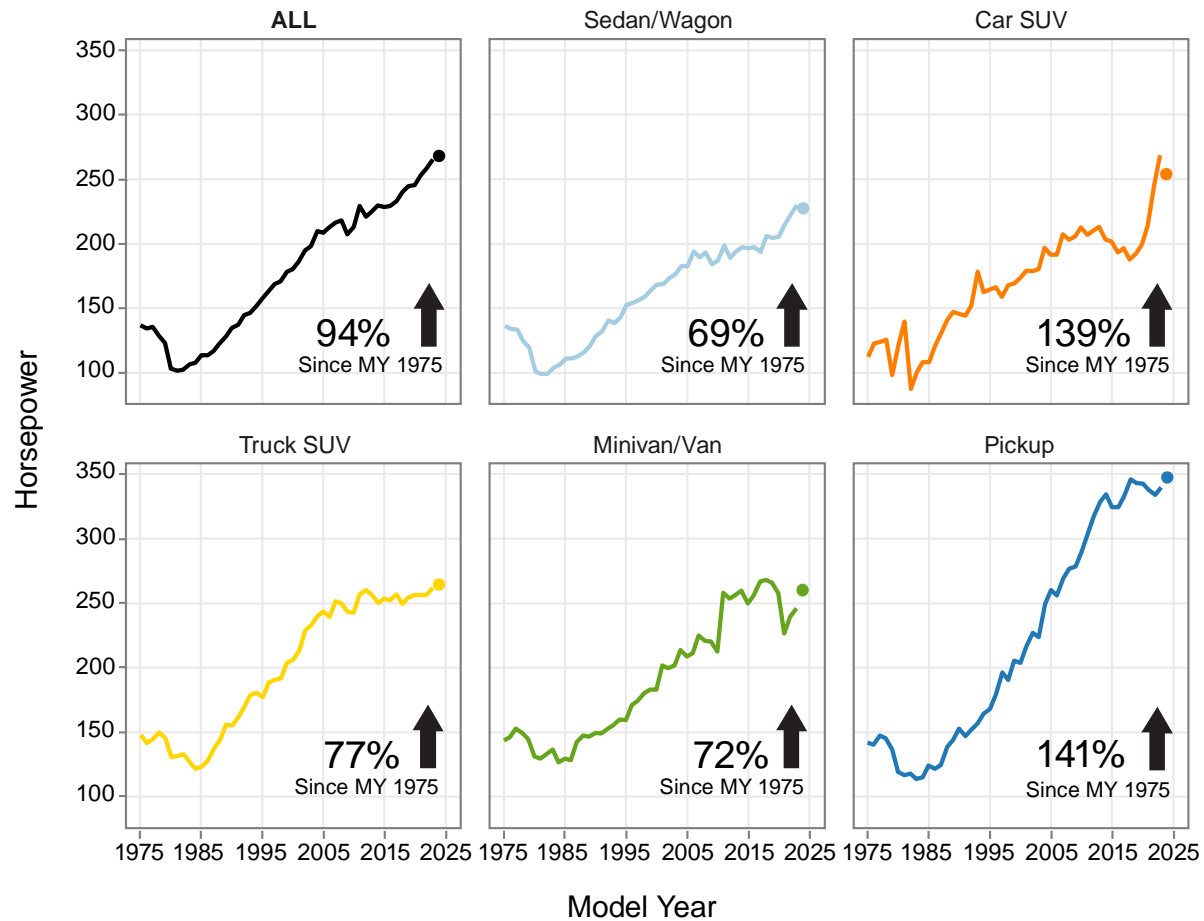
The distribution of horsepower over time has shifted towards vehicles with higher horsepower, as shown in Figure 3.10. While few new vehicles in the early 1980s had greater than 200 hp, the average vehicle in model year 2023 had 266 hp. In addition, vehicles with more than 250 hp make up more than half of new vehicle production, and the maximum horsepower for an individual vehicle is now 1,600 hp. Horsepower is projected to increase again in model year 2024, with almost 10% of vehicles projected to reach 400 hp or higher.
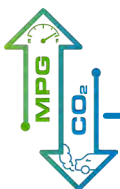
Figure 3.10. Horsepower Distribution by Model Year
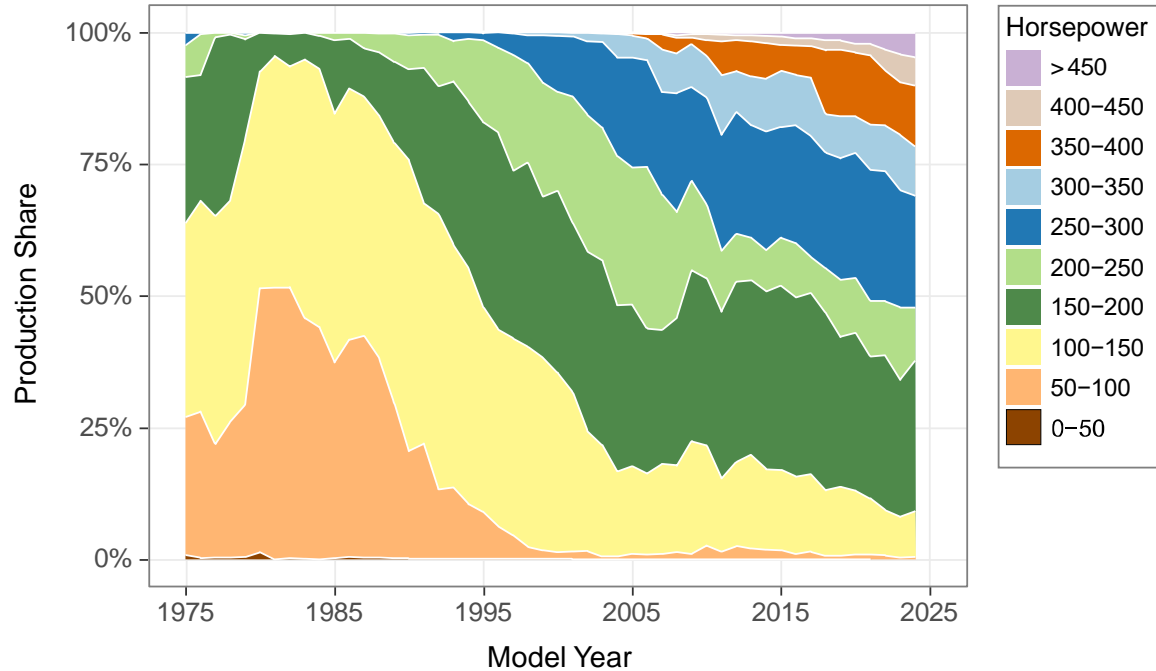
Vehicle Power and Technology

Electric vehicles utilize an electric motor, instead of a gasoline internal combustion engine, to move the vehicle. Electric motors have the advantage of having maximum torque available from a standstill and can be used to create vehicles with high horsepower. Figure 3.11 shows the average horsepower, by vehicle type, of internal combustion engine (ICE) vehicles (including those with stop start, but not hybrids or PHEVs) compared to PHEVs and BEVs. For each of the four most popular vehicle types, PHEVs and BEVs have higher horsepower than their ICE counterparts. For minivan/vans, the average PHEV and BEV have lower horsepower, but there are also limited vehicles available to compare. The average of all vehicles within each vehicle type is also shown. PHEVs and BEVs do appear to be increasing the overall horsepower within each vehicle type (except for minivan/vans – in part due perhaps to very limited offerings within this vehicle type) with the overall impact dependent on the uptake of PHEVs and BEVs within each vehicle type.
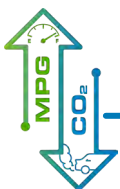
Figure 3.11. Average New Vehicle Horsepower by Vehicle Type and Powertrain
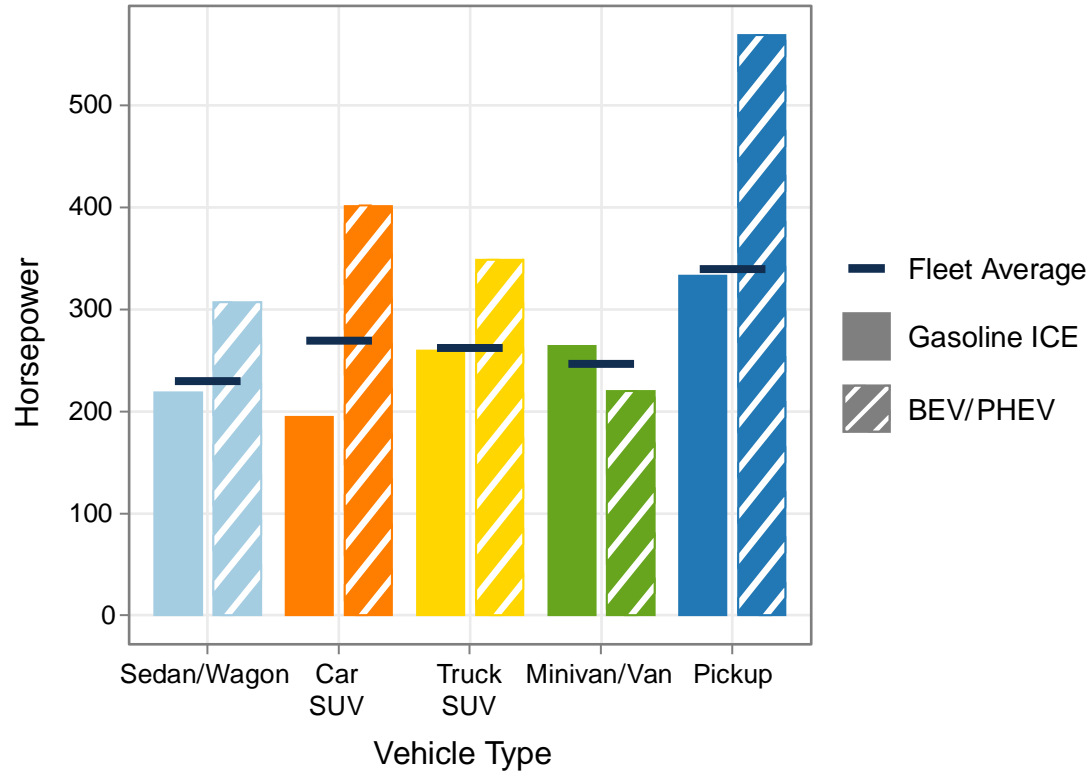
Vehicle Power and CO_2 Emissions

As with weight, higher horsepower vehicles are generally less efficient and have higher CO_2 emissions, if all other factors are the same. However, 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. Figure 3.12, shows estimated real-world CO_2 emissions and fuel economy as a function of vehicle horsepower for several model year 2023 technologies. Increased horsepower correlates to lower fuel economy and higher CO_2 emissions for ICE, hybrid, and PHEV vehicles. For BEVs, horsepower does not impact tailpipe emissions, since all BEVs have zero tailpipe emissions, however the relationship between increasing BEV horsepower and vehicle efficiency, as measure in miles per gallon of gasoline equivalent (mpge), is less clear. Limited data did not allow for trendlines in Figure 3.12 for BEV data.
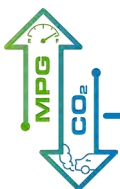
Figure 3.12. Relationship of Horsepower and CO₂ Emissions
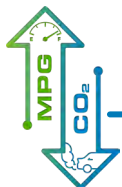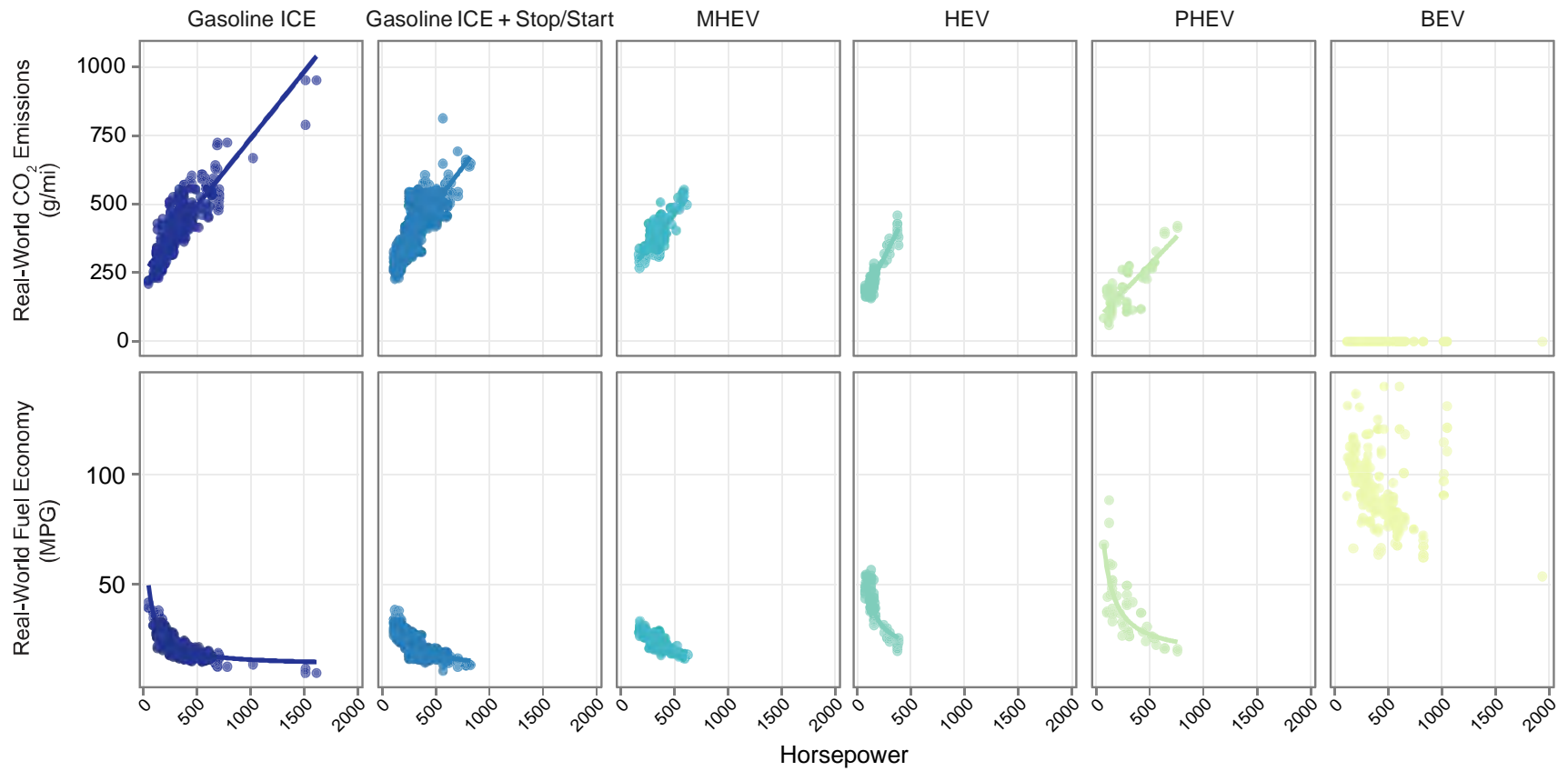
Vehicle Acceleration

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

The relationship between power and acceleration is different for BEVs 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 BEVs can have very fast 0-to-60 acceleration times, and the calculation methods used for vehicles with internal combustion engines are not valid for BEVs. PHEVs and hybrids may also use their motors to improve acceleration. Acceleration times for BEVs, PHEVs, and hybrids must be obtained from external sources, and as with horsepower values for these vehicles, 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 3.13 shows the average new vehicle 0-to-60 time since model year 1978. The average new vehicle in model year 2023 had a 0-to-60 time of 7.3 seconds, which is the fastest average 0-to-60 time for any model year and less than half of the average 0-to-60 time of the early 1980s. The calculated 0-to-60 time for model year 2024 is projected to increase slightly to 7.4 seconds. The long-term downward trend in 0-to-60 times is consistent across all vehicle types. Increasing BEV production will likely continue, and perhaps increase, the trend towards lower 0-to-60 acceleration times.

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[8] MacKenzie, D. Heywood, J. 2012. Acceleration performance trends and the evolving relationship among power, weight, and acceleration in U.S. light-duty vehicles: A linear regression analysis. Transportation Research Board, Paper NO 12-1475, TRB 91st Annual Meeting, Washington, DC, January 2012.
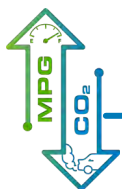
Figure 3.13. Calculated 0-to-60 Time by Vehicle Type
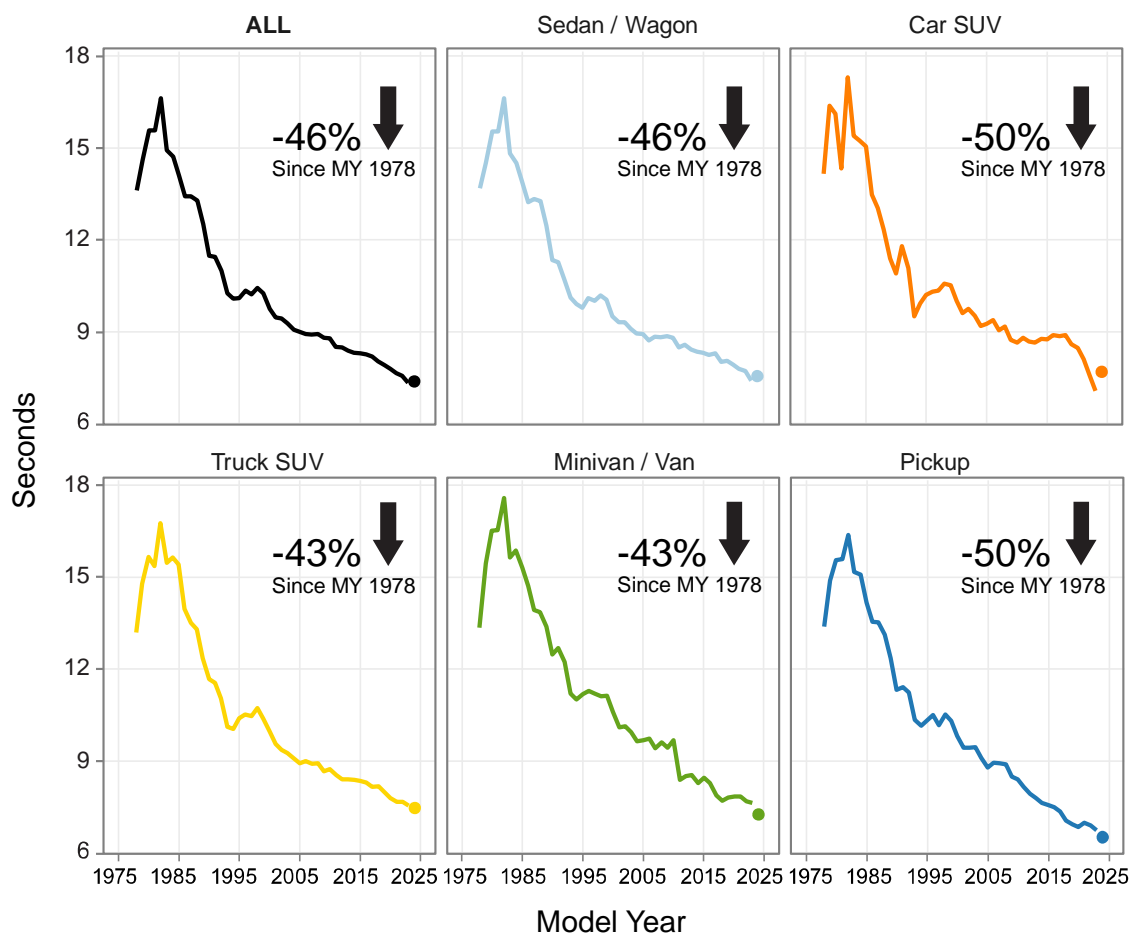
D. Vehicle Footprint

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 2023. EPA projects footprint data for the preliminary model year 2024 fleet based on footprint values from the previous model year and, for new vehicle designs, publicly available data.
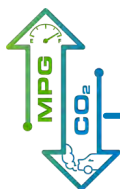
Vehicle Footprint by Vehicle Type

Figure 3.14 shows overall new vehicle and vehicle type footprint data since model year 2008. Between model year 2008 and 2023, the overall average footprint increased 6%, from 48.9 to 51.8 square feet. All five vehicle types have increased average footprint since model year 2008, with sedan wagons increasing 4.9%, Car SUVs and minivans/vans increasing 4.5%, truck SUVs increasing 3.7%, and pickups increasing 3.4%. This increase, which is larger than the increase within any individual vehicle type, was 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.

Figure 3.14. Footprint by Vehicle Type for Model Years 2008–2023
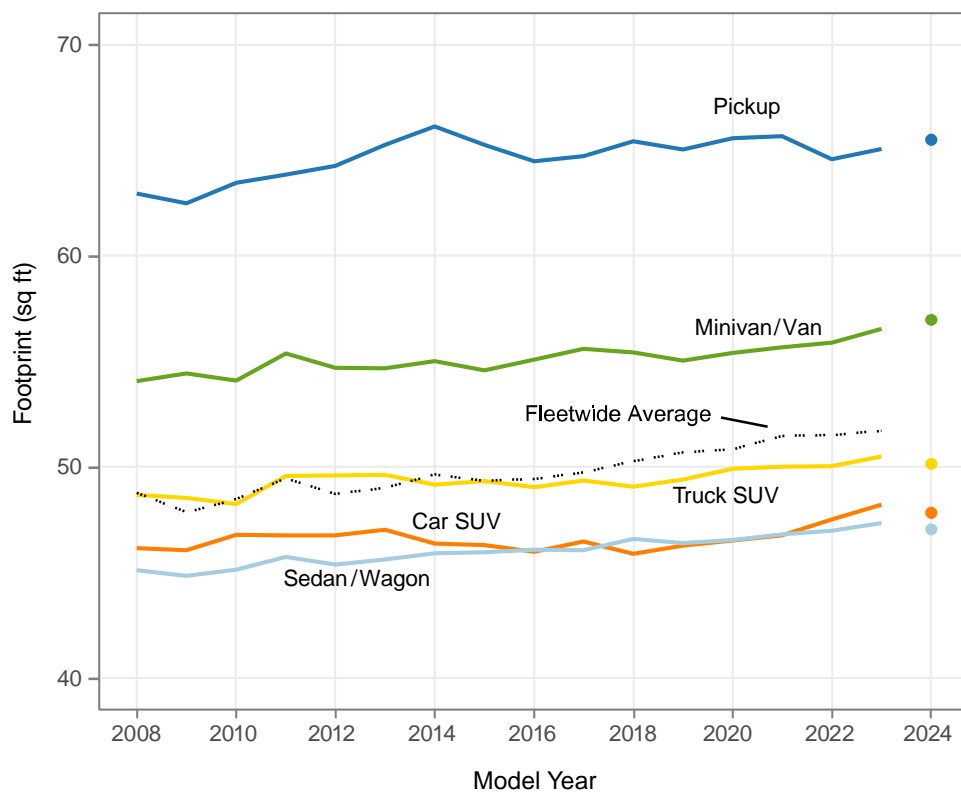
The distribution of footprints across all new vehicles, as shown in Figure 3.15, also shows a slow reduction in the number of smaller vehicles with a footprint of less than 45 square feet, along with growth in larger vehicle categories. This is consistent with the changes in market trends towards larger vehicles, as seen in Figure 3.2 and elsewhere in this report. Projected data for model year 2024 suggest that overall average footprint will decrease slightly to 51.6 square feet.
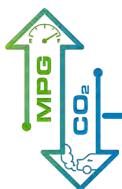
Figure 3.15. Footprint Distribution by Model Year
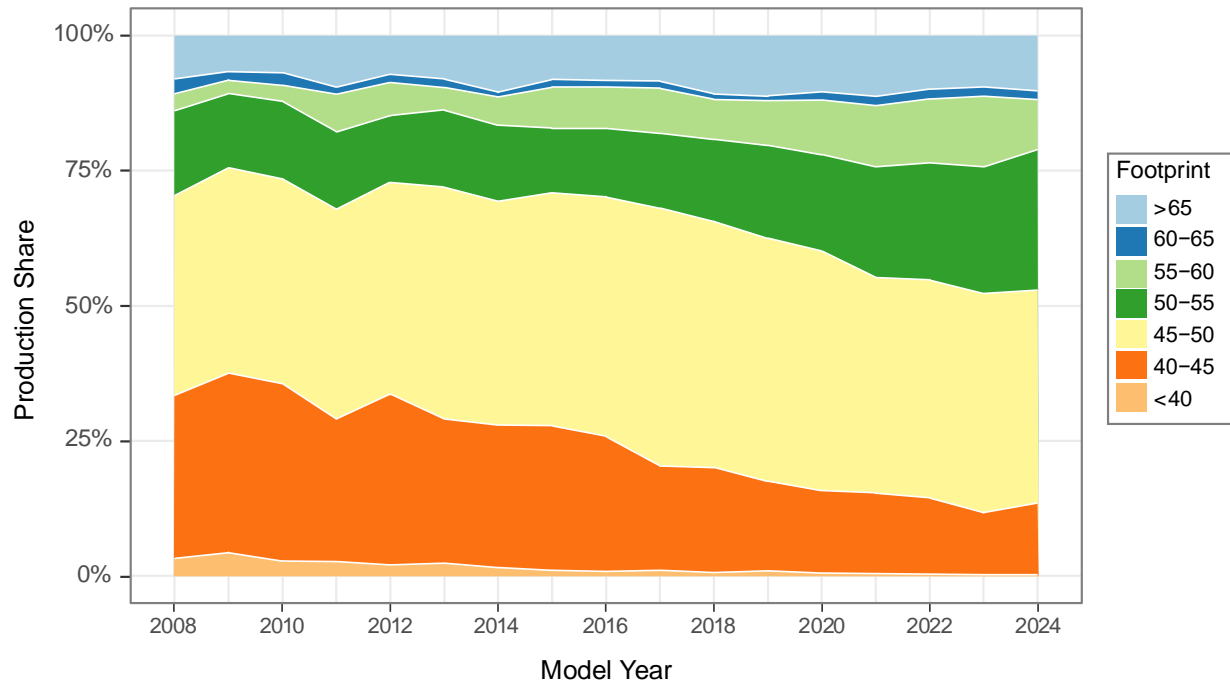
Vehicle Footprint and Technology

Figure 3.16 shows the average footprint, by vehicle type, of internal combustion engine (ICE) vehicles (including those with stop start, but not hybrids or PHEVs) compared to BEVs and PHEVs. For all vehicle types, BEVs and PHEVs have slightly larger footprints than their ICE counterparts. The average of all vehicles within each vehicle type is also shown, with the overall impact dependent on the uptake of BEVs and PHEVs within each vehicle type.
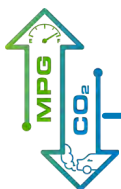
Figure 3.16. Average New Vehicle Footprint by Vehicle Type and Powertrain
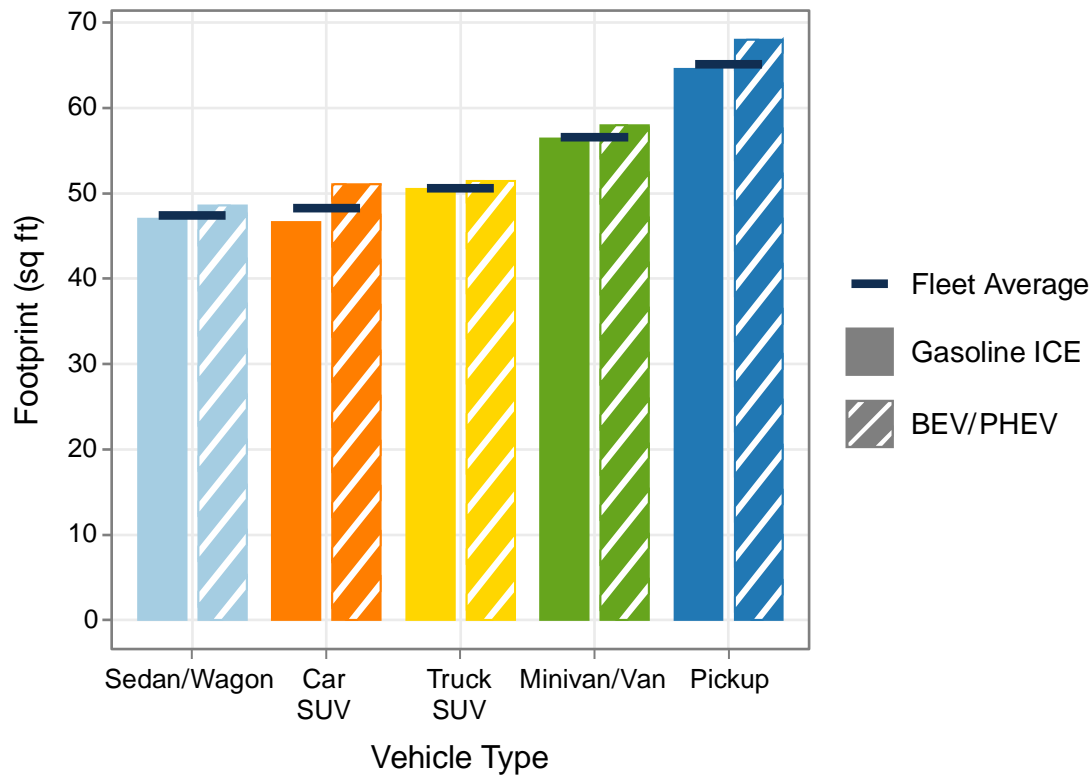
Vehicle Footprint and CO_2 Emissions

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 decrease fuel economy. Figure 3.17 shows estimated real-world CO_2 emissions and fuel economy as a function of vehicle footprint for several model year 2023 technologies. Increased footprint correlates to lower fuel economy and higher CO_2 emissions for ICE and hybrid technologies and may also correlate for PHEVs. For BEVs, footprint does not impact tailpipe emissions, since all BEVs have zero tailpipe emissions, however increasing BEV footprint likely correlates to reduced vehicle efficiency, as measure in miles per gallon of gasoline equivalent (mpge). Limited data did not allow for trendlines in Figure 3.17 for PHEV and BEV data.
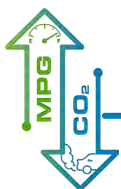
Figure 3.17. Relationship of Footprint and CO₂ Emissions
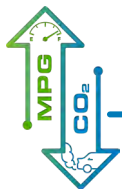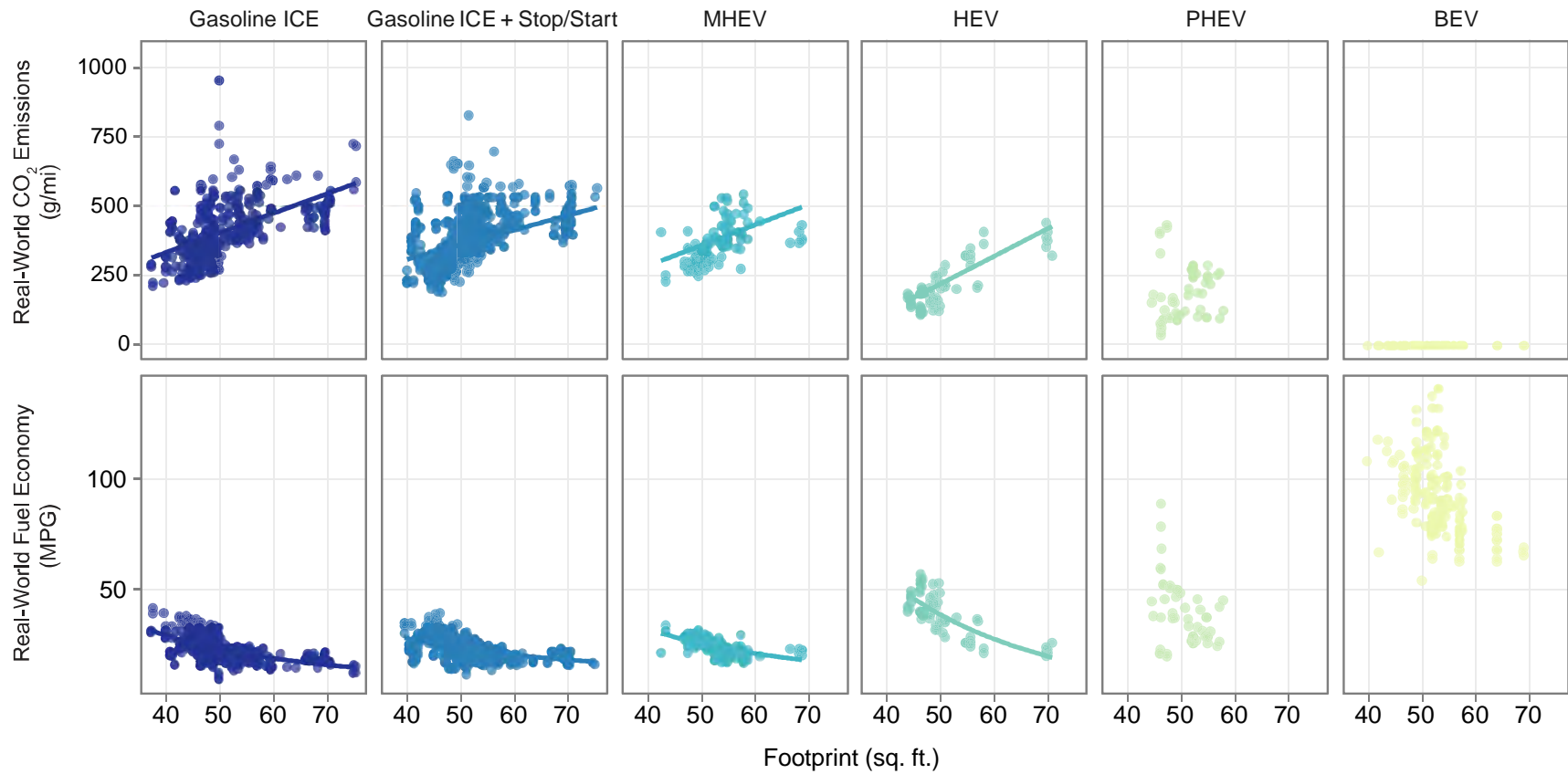
E. Vehicle Type and Attribute Tradeoffs

The past 50 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. Between 1975 and the early 1980s, average new vehicle fuel economy increased rapidly, while the vehicle weight and horsepower fell. For the next twenty years, average new vehicle weight and horsepower steadily increased, while fuel economy steadily decreased. Model year 2004 was another inflection point, after which fuel economy, horsepower, and weight have all generally increased together, to historic highs in model year 2023. Since model year 2004, average new vehicle fuel economy has increased 40%, horsepower increased 26%, and weight increased 6%. Footprint has increased 6% since EPA began tracking it in model year 2008. Fuel economy, weight, and horsepower are all projected to increase again in model year 2024, as shown in Figure 3.18.

The changes within each of these metrics is due to the combination of design and technology changes within each vehicle type, as well as 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.
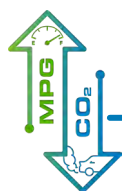
Figure 3.18. Relative Change in Fuel Economy, Weight, Horsepower, and Footprint
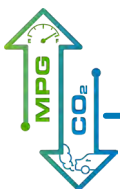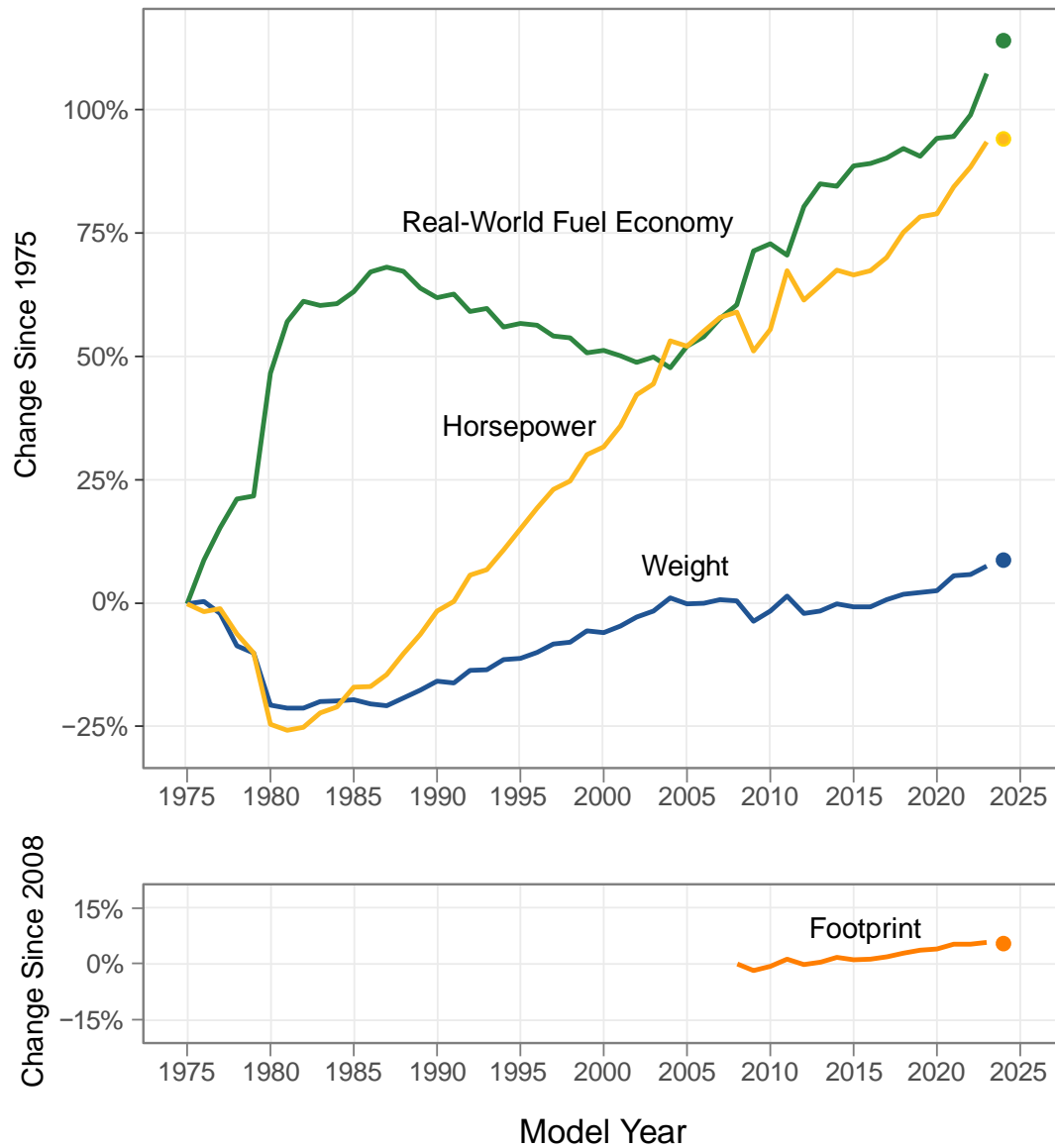
Table 3.1. Vehicle Attributes by Model Year

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%
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	337	26.0	4,303	259	7.6	51.6	36.9%	63.1%
2023	319	27.1	4,371	266	7.3	51.8	37.5%	62.5%
2024 (prelim)	305	28.0	4,419	267	7.4	51.6	36.7%	63.3%

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

Model Year	Sedan/Wagon			Car SUV			Truck SUV			Minivan/Van			Pickup		
	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
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	26.5%	260	33.2	10.4%	250	33.4	43.8%	364	24.2	2.9%	339	26.0	16.4%	444	20.0
2023	25.0%	249	34.1	12.5%	190	40.5	45.3%	356	24.7	2.5%	339	25.9	14.7%	432	20.5
2024 (prelim)	21.3%	248	34.3	15.4%	190	40.3	46.6%	333	26.0	1.8%	332	26.3	14.9%	418	21.0

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

Table 3.3. Model Year 2023 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	305	27.6	4600	321	6.0	50.2
Ford	374	23.2	4845	316	6.6	58.2
GM	396	22.4	4766	288	7.3	55.7
Honda	314	28.3	3936	212	7.7	49.4
Hyundai	292	29.8	3824	206	8.1	48.7
Kia	289	30.4	3721	191	8.3	47.9
Mazda	322	27.6	3864	196	8.9	46.7
Mercedes	304	27.5	4843	306	6.4	52.3
Nissan	305	28.9	4075	222	8.3	48.4
Stellantis	402	21.8	4836	316	7.0	56.0
Subaru	311	28.4	3939	198	9.0	46.0
Tesla	0	120.6	4384	407	4.6	50.7
Toyota	322	27.5	4227	231	7.7	50.4
VW	317	27.0	4361	263	7.0	48.8
Other	276	29.1	4940	352	6.6	50.8
All Manufacturers	**319**	**27.1**	**4371**	**266**	**7.3**	**51.8**

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends
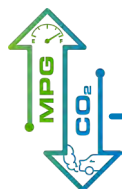
Table 3.4. Model Year 2023 Estimated Real-World Fuel Economy and CO_2 by Manufacturer and Vehicle Type

Manufacturer	Sedan/Wagon Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Car SUV Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Truck SUV Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Minivan/Van Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Pickup Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)
BMW	46.6%	268	31.0	4.7%	342	26.0	48.7%	338	25.2	-	-	-	-	-	-
Ford	1.3%	408	21.8	8.4%	135	47.5	44.7%	401	22.1	1.6%	351	25.3	44.0%	392	22.2
GM	14.5%	252	32.5	11.6%	301	29.4	48.6%	422	21.1	-	-	-	25.3%	474	19.0
Honda	42.5%	267	33.3	7.3%	269	33.0	35.3%	344	25.9	8.0%	377	23.6	6.9%	424	21.0
Hyundai	33.9%	246	35.4	27.1%	262	32.1	39.1%	352	25.2	-	-	-	-	-	-
Kia	45.3%	242	35.7	9.9%	300	29.6	41.9%	330	26.7	2.9%	386	23.0	-	-	-
Mazda	11.3%	285	31.1	-	-	-	88.7%	327	27.2	-	-	-	-	-	-
Mercedes	34.6%	297	28.6	16.2%	129	48.0	40.0%	357	24.0	9.2%	411	21.6	-	-	-
Nissan	38.5%	257	33.6	16.3%	268	33.2	36.5%	339	26.2	-	-	-	8.7%	447	19.9
Stellantis	15.2%	425	20.9	0.0%	329	27.0	50.8%	382	22.7	10.2%	334	25.6	23.8%	458	19.5
Subaru	13.5%	321	27.6	-	-	-	86.5%	310	28.5	-	-	-	-	-	-
Tesla	36.1%	0	126.8	55.1%	0	117.1	8.8%	0	118.5	-	-	-	-	-	-
Toyota	29.4%	258	34.4	8.6%	284	31.0	39.7%	329	26.8	3.1%	249	35.7	19.1%	435	20.4
VW	25.3%	310	28.0	13.8%	203	38.6	60.9%	345	25.0	-	-	-	-	-	-
Other	11.3%	182	40.7	8.7%	88	54.4	76.1%	323	26.0	0.5%	331	26.9	3.5%	0	69.4
All Manufacturers	**25.0%**	**249**	**34.1**	**12.5%**	**190**	**40.5**	**45.3%**	**356**	**24.7**	**2.5%**	**339**	**25.9**	**14.7%**	**432**	**20.5**

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends
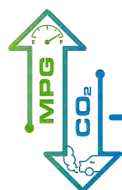
Table 3.5. Footprint by Manufacturer for Model Year 2022–2024 (ft^2)

Manufacturer	Final MY 2022			Final MY 2023			Preliminary MY 2024		
	Car	Truck	All	Car	Truck	All	Car	Truck	All
BMW	48.3	52.8	50.5	48.6	52.0	50.2	48.8	52.1	50.5
Ford	48.1	56.9	55.9	49.2	59.2	58.2	48.0	57.8	56.4
GM	46.1	59.3	56.0	46.4	59.0	55.7	46.3	59.6	55.0
Honda	46.3	50.4	48.3	46.9	51.9	49.4	46.6	50.9	48.4
Hyundai	46.9	50.3	48.3	47.6	50.3	48.7	47.8	50.8	49.2
Kia	46.6	51.2	48.8	46.2	50.0	47.9	47.0	51.3	49.4
Mazda	44.2	46.7	46.3	44.0	47.0	46.7	44.4	47.1	46.9
Mercedes	50.6	53.4	52.2	50.7	53.9	52.3	51.3	53.0	52.1
Nissan	46.6	52.9	49.1	46.6	50.6	48.4	46.6	51.6	48.9
Stellantis	51.5	57.5	56.7	52.8	56.6	56.0	42.0	56.0	55.7
Subaru	45.2	46.5	46.3	45.0	46.2	46.0	45.4	46.1	46.0
Tesla	50.7	51.7	50.8	50.7	51.5	50.7	50.8	51.1	50.8
Toyota	46.5	52.0	49.7	46.9	52.6	50.4	46.5	53.6	51.3
VW	46.2	50.1	48.6	46.5	50.3	48.8	46.7	50.3	49.2
Other	45.7	51.1	49.2	47.4	51.6	50.8	47.5	53.4	52.1
All Manufacturers	**47.2**	**54.2**	**51.6**	**47.7**	**54.2**	**51.8**	**47.5**	**54.0**	**51.6**

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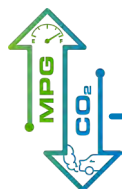
4. Vehicle Technology

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.

Vehicle Architecture

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. The generalized vehicle architecture for a vehicle with a gasoline internal combustion engine (ICE) is shown in Figure 4.1. Internal combustion engines typically combust gasoline or diesel fuel to rotate an output shaft. The engine is 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.

Figure 4.1. Vehicle Energy Flow for an Internal Combustion Engine Vehicle
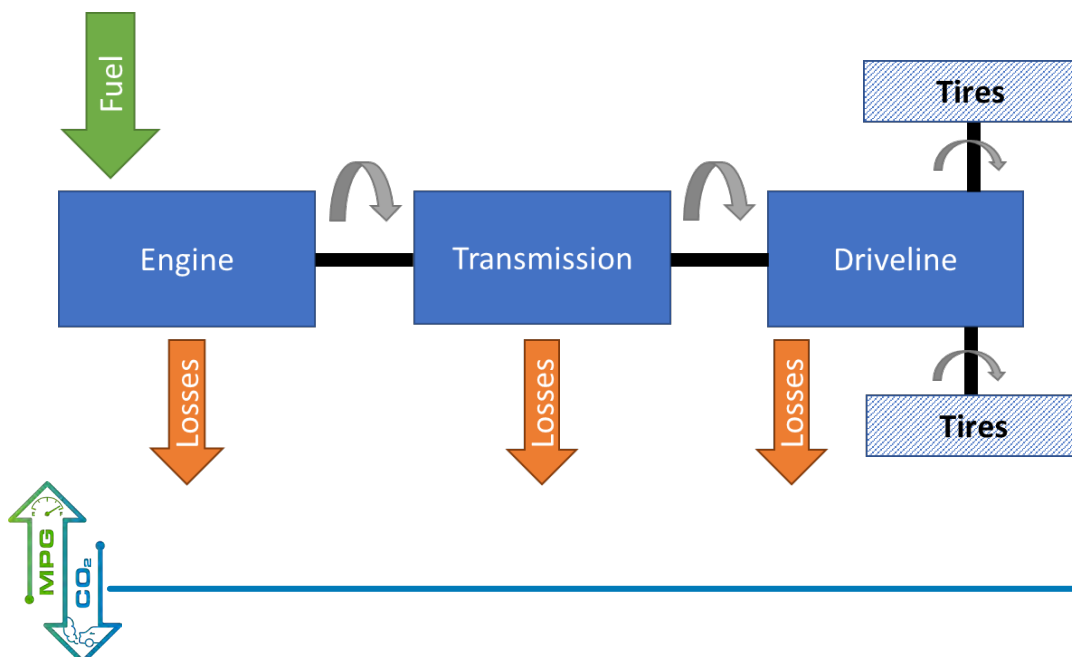
The general vehicle design shown in Figure 4.1 was nearly universal in the automotive industry for decades, but more recent technology developments have created vehicle architectures that look quite different.

Vehicles that have stop/start systems generally use a larger alternator and enhanced battery, which enables the vehicle to turn off the engine at idle to save fuel. Hybrid vehicles use a larger battery to recapture braking energy and provide traction power when necessary, allowing for a smaller, more efficiently operated engine. Hybrids can be separated into smaller "mild" hybrid systems (MHEVs) that provide launch assist but cannot propel the vehicle on their own, and "strong" hybrid systems (HEVs) that can temporarily power the vehicle without engaging the engine. Plug-in hybrid vehicles (PHEV) have both a battery that can be charged from an external electricity source and a gasoline engine and operate on electricity until the battery is depleted or cannot meet driving needs. Strong hybrids and PHEVs often have much more complicated architectures that allow for complex energy optimization strategies that ultimately improve some combination of vehicle CO_2 emission, fuel economy, and vehicle performance. These vehicles use a combination of an engine and one or more motors to power the wheels, and recapture braking energy.

Full battery electric vehicles (BEVs) employ a battery pack that is externally charged and an electric motor exclusively for propulsion, and do not have an onboard gasoline engine. BEVs can have very simple layouts, as vehicles with one electric motor can be directly connected to the driveline without a traditional transmission.[9] However, some manufacturers are producing electric vehicles with 2-speed transmissions, and others have developed vehicles with 2 or more motors that propel the vehicle in combination.

Vehicles with diesel engines are also present in the light-duty automotive market, and briefly reached 6% of all production in model year 1981. Vehicles relying on the combustion of a fuel other than gasoline or diesel, such as compressed natural gas (CNG), have occasionally been produced for sale in the U.S. Fuel cell electric vehicles (FCEVs) which use a fuel cell stack to create electricity from an onboard fuel source (usually hydrogen) to power a motor, have also been produced in recent years. These vehicles are included in the data for this report, but generally have not been produced in large volumes.[10]

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[9] For more information on electric vehicles, see EPA's Green Vehicle Guide (https://www.epa.gov/greenvehicles) or the U.S. Department of Energy's Alternative Fuels Data Center (https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work), or www.fueleconomy.gov (https://fueleconomy.gov/feg/evtech.shtml)

[10] Vehicles converted to an alternative fuel in the aftermarket are not included in this data.
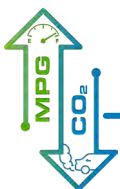
Overall Industry Trends

Innovation in the automobile industry has led to a wide array of technology available to manufacturers to achieve CO_2 emissions, fuel economy, and performance goals. Figure 4.2 illustrates manufacturer-specific technology usage for model year 2023 for technologies that represent increasing levels of vehicle electrification, as well as the recent adoption trends of those technologies across the industry. The technologies in Figure 4.2 are being used by manufacturers, in part, to reduce CO_2 emissions and increase fuel economy. Manufacturers' strategies to develop and adopt these technologies are unique and vary significantly. Each manufacturer is choosing technologies that best meet the design requirements of their vehicles. In model year 2023, gasoline vehicles with stop/start, MHEVs, HEVs, PHEVs, and BEVs all gained market share and captured their largest market shares on record.

In addition to electrification technologies, other technologies continue to improve the performance of internal combustion engines (ICE), including the engines found in hybrids and PHEVS. These technologies include a combination of turbocharged engines (Turbo), gasoline direct injection (GDI), fuel injection systems that can alternate between GDI or port fuel injection (GDPI), and cylinder deactivation (CD). Higher speed transmissions and continuous variable transmissions (CVT) also enable the engine to operate in the most efficient way possible. Table 4.1 shows the implementation of several of these technologies, as used in conjunction with the electrification technologies identified in Figure 4.2.
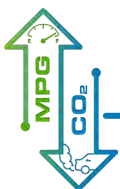
Figure 4.2. Manufacturer Use of Electrification Technologies for Model Year 2023
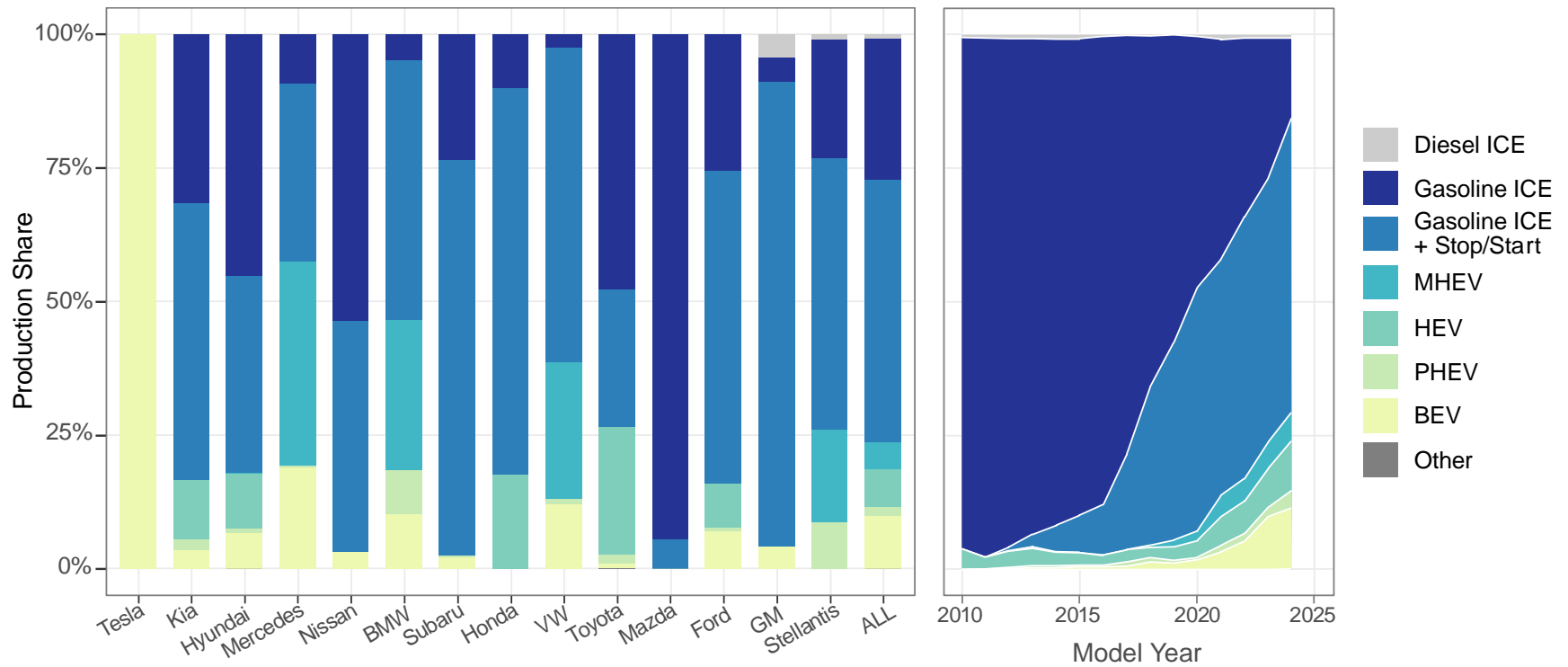
Table 4.1. Production Share by Drive Technology for Model Year 2023

Technology	Diesel	Gasoline ICE without Stop/Start	Gasoline ICE with Stop/Start	Mild Hybrid (MHEV)	Strong Hybrid (HEV)	Plug-In Hybrid (PHEV)	Battery Electric (BEV)	Fuel Cell (FCEV)	All
Production Share	0.8%	26.3%	49.2%	4.9%	7.2%	1.7%	9.8%	0.0%	100.0%
Stop/Start	95.0%	-	100.0%	100.0%	100.0%	100.0%	-	-	63.8%
GDI	-	36.2%	67.7%	68.0%	43.1%	68.7%	-	-	50.5%
GDPI	-	34.3%	20.6%	3.2%	46.8%	13.5%	-	-	22.9%
Turbo	100.0%	21.4%	52.6%	58.5%	23.9%	66.0%	-	-	38.0%
7+ Gears	100.0%	44.1%	75.9%	100.0%	10.6%	56.6%	-	-	56.4%
CVT	-	31.7%	21.4%	-	69.6%	28.8%	-	-	24.4%
Average Fuel Economy (mpge)	24.1	24.9	24.0	23.0	36.4	36.8	106.7	70.1	27.1
Average GHG Emissions (g/mi)	422	357	370	387	244	174	0	0	319
Average # Cylinders	6	4.9	4.9	5.7	4.2	4.4	-	-	4.9

Figure 4.3. shows the current adoption rates of electrification and engine improvement technologies for the fourteen largest manufacturers. The technologies in Figure 4.3. have emerged as significant technology developments within the last 10-15 years (some, like turbocharged engines, were available before this timeframe, but in small numbers). Manufacturers are continuing to implement both electrification and engine technology improvements across their vehicles to improve CO_2 emissions, fuel economy, and performance.

The following sections provide a deeper look into many of the technology trends identified here, beginning with engine/propulsion technologies, then transmissions, and drivelines. While the evolution of vehicles in more recent years challenges the breakdown of technology into these traditional categories, it is still a useful context for evaluating different aspects of vehicle technology and the many changes taking place across the automotive industry.

Figure 4.3. Manufacturer Use of Emerging Technologies for Model Year 2023

	Turbo	GDI or GDPI	Cylinder Deactivation	CVT	7+ Gears	Non-Hybrid StopStart	MHEV	HEV	PHEV	BEV	FCEV
Tesla										100%	
Kia	26%	63%		34%	50%	52%		11%	2%	3%	
Hyundai	25%	70%		23%	59%	37%	0%	10%	1%	7%	0%
Nissan	41%	82%		74%	23%	43%				3%	
Subaru	25%	98%		91%		74%			0%	2%	
Honda	31%	81%	33%	60%	38%	72%		18%			
BMW	90%	90%			89%	49%	28%		8%	10%	
Mazda	21%	100%	76%			5%				0%	
Toyota	18%	87%		33%	43%	26%		24%	2%	1%	0%
Mercedes	75%	81%	4%		81%	33%	38%		0%	19%	
VW	78%	88%	3%		86%	59%	25%		1%	12%	
Ford	75%	83%	6%	5%	88%	58%		8%	1%	7%	
GM	49%	91%	56%	11%	78%	87%				4%	
Stellantis	23%	19%	19%	2%	97%	51%	17%		9%		
All Manufacturers	38%	73%	15%	24%	56%	49%	5%	7%	2%	10%	0%

A. Vehicle Propulsion

As discussed above, all vehicles use at least one engine or motor to convert stored energy into rotational energy to propel the vehicle forward. Over the 50 years that EPA has been collecting data, the technology used in engines, and now motors, has continually evolved. The industry continues to develop new and innovative technologies to improve vehicle efficiency, reduce emissions, and increase vehicle performance and features. The following analysis will look at technology trends within gasoline engine vehicles, hybrids, PHEVs and EVs, and diesels. Each of these categories of engine technologies has unique properties, metrics, and trends over time.

Gasoline Engines

Since EPA began tracking vehicle data in 1975, nearly 700 million vehicles have been produced for sale in the United States. While electric vehicles have been capturing a growing share of the market in recent years, as shown in Figure 4.2, vehicles with gasoline engines still make up most of the market today and in past years have often been nearly the only option available.

The following analysis focuses on engine technology and metrics for gasoline engines. Hybrid and plug-in hybrid vehicles are included in this data unless they are explicitly excluded. For the purposes of this report "flex fuel" vehicles that are capable of operating on gasoline or a blend of 85% ethanol and 15% gasoline (E85) are included with gasoline engines and are not evaluated seperately.

Engine Size and Displacement

Measuring and tracking new vehicle engine size is one of the most basic, and important ways to track engine trends, because larger engines strongly correlate with higher fuel use. Engine size is a 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). Figure 4.4 shows the production share of gasoline engines by number of cylinders over time.

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, as larger 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
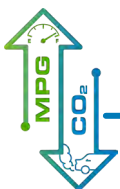
engines. This trend reversed again in 2005 as production began trending back towards 4-cylinder engines. Four-cylinder gasoline engines are the most popular engine option, capturing about 51% of the market in model year 2023.

Figure 4.4. Gasoline Engine Production Share by Number of Cylinders
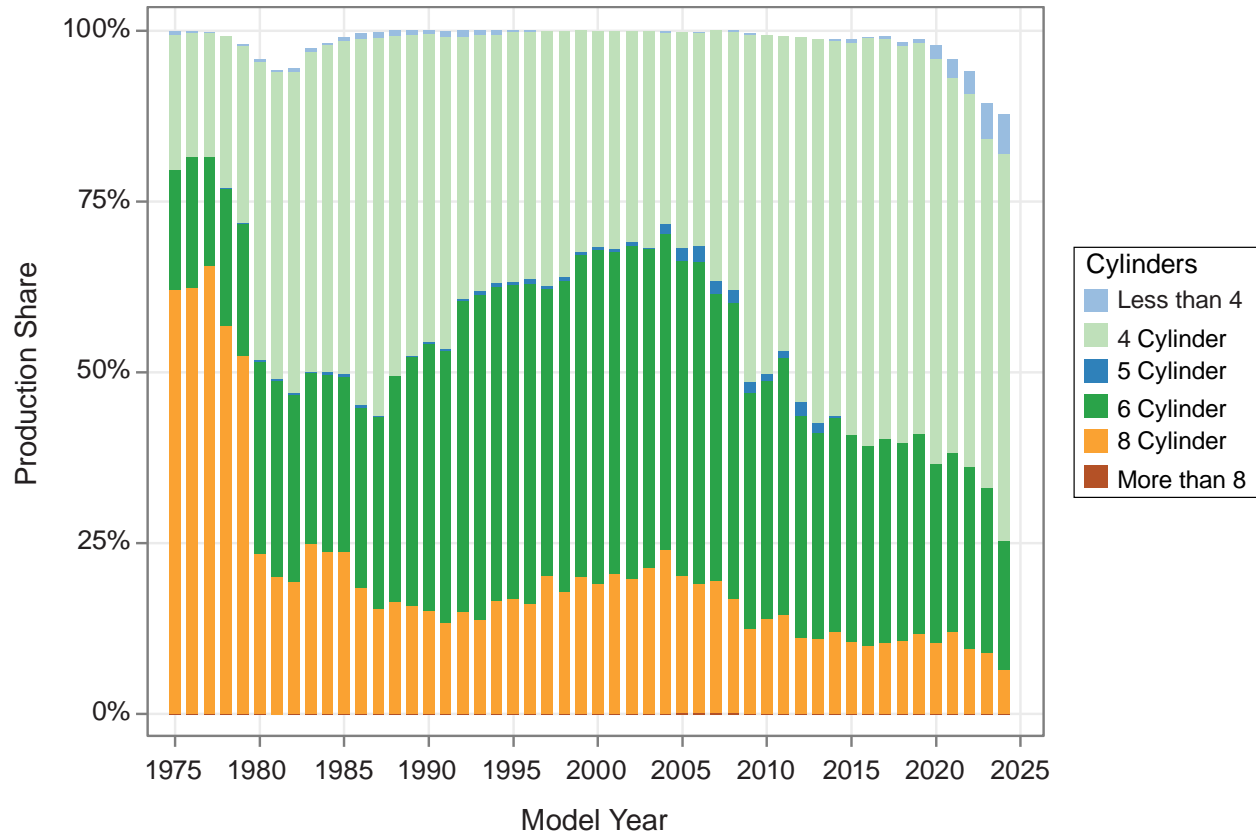
Overall engine size, as measured by the total volume of all the engine's cylinders, is directly related to the number of cylinders. As vehicles have moved towards engines with a lower number of cylinders, the total engine size, or displacement, is also at an all-time low. The average new vehicle in model year 1975 had a displacement of nearly 300 cubic inches (or just under 5 liters), compared to an average of 170 cubic inches (about 2.8 liters) in model year 2023. Gasoline engine displacement per cylinder has been relatively stable over the time of this report (around 35 cubic inches, or 0.6 liters, 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.

Even as gasoline engine displacement has fallen over time, horsepower has generally increased. One way to examine the relationship between gasoline engine horsepower and
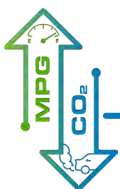
displacement is to look at the trend in *specific* power (HP/Displacement), which is a metric to compare the power output of an engine relative to its size. Specific power has doubled between model year 1975 and model year 2023. The rate at which specific power has increased has been remarkably steady, as shown in Figure 4.5. The specific power of new vehicle gasoline engines (excluding hybrids and PHEVS) has increased by about 0.02 horsepower per cubic inch every year for 50 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). For Figure 4.5, gasoline engines in hybrids and PHEVs have been excluded. The amount of fuel consumed by a gasoline engine in model year 2023, relative to the total displacement, is about 11% 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.
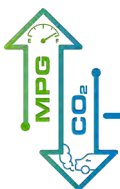
Figure 4.5. Percent Change for Specific Gasoline Non-Hybrid Engine Metrics
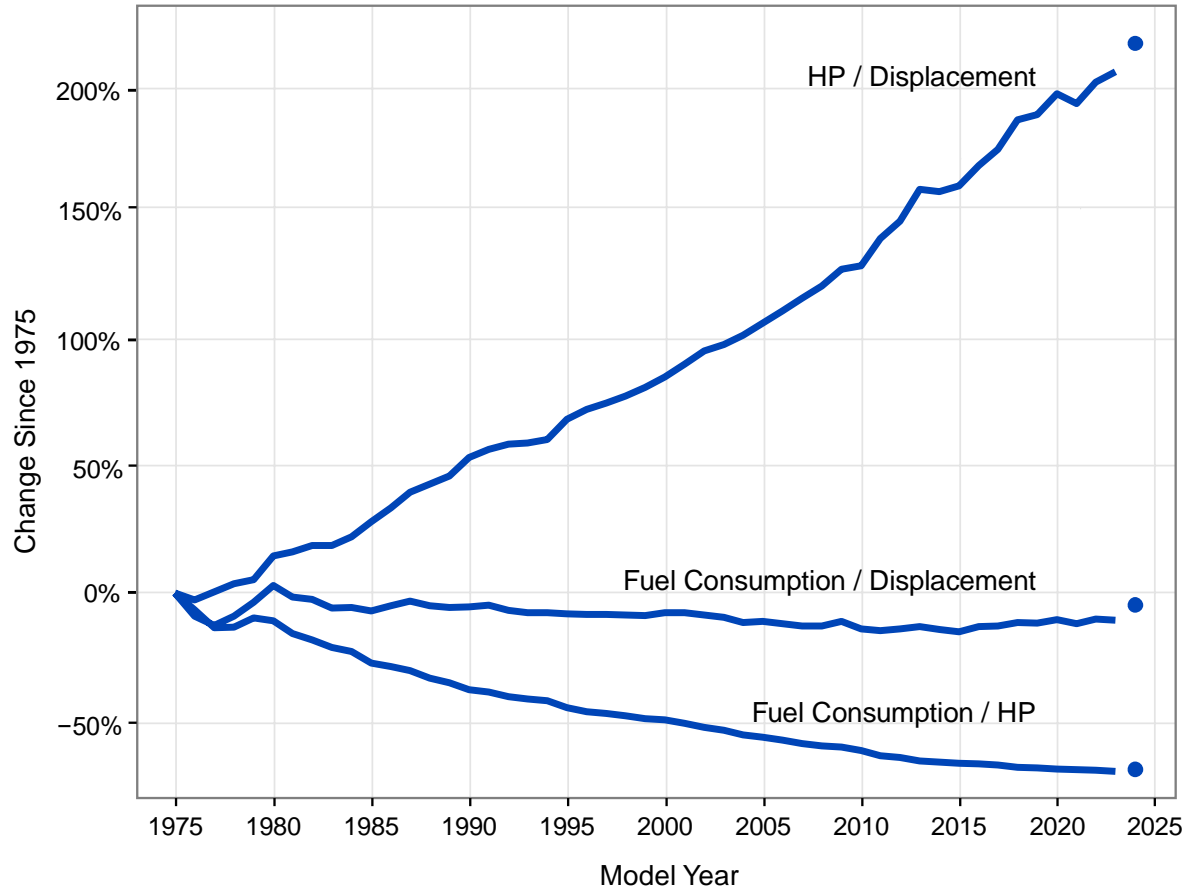
Fuel Delivery Systems and Valvetrains

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. Figure 4.6 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.

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) and combined gasoline direct and port injection

engines (GDPI), as shown in Figure 4.6. 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. The use of GDI has increased in subsequent years to the point where 74% of the model year 2023 fleet had either GDI or GDPI. In model year 2023, GDI engines were installed in 51% of model year 2023 vehicles, while GDPI engines were installed in 23% of new 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 precise control of the combustion process and therefore 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 4.6 shows the evolution of engine technology, including fuel delivery method and the introduction of VVT and multi-valve engines.

As shown in Figure 4.6, 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. Production Share by Engine Technology
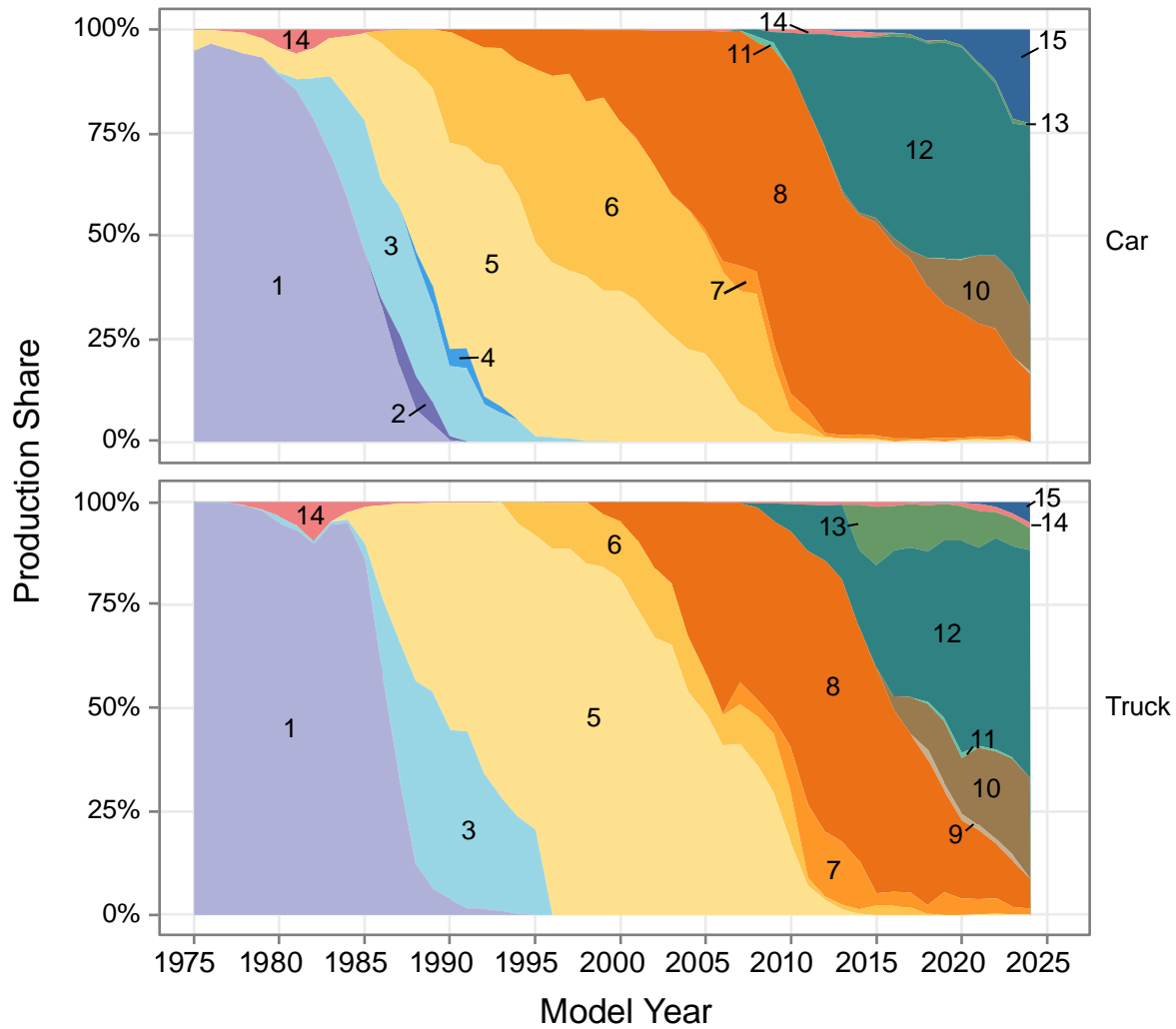
Fuel Delivery	Valve Timing	Number of Valves	Key
Carbureted	Fixed	Two-Valve	1
		Multi-Valve	2
Throttle Body Injection	Fixed	Two-Valve	3
		Multi-Valve	4
Port Fuel Injection	Fixed	Two-Valve	5
		Multi-Valve	6
	Variable	Two-Valve	7
		Multi-Valve	8
Gasoline Direct Injection (GDPI)	Fixed	Multi-Valve	9
	Variable	Multi-Valve	10
Gasoline Direct Injection (GDI)	Fixed	Multi-Valve	11
	Variable	Multi-Valve	12
		Two-Valve	13
Diesel	—	—	14
BEV/FCEV	—	—	15

Figure 4.7 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 pairing of GDI engines 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 4.7 after model year 2015 due to very limited production.
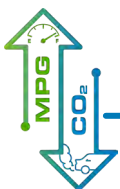
Figure 4.7. Engine Metrics for Different Gasoline Technology Packages
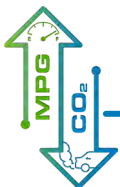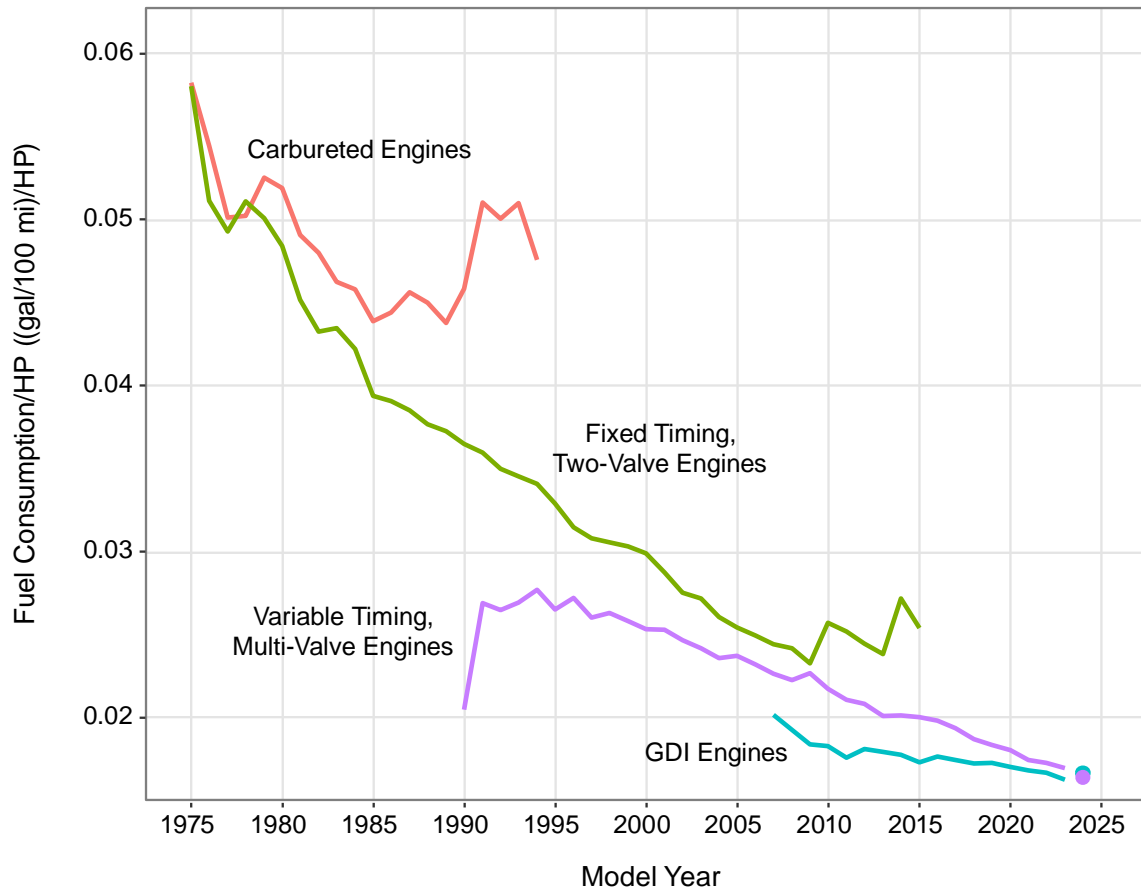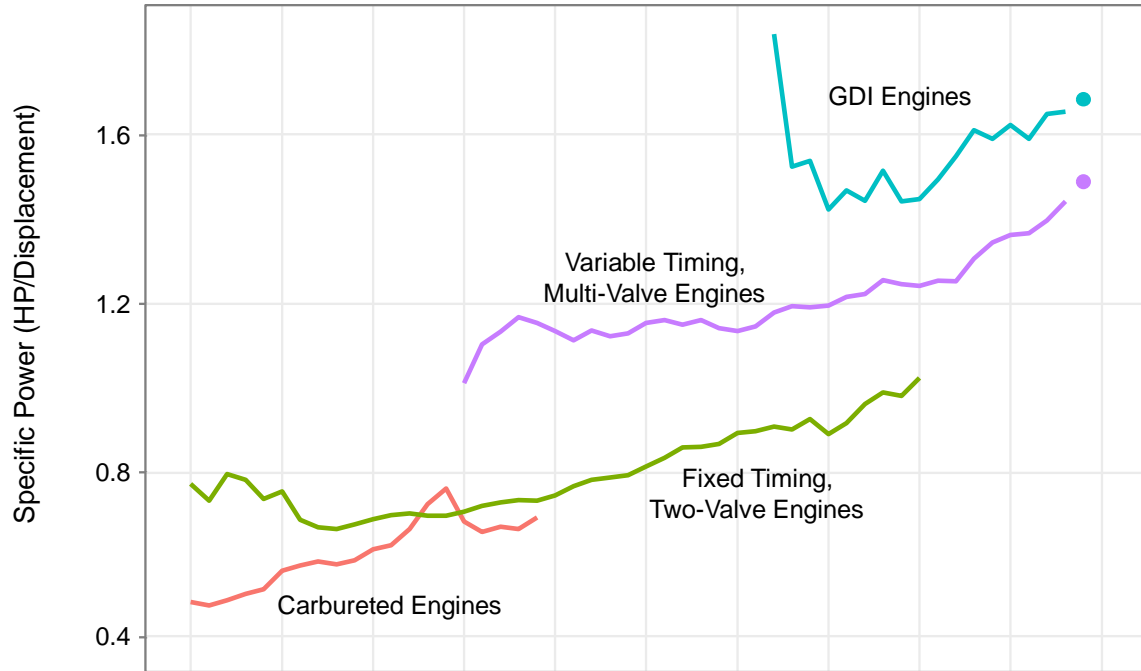
Turbocharging

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. Most 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).

Gasoline turbocharged engines have grown steadily in the marketplace, accounting for more than 35% of all production in model year 2023, as shown in Figure 4.8. 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, most gasoline turbocharged engines in model year 2023 are either 4-cylinder or 3-cylinder engines. Model year 2024 is projected to be a similar distribution, as shown in Figure 4-9.

Figure 4.8. Gasoline Turbo Engine Production Share by Vehicle Type
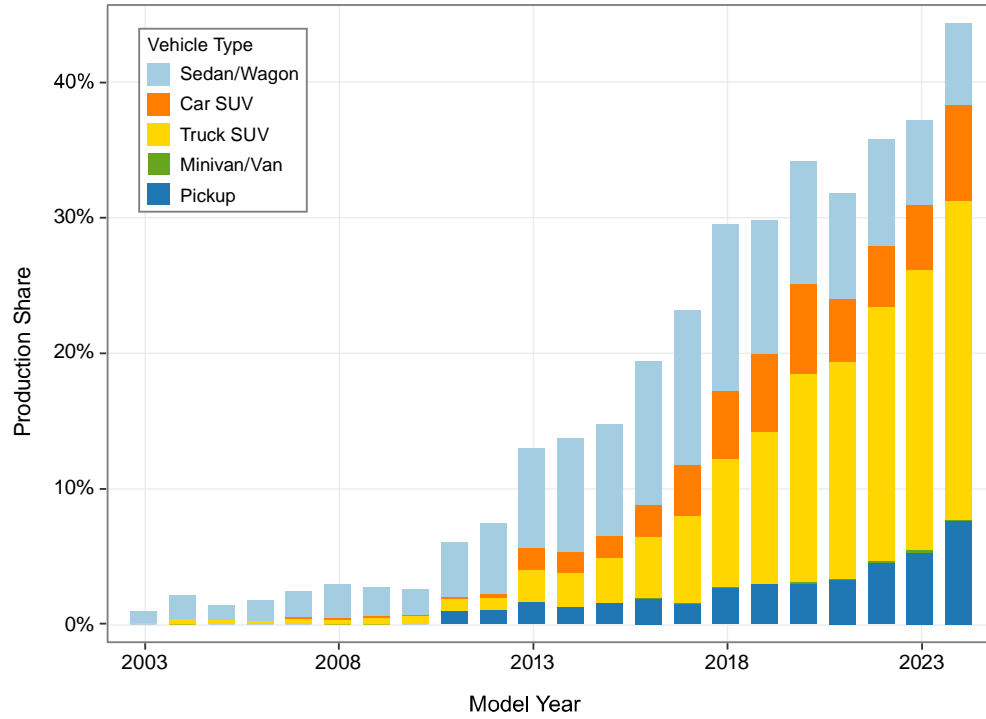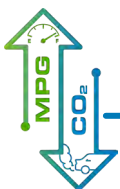
Figure 4-9. Gasoline Turbo Engine Production Share by Number of Cylinders
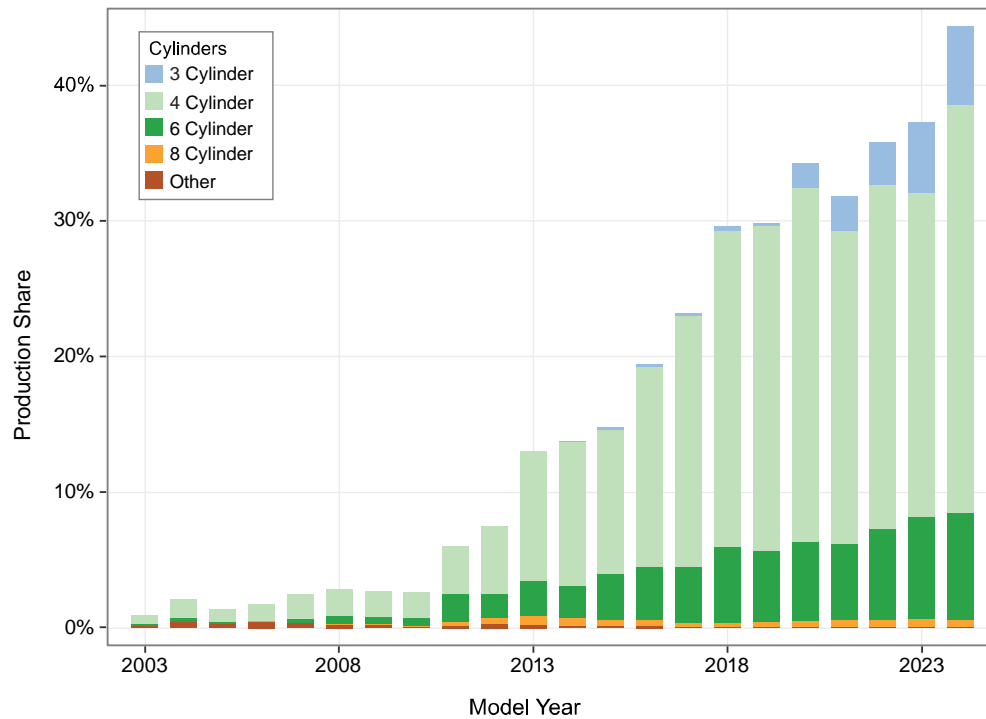
Cylinder Deactivation

Cylinder deactivation is an engine management approach that turns off the flow of fuel to one or more engine cylinders, and the corresponding spark plugs, 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 steadily climbed through model year 2021, but fell slightly, less than one percentage point, in model year 2023 to 15% of all new vehicles. Projected model year 2023 data suggests another small drop in the use of cylinder deactivation across all new vehicles.

Non-hybrid 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 more than 50% of all new gasoline non-hybrid vehicles in model year 2023. 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.

Figure 4.10. Gasoline Non-Hybrid Stop/Start Production Share by Vehicle Type
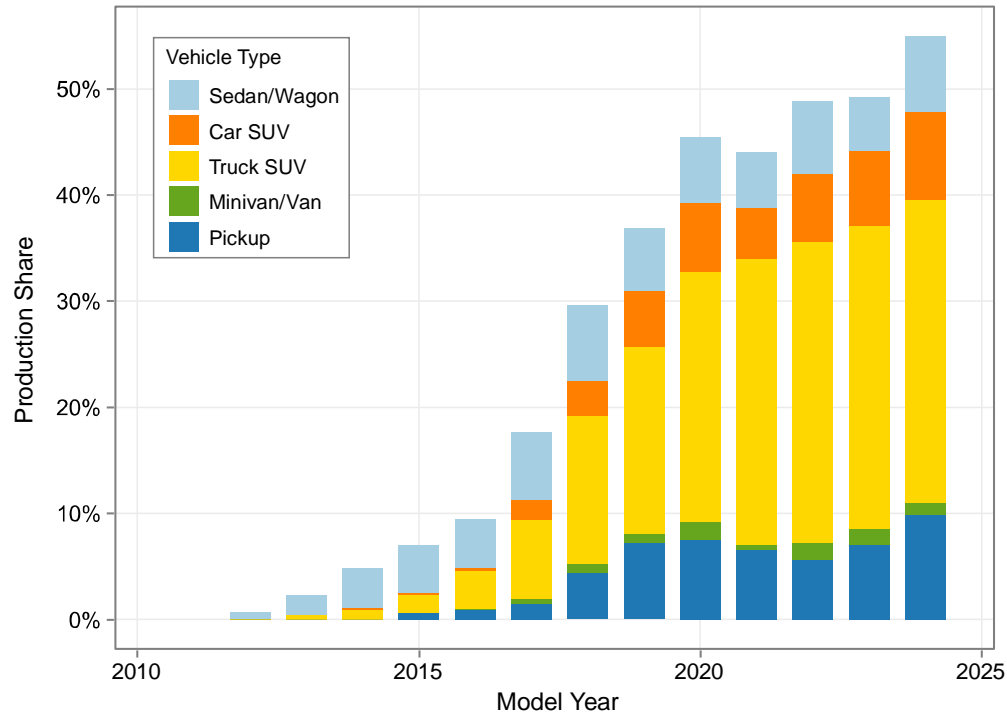
Figure 4.11. Gasoline Non-Hybrid Stop/Start Production Share by Number of Cylinders
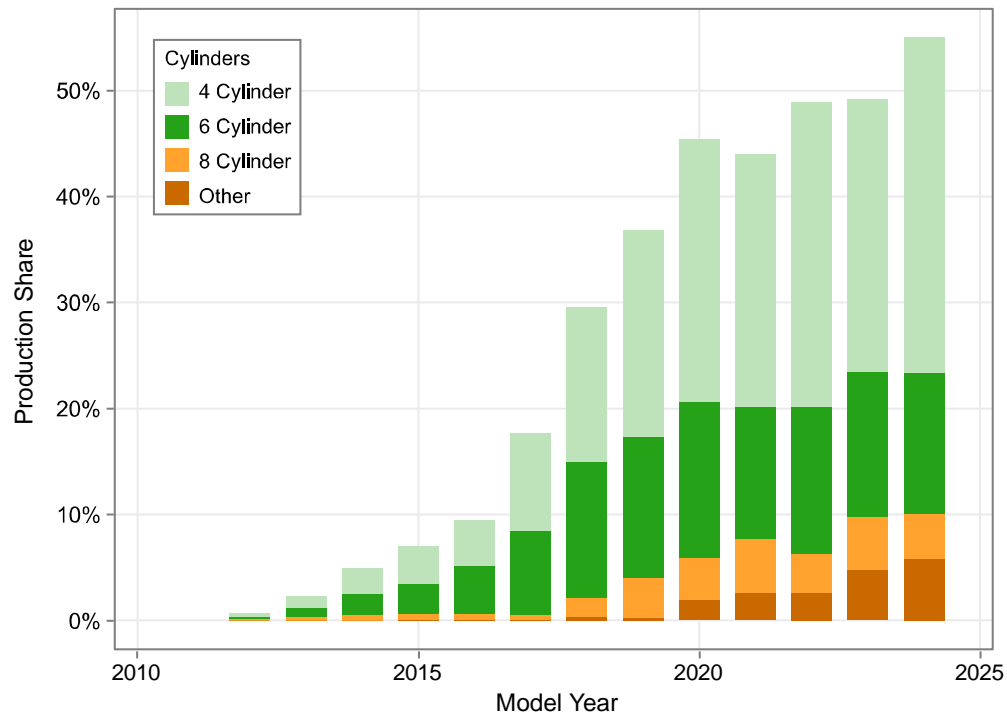
Hybrids

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.

The hybrid category includes "mild" hybrids (MHEVs), which employ a lower voltage electrical system that can provide launch assist and assist the engine but cannot directly propel the vehicle. "Strong" hybrid systems (HEVs) can temporarily power the vehicle without engaging the engine and may be able to capture more regenerative braking. For the purposes of this report, new vehicles with a 48V or less electrical system are classified as mild hybrids, while higher voltage electrical systems are classified as strong hybrids.

Hybrids were first introduced in the U.S. marketplace in model year 2000 with the Honda Insight. As more models and options were introduced into the market, hybrid production increased to 3.8% of all vehicles in model year 2010, before slowly declining to 1.8% of new vehicle production in model year 2016. Since model year 2016 however, the percent of new vehicles that are hybrids has steadily grown and reached a new high of 12.1% of all new vehicles in model year 2023. Hybrid growth is projected to continue growing in model year 2024, to 14.6% of new vehicle production.

Early hybrids were mostly the sedan/wagon vehicle type, but recent growth in other vehicle types, particularly truck SUVs, has propelled recent growth, as shown in Figure 4.12. 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 are also being used in the pickup and minivan/van vehicle types. Sedan/wagon hybrids accounted for only 25% of all hybrid production in model year 2023. 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.

Figure 4.12. Gasoline Hybrid Engine Production Share by Vehicle Type
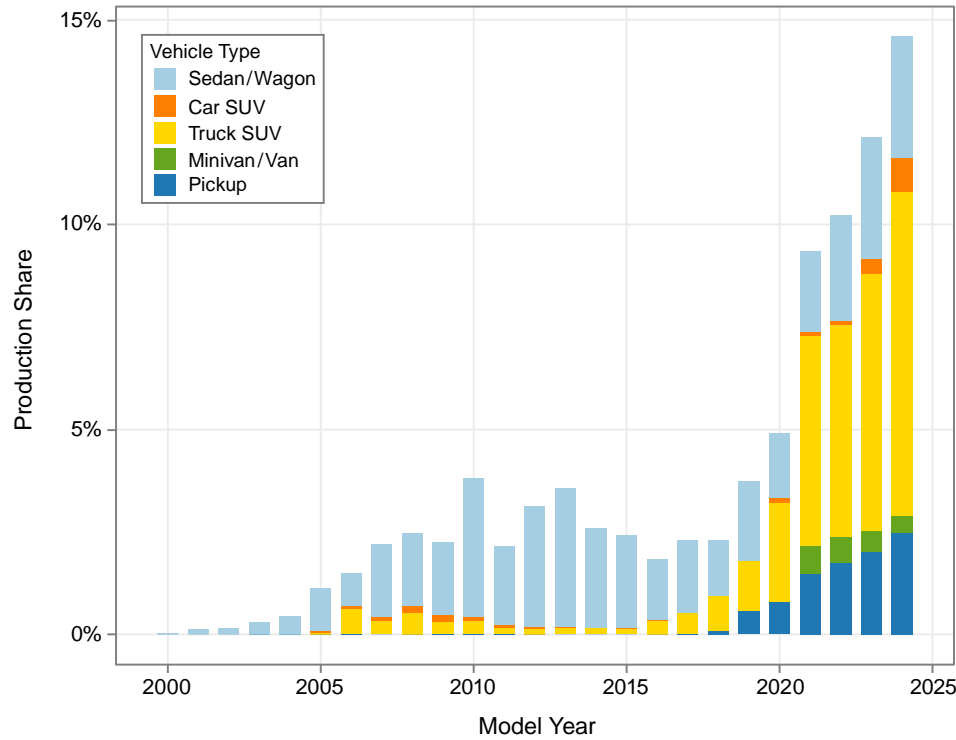
Figure 4.13. Gasoline Hybrid Engine Production Share by Number of Cylinders
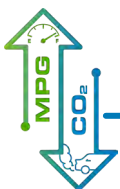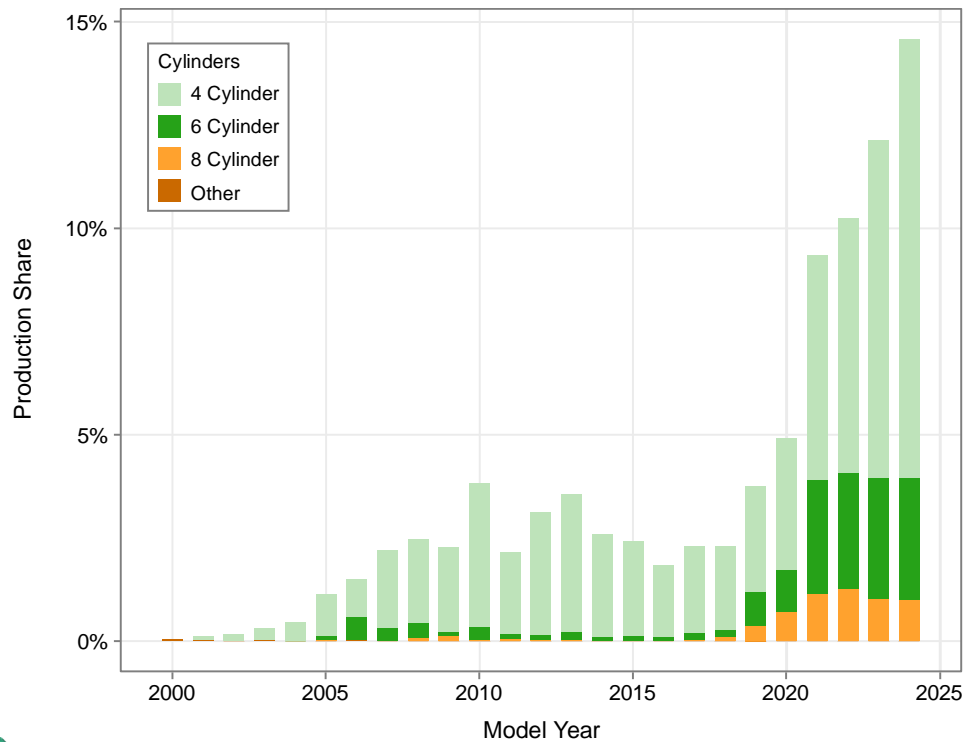
While strong hybrids have grown market penetration in recent years, the growth of mild hybrids from very limited numbers to current production has contributed to the overall market share rise for hybrids. Mild hybrids accounted for about 40% of hybrid production in model year 2023, as shown in Figure 4.14.

Figure 4.14. Gasoline Hybrid Engine Production Share Hybrid Type
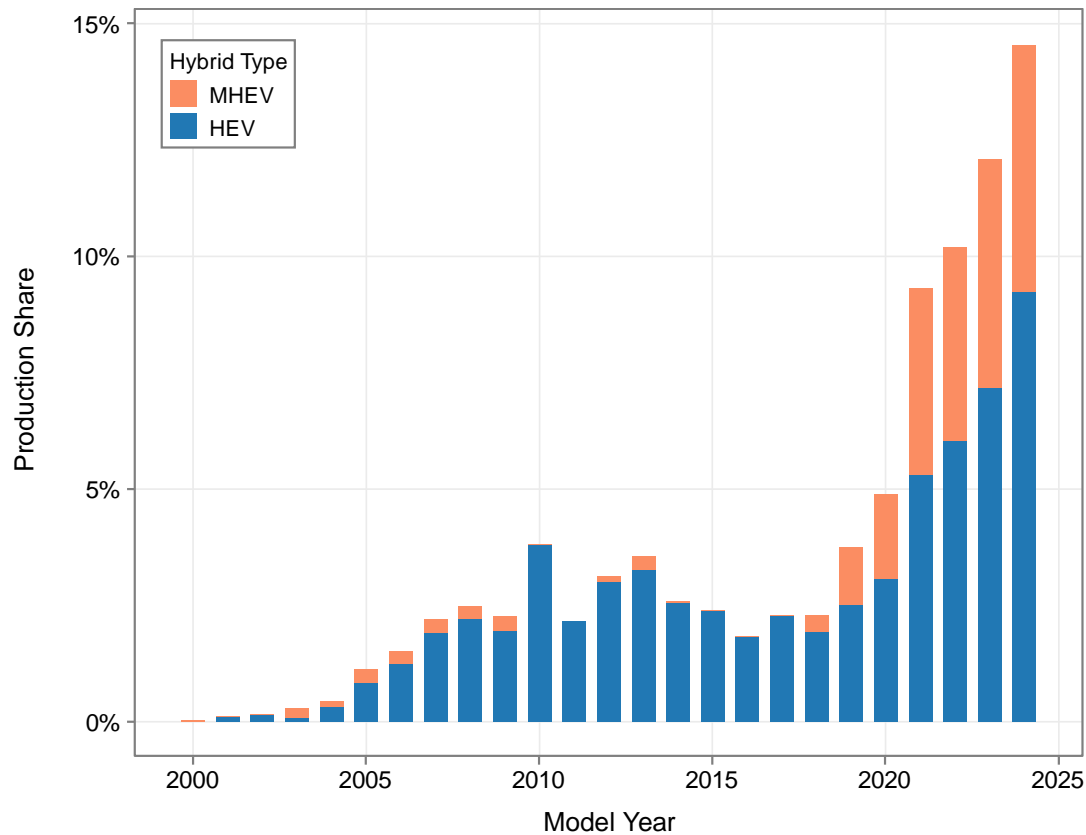
Plug-In Hybrid Electric, Battery Electric, and Fuel Cell Electric Vehicles

PHEVs and BEVs 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 mild or strong hybrids. BEVs operate using only energy stored in a battery from external charging. Fuel cell electric 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. The use of electricity instead
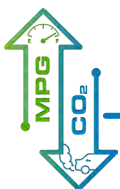
of gasoline as a fuel source complicates the comparison of BEVs (and PHEVs) to ICE vehicles, requiring different metrics[11] and an evolving analysis of vehicle technology.

BEVs rely on electricity stored in a battery for fuel. Combustion does not occur onboard the vehicle, and therefore there are no tailpipe emissions created by the vehicle. The electricity used to charge BEVs 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 U.S. has also been changing over time, as natural gas and renewable energy resources make up a growing portion of electricity generation across the U.S. Depending on the source of electricity, BEVs often result in lower CO_2 emissions over their lifetime compared to gasoline vehicles.

Since BEVs do not use gasoline, the familiar metric of miles per gallon cannot be applied to BEVs. Instead, BEVs are rated in terms of miles per gallon-equivalent (mpge), which is the number of miles that a BEV 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 BEVs and gasoline vehicles. BEVs 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 a BEV, for a limited range, and then will operate like a strong 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 BEV and PHEV metrics, as well as upstream emissions from electricity, see Appendix E.

The production of BEVs and PHEVs has increased rapidly in recent years. Prior to model year 2011, BEVs were available, but generally only in small numbers for lease in California.[12] In model year 2011 the first PHEV, the Chevrolet Volt, was introduced along with the Nissan Leaf BEV. Many additional models have been introduced since, and in model year 2023 combined BEV/PHEV production reached almost 12% of all new vehicles. Combined BEV and PHEV production is projected to reach a new high of almost 15% of all production in model year 2024. In model year 2023 there were two hydrogen FCEV models

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[11] See Appendix E for a detailed discussion of BEV and PHEV metrics.

[12] At least over the timeframe covered by this report. BEVs were initially produced more than 100 years ago.
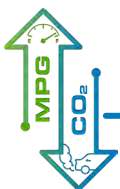
produced, but they were only available in small numbers and in the state of California and Hawaii. However there continues to be interest in FCEVs as a future technology. The trend in EVs, PHEVs, and FCEVs are shown in Figure 4.15.

Figure 4.15. Production Share of BEVs, PHEVs, and FCEVs[13]
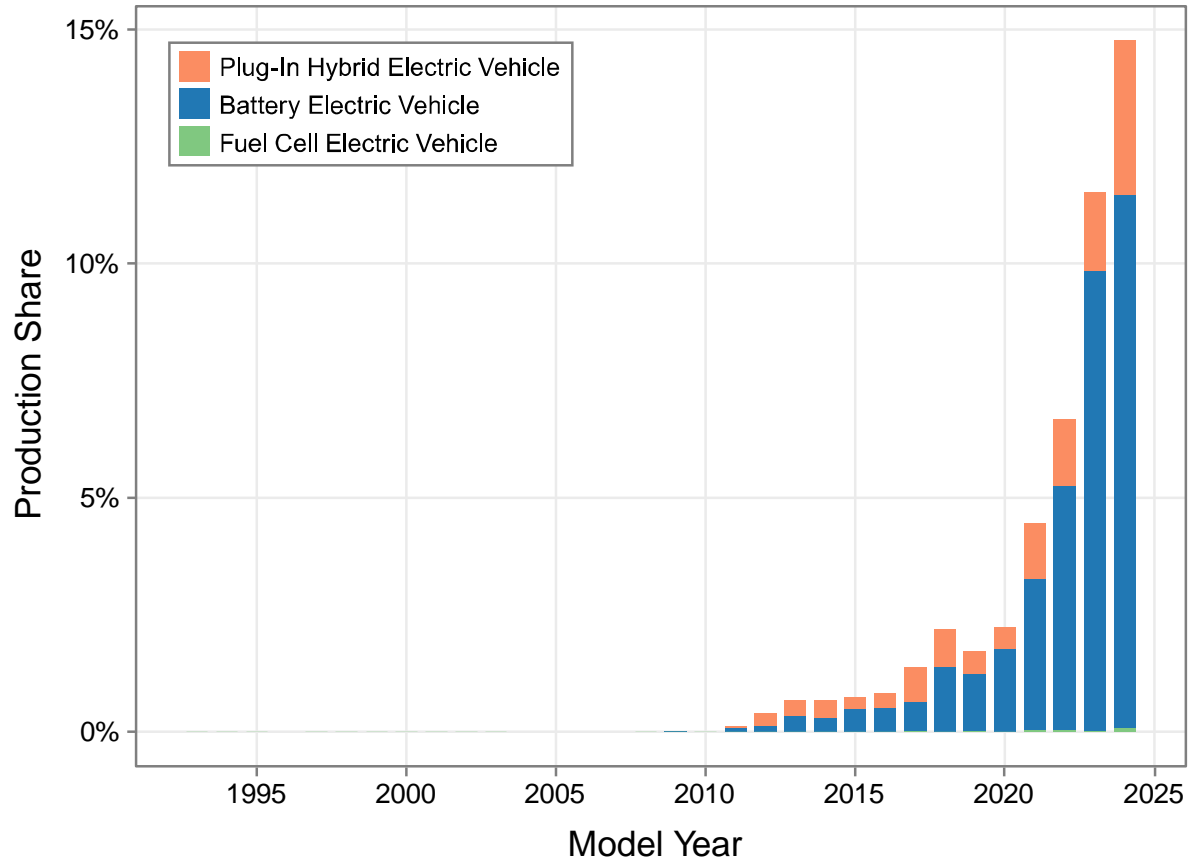
The inclusion of model year 2023 BEV and PHEV production reduced the overall new vehicle average CO_2 emissions by 38 g/mi and increased new vehicle average fuel economy by 2.2 mpg, as shown in Figure 4.16. Without BEV and PHEV production, the CO_2 emissions and fuel economy of the remaining new vehicles was relatively flat.

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[13] BEV 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 4.16. Impact of BEVs and PHEVs
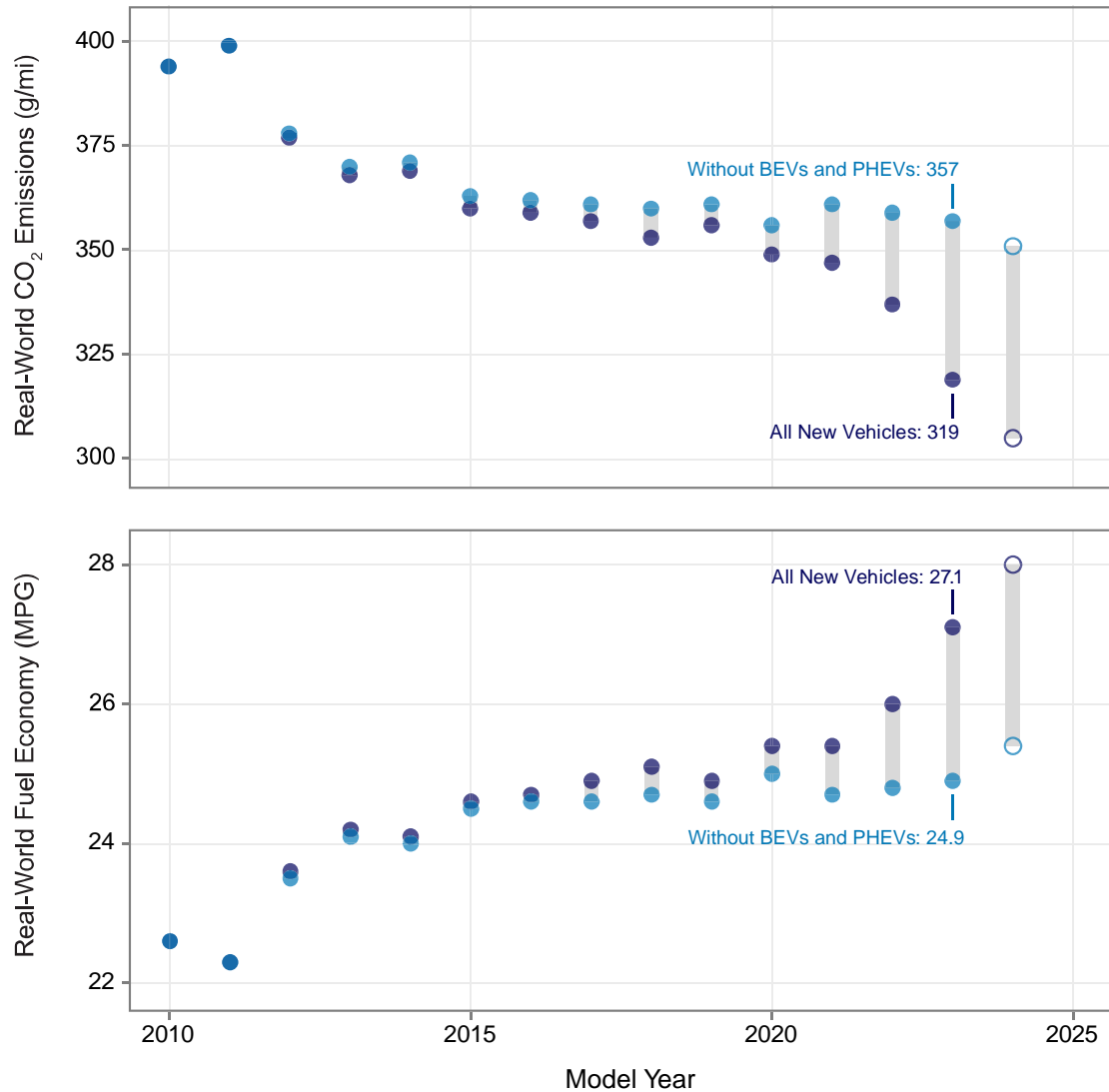
Figure 4.17 and Figure 4.18 show the production share by vehicle type for BEVs and PHEVs. Early production of BEVs was mostly in the sedan/wagon vehicle type, but recent model years have shown growth in car SUVs and truck SUVs. Electric pickup trucks first entered the market in model year 2022, along with new BEV 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.

Figure 4.17. Battery Electric Vehicle Production Share by Vehicle Type
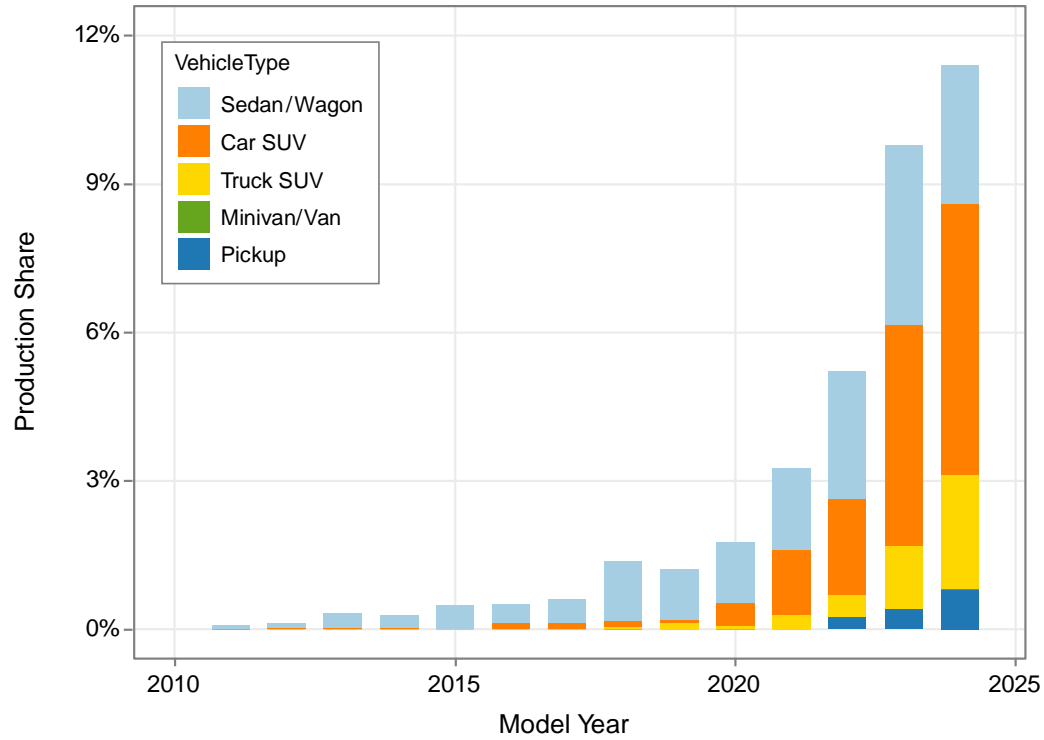
Figure 4.18. Plug-In Hybrid Vehicle Production Share by Vehicle Type
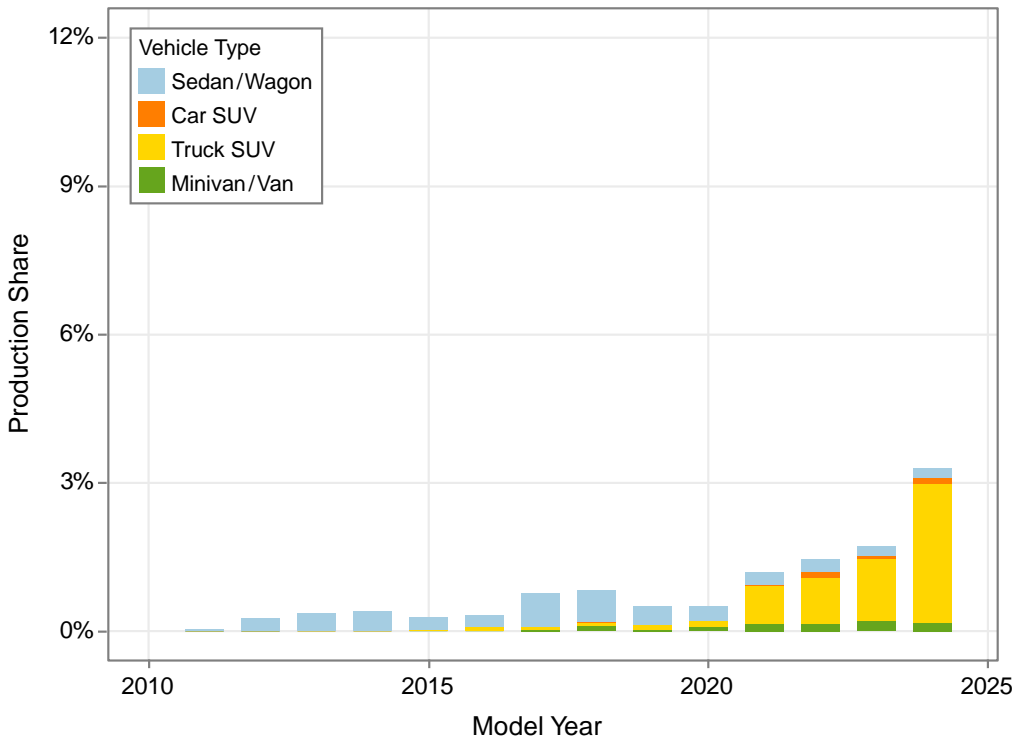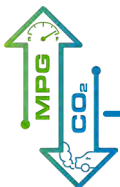
Figure 4.19 shows the range and fuel economy trends for BEVs and PHEVs[14]. The average range of new BEVs has climbed substantially. In model year 2023, the average new BEV range is 292 miles, or almost four times the range of an average BEV in 2011. The range values shown for PHEVs are the charge-depleting range, where the vehicle is operating on energy in the battery from an external source. This is generally the all-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.

Figure 4.19. Charge Depleting Range and Fuel Economy for BEVs and PHEVs
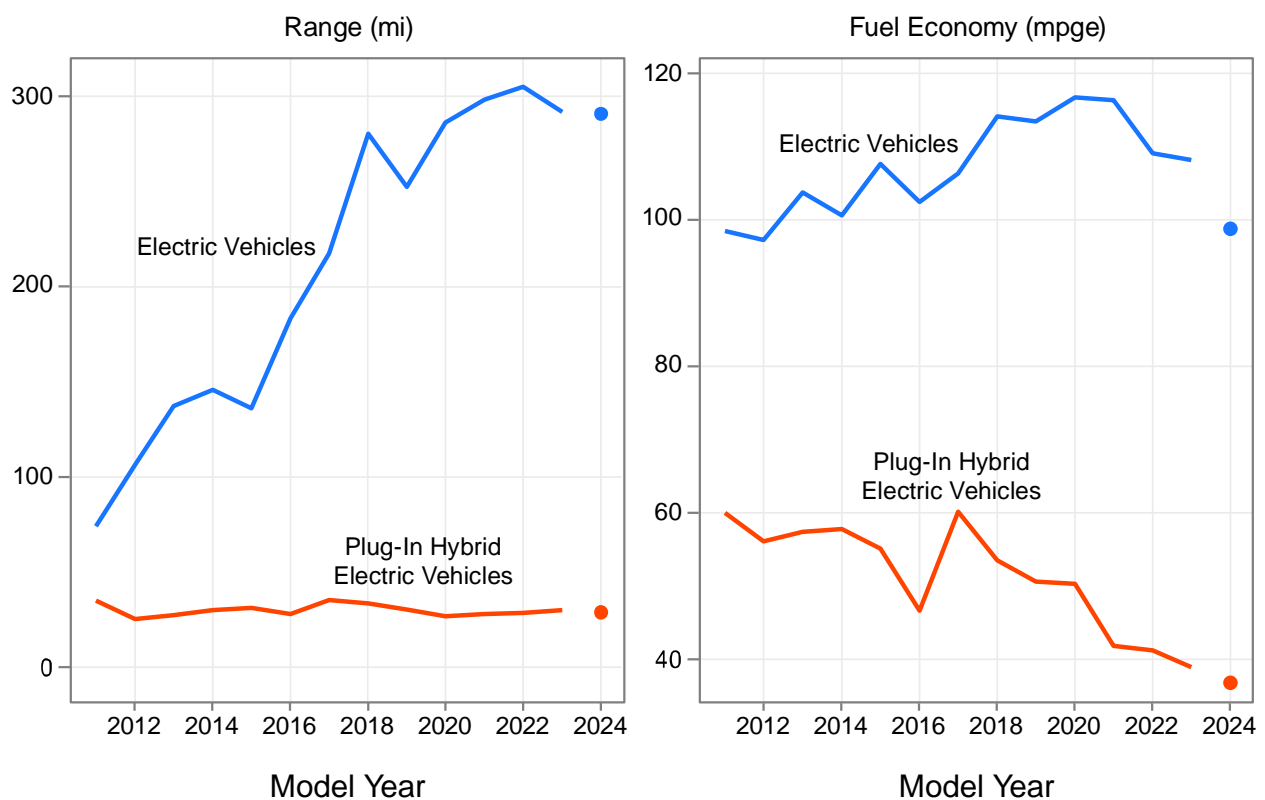
The fuel economy of electric vehicles has also improved since model year 2011, as measured in miles per gallon of gasoline equivalent (mpge). In model year 2022 and 2023
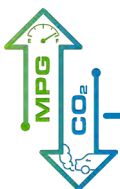
[14] The range and fuel economy values in this figure are the combined values from the fuel economy label, which weights city and highway driving 55% and 45%, as compared to the rest of the report, which uses a 43% city and 57% highway weighting. See Appendix C for more information.

the fuel economy of average new BEVs fell, mostly due to the introduction of larger vehicles that have lower overall fuel economy ratings. The combined fuel economy of PHEVs has been more variable but is about 35% lower in model year 2023 than in model year 2011 and is expected to decrease further in 2024. This may be attributable to the growth of truck SUV PHEVs, as shown in Figure 4.18. For more information about BEV and PHEV metrics, see Appendix E.

As the number of electric vehicles available continues to increase and diversify, comparing technology trends across electric vehicles will become more meaningful and important. Figure 4.20 shows the distribution of BEV energy consumption, in terms of kWh per 100 miles, compared to vehicle inertia weight class. There is a general trend that heavier EVs have a higher energy consumption, but there is a large spread at each inertia weight class. Pickups and truck SUVs represent the heaviest BEVs and are somewhat less efficient than other vehicle types, consistent with trends across the broader industry.

Figure 4.20. BEV Energy Consumption by Weight and Vehicle Type
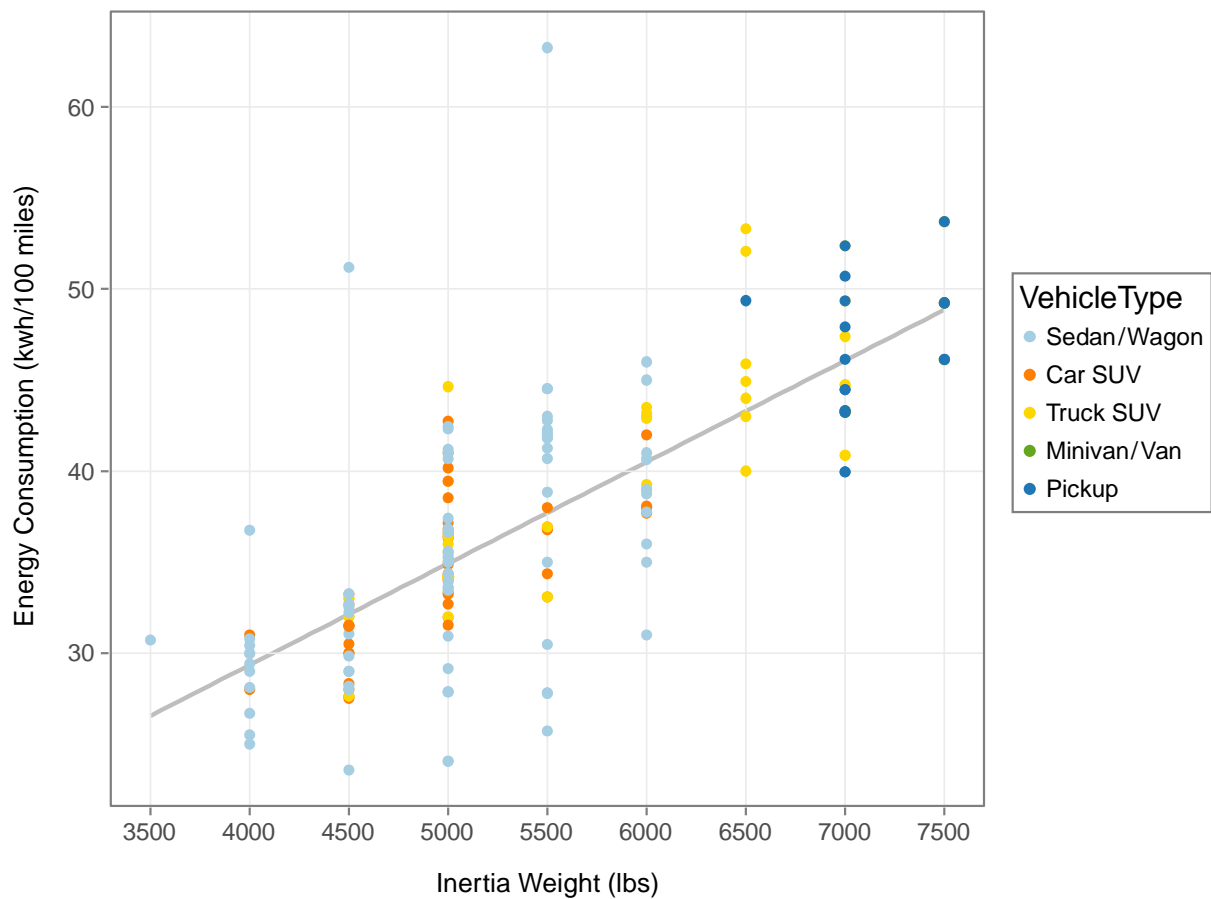
Diesel Engines

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 2023, 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 4.21 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/wagon vehicles with diesel engines and most light-duty diesel production has been pickups. This report does not include the largest heavy-duty pickup trucks, work vans, or vocational trucks, which have a higher penetration of diesel engines. As shown in Figure 4.22, 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 4.23 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.
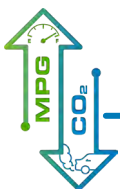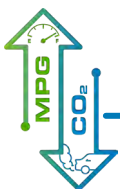
Figure 4.21. Diesel Engine Production Share by Vehicle Type
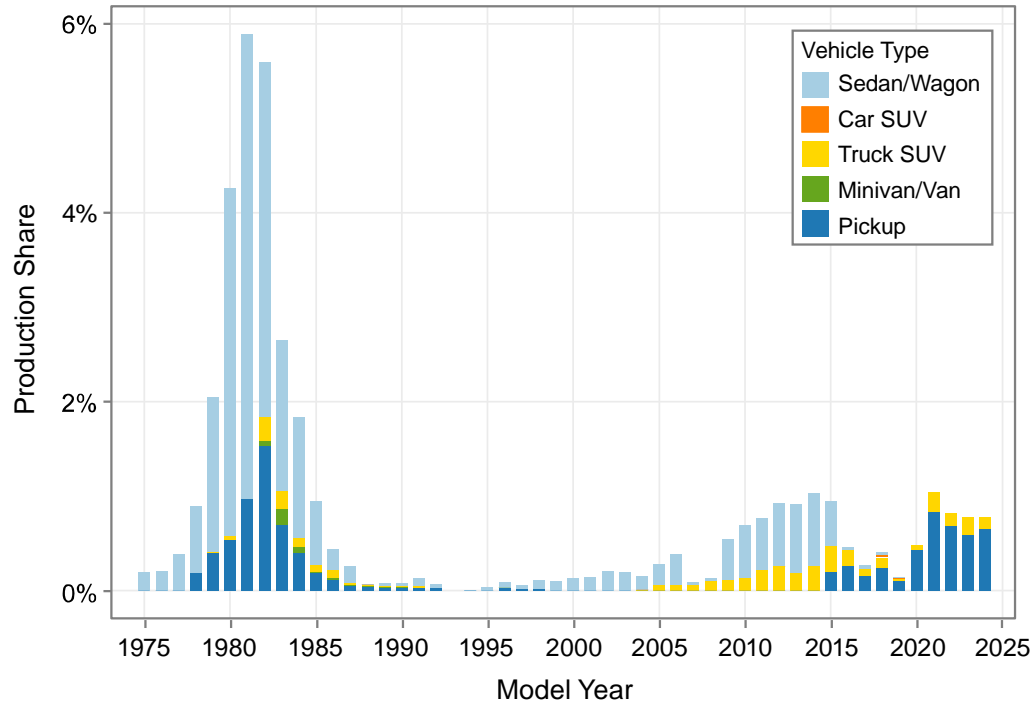
## Figure 4.22. Diesel Engine Production Share by Number of Cylinders
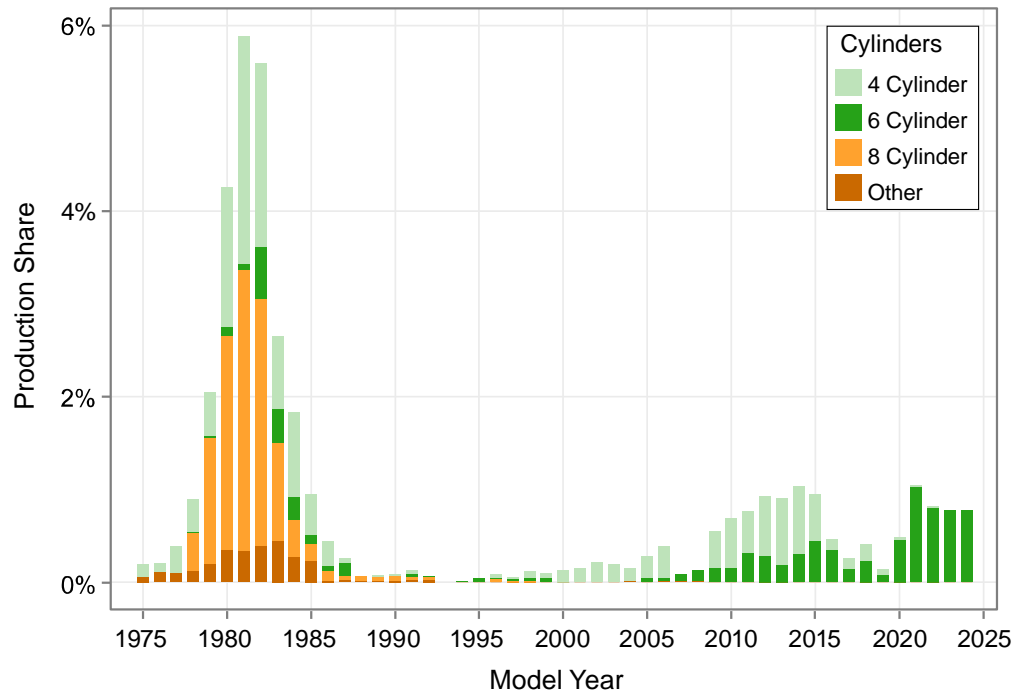
Figure 4.23. Percent Change for Specific Diesel Engine Metrics
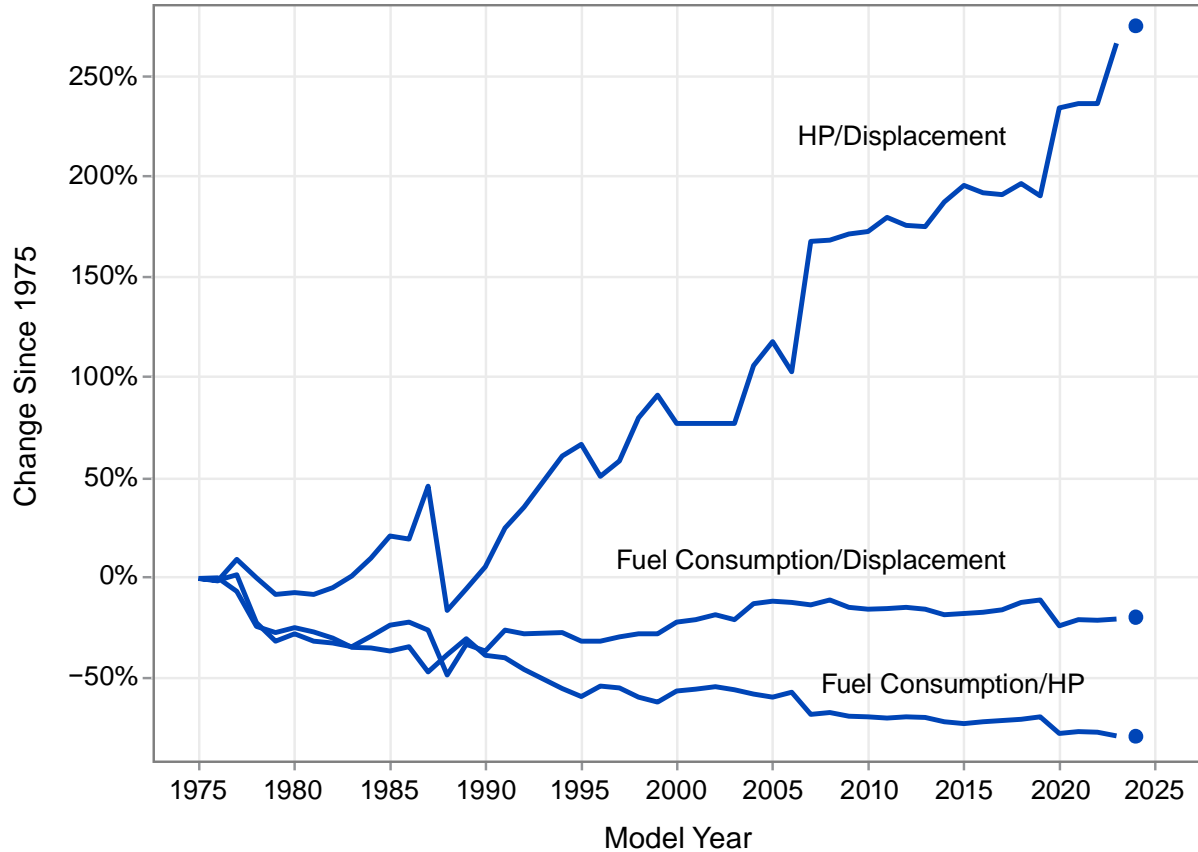
Other Engine Technologies

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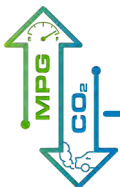
B. Vehicle Drivetrain

A vehicle drivetrain includes all components responsible for transmitting rotational energy from an engine or electric 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 electric 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 4.24. Mild hybrids generally use a conventional transmission and drivetrain, but strong hybrids often replace the transmission entirely with a planetary gearset or some other enabling configuration. PHEVs generally resemble full hybrids but can have numerous configurations that allow for complicated energy optimization. Battery electric vehicles generally use a single speed transmission and do not need the numerous gears required by combustion engines. However, some high-performance electric vehicles are now being produced with 2-speed transmissions (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 4.24 shows the evolution of transmission production share for cars and trucks since model year 1980.[15] For this analysis, transmissions are separated into

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[15] EPA has incomplete transmission data prior to model year 1980.
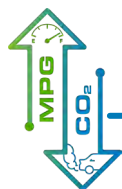
manual transmissions, CVTs, and automatic transmissions. Automatic transmissions are further separated into those with and without lockup mechanisms, which can lock up the torque converter in an automatic transmission under certain driving conditions and improve efficiency. CVTs have also been split into hybrid and non-hybrid versions to reflect the fact that hybrid CVTs are generally very different mechanically from traditional CVTs. The hybrid CVT category includes CVTs used for PHEVs.

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 4.24 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 8% by model year 2023. Eight-speed transmissions became the most popular transmission in model year 2019. In model year 2023, vehicles with eight-speed transmissions accounted for about 30% 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.

Figure 4.24. Transmission Production Share
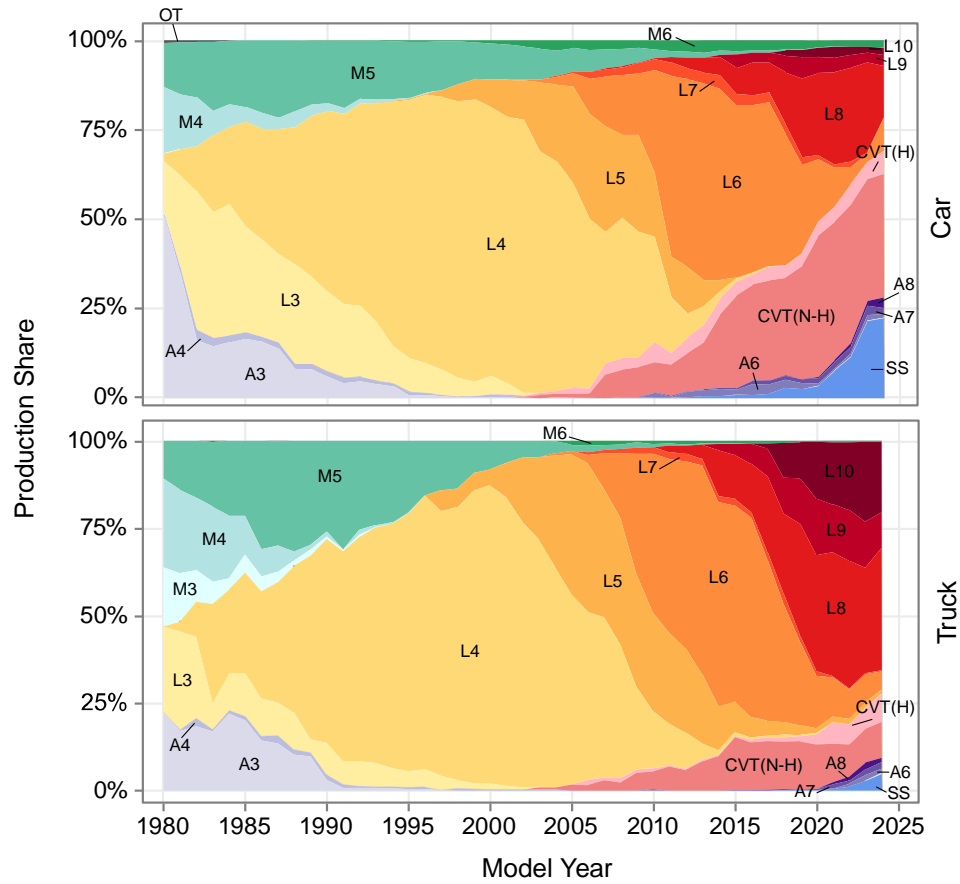
Transmission	Lockup?	Number of Gears	Key
Single Speed	—	1	SS
Automatic Semi-Automatic Automated Manual	No	2	A2*
		3	A3
		4	A4
		5	A5*
		6	A6
		7	A7
		8	A8
	Yes	2	L2*
		3	L3
		4	L4
		5	L5
		6	L6
		7	L7
		8	L8
		9	L9
		10	L10
Manual	—	3	M3
		4	M4
		5	M5
		6	M6
		7	M7*
ContinuouslyVariable (Non-Hybrid)	—	—	CVT(N-H)
ContinuouslyVariable (Hybrid)	—	—	CVT(H)
Other	—	—	OT

*Categories A2, A5, L2, and M7 are too small to depict in the area plot.

Transmission trends also vary by vehicle engine technology, as shown in Figure 4.25. For model year 2023, diesel engines were most often paired with a ten-speed lockup transmission, with some eight speed transmissions. Gasoline engines were paired with a wide variety of transmissions, including CVTs, lockup transmissions from ten to five speeds, a small number of manual transmissions, and a small number of non-lockup transmissions (likely dual clutch transmissions). Mild hybrids are most often paired with an eight or nine speed transmission, while strong hybrids most often use a hybrid CVT transmission. PHEVs currently use a wide array of transmission technologies, including traditional automatic transmissions, CVTs, and single-speed transmissions. BEVs are generally designed without a traditional transmission and utilize a single speed design. However, a limited number of high-performance EVs do have a 2-speed transmission.

Figure 4.25. Transmission By Engine Technology, Model Year 2023
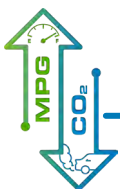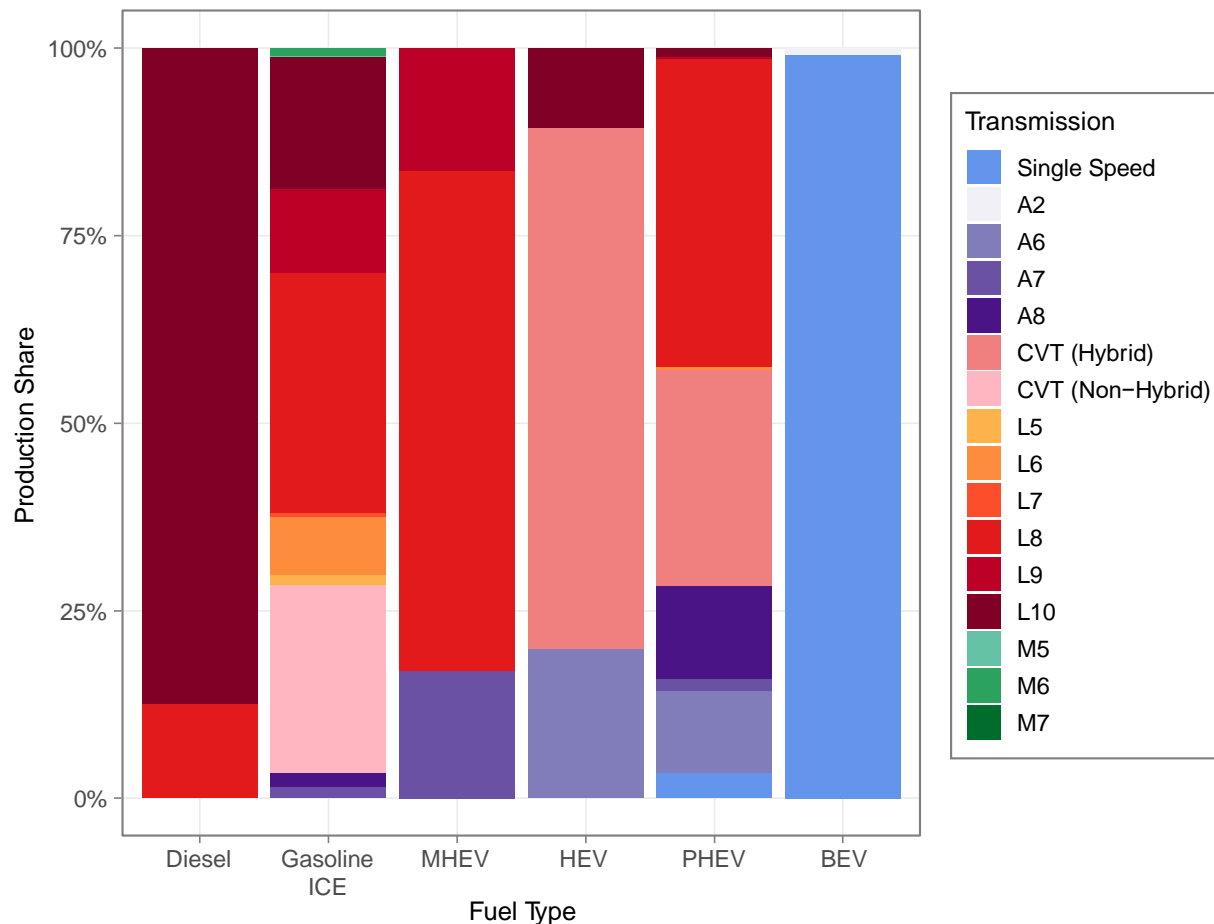
Another notable trend in Figure 4.24 is the decline in manual transmissions. Manual transmissions were included in almost 35% of new vehicles in model year 1980, but have been gradually declining since, and have been below 1% of all production since model year 2021. Today, manual transmissions are available only in a limited number of small vehicles, sports cars, off-road truck SUVs, and a few small pickups.

Part of the reason for the decline in manual transmission is because modern automatic transmissions are now generally more efficient and can offer better performance than manual transmissions. In the past, automatic transmissions have generally been less efficient than manual transmissions, largely due to inefficiencies in the automatic transmission torque converter and fewer gears. Over time, both manual and automatic transmissions added gears, but automatic transmissions added gears faster. In model year 2012, the average number of gears in an automatic transmission passed the average number of gears in a manual transmission. Figure 4.26 shows the average number of gears in new vehicle transmissions since model year 1980 for automatic and manual transmissions (excluding BEVs and PHEVs). The continued shrinking availability of manual transmissions in each model year limits the relevance of analyses comparing current manual transmissions to automatic transmissions.

Figure 4.26. Average Number of Transmission Gears
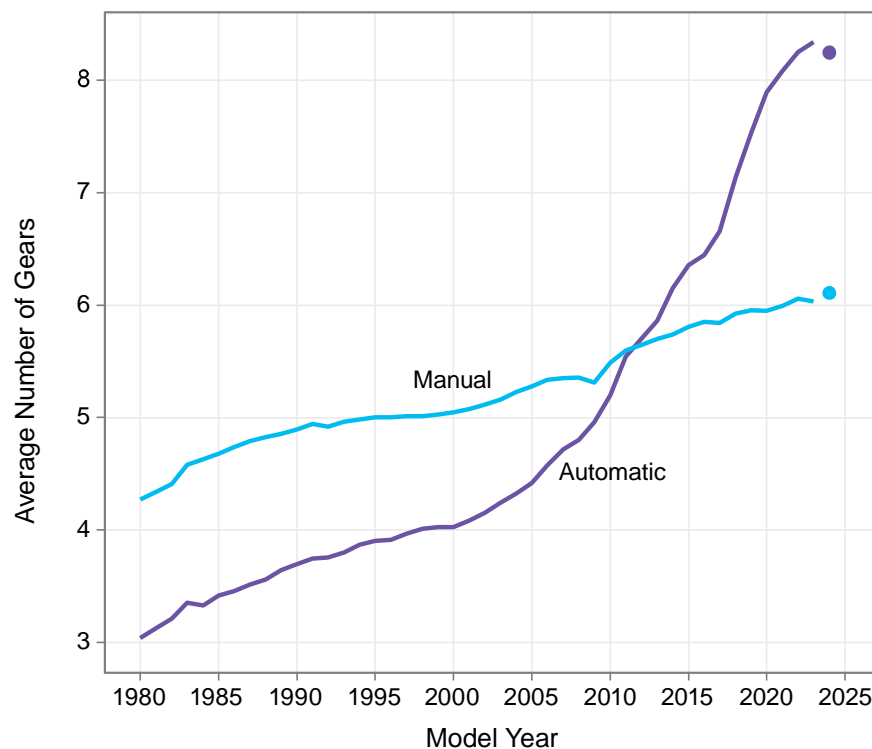
Drive Types

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 4.27. 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 2023. 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 29% in model year 2023. Four-wheel drive systems have steadily increased from 3.3% of new vehicle production in model year 1975 to 61% of production in model year 2023. Four-wheel drive systems have increased for both cars and trucks, but the high penetration rate of 83.0% 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 4.27. Front-, Rear-, and Four-Wheel Drive Production Share
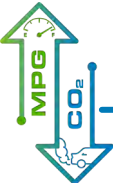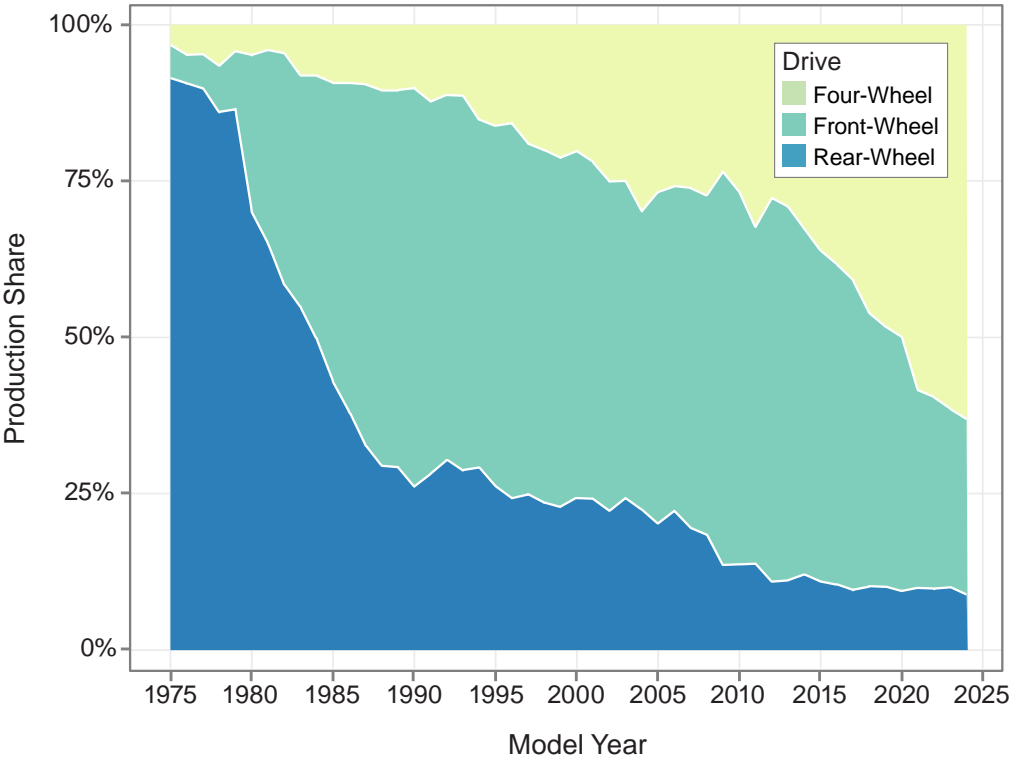
C. Technology Adoption and Comparison

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 4.28 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 4.28 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 4.28 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.
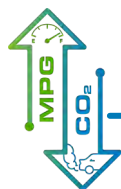
Figure 4.28. Industry-Wide Car Technology Penetration after First Significant Use
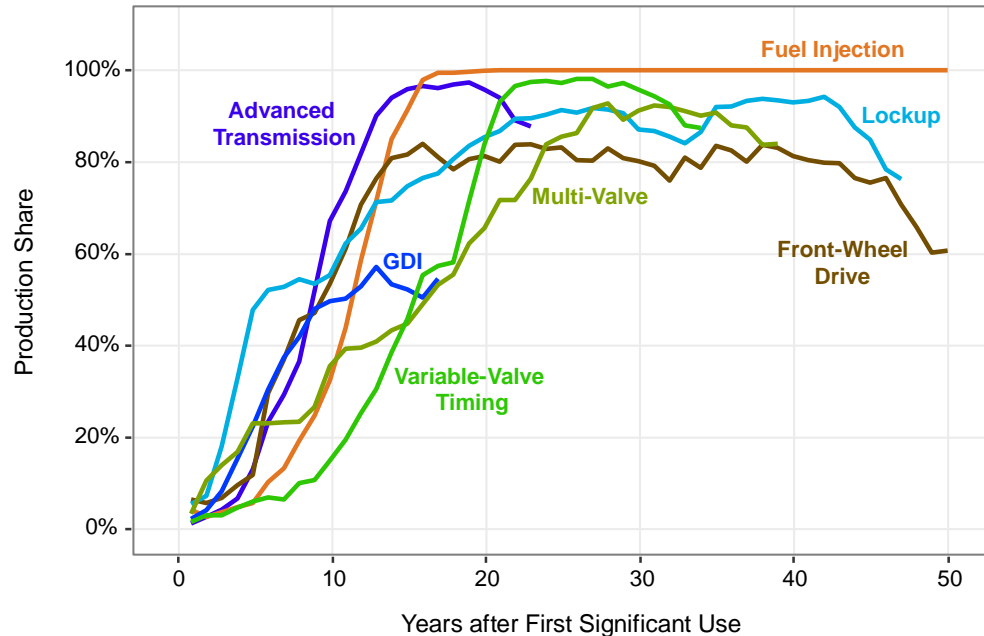
Technology Adoption by Manufacturers

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 4.28 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 4.29 begins to disaggregate the industry-wide trends to examine how individual manufacturers have adopted new technologies.[16] For each technology, Figure 4.29 shows

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[16] 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.

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 4.29, five are now at or near full market penetration for the included manufacturers, and two are still in the process of adoption by manufacturers. The technologies shown in Figure 4.29 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 4.29. Manufacturer Specific Technology Adoption over Time for Key Technologies
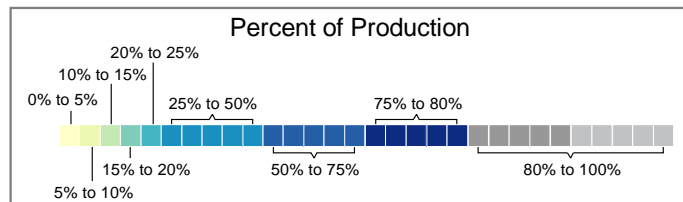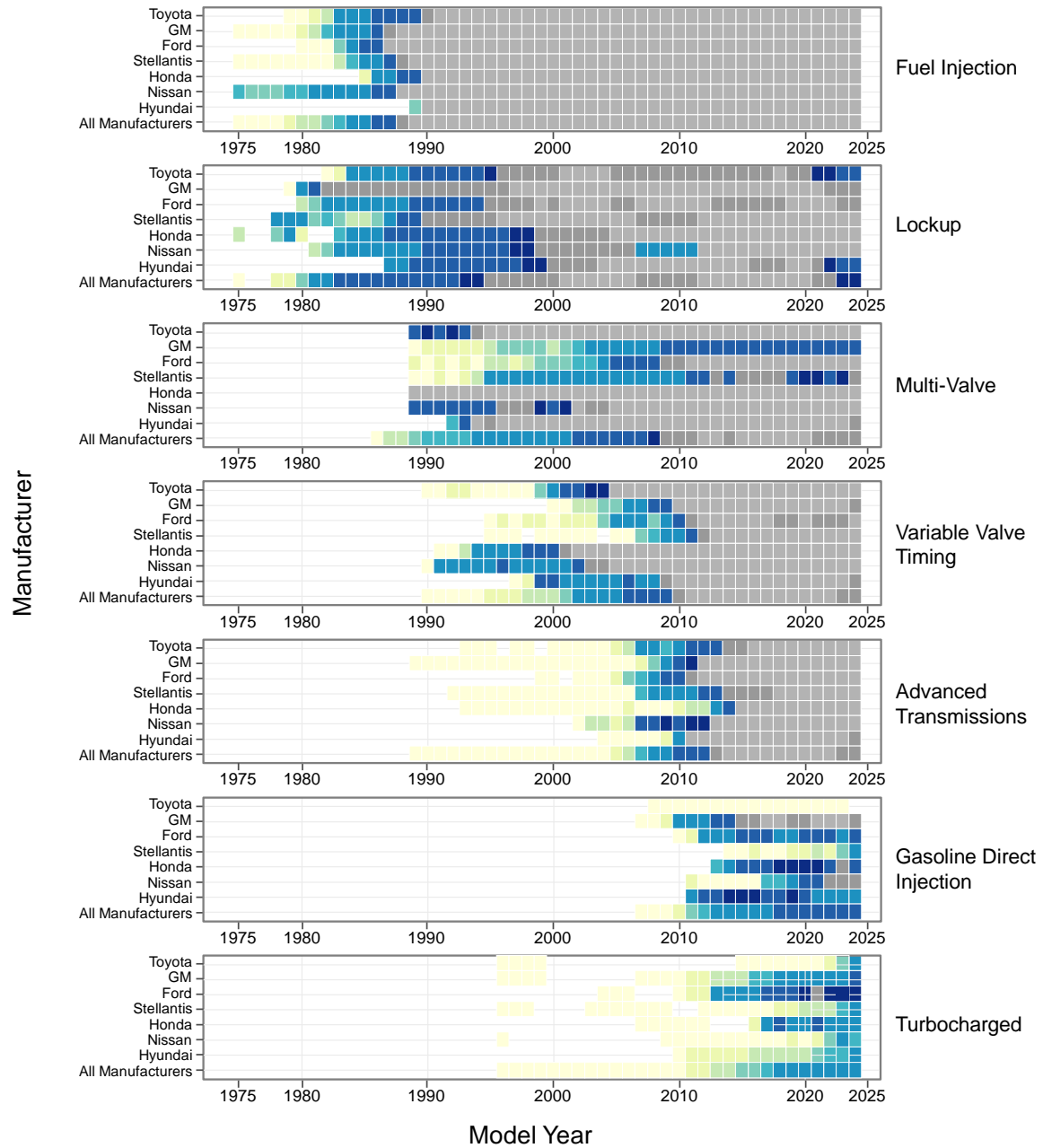
Table 4.2. Production Share by Powertrain

Model Year	Diesel ICE	Gasoline ICE without Stop/Start	Gasoline ICE with Stop/Start	Mild Hybrid (MHEV)	Strong Hybrid (HEV)	Plug-in Hybrid (PHEV)	Battery Electric (BEV)	Fuel Cell Electric (FCEV)	Other
1975	0.2%	99.8%	-	-	-	-	-	-	-
1980	4.3%	95.7%	-	-	-	-	-	-	-
1985	0.9%	99.1%	-	-	-	-	-	-	-
1990	0.1%	99.9%	-	-	-	-	-	-	-
1995	0.0%	100.0%	-	-	-	-	-	-	-
2000	0.1%	99.8%	-	0.0%	-	-	-	-	-
2005	0.3%	98.6%	-	0.3%	0.8%	-	-	-	-
2010	0.7%	95.5%	-	0.0%	3.8%	-	-	0.0%	-
2011	0.8%	97.0%	-	-	2.2%	0.0%	0.1%	0.0%	0.0%
2012	0.9%	95.2%	0.3%	0.1%	3.0%	0.3%	0.1%	0.0%	0.0%
2013	0.9%	92.6%	2.3%	0.3%	3.3%	0.4%	0.3%	-	0.0%
2014	1.0%	90.8%	4.9%	0.1%	2.5%	0.4%	0.3%	0.0%	0.0%
2015	0.9%	88.9%	7.0%	0.0%	2.4%	0.3%	0.5%	0.0%	0.0%
2016	0.5%	87.5%	9.4%	0.0%	1.8%	0.3%	0.5%	0.0%	0.0%
2017	0.3%	78.4%	17.7%	0.0%	2.3%	0.8%	0.6%	0.0%	-
2018	0.4%	65.5%	29.6%	0.4%	1.9%	0.8%	1.4%	0.0%	-
2019	0.1%	57.6%	36.8%	1.3%	2.5%	0.5%	1.2%	0.0%	-
2020	0.5%	46.9%	45.4%	1.8%	3.1%	0.5%	1.8%	0.0%	-
2021	1.0%	41.1%	44.0%	4.0%	5.3%	1.2%	3.2%	0.0%	-
2022	0.8%	33.4%	48.9%	4.2%	6.0%	1.5%	5.2%	0.0%	-
2023	0.8%	26.3%	49.2%	4.9%	7.2%	1.7%	9.8%	0.0%	-
2024 (prelim)	*0.8%*	14.9%	55.0%	5.3%	9.3%	*3.3%*	*11.4%*	*0.1%*	-

To explore this data in more depth, please see the report website at https://www.epa.gov/automotive-trends.
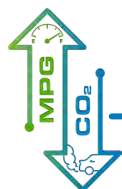
Table 4.3. Production Share by Fuel Delivery Method

Model Year	Gasoline Engines - Fuel Delivery Method					Diesel	BEV	Other
	Carb	TBI	Port	GDI	GDPI			
1975	95.7%	0.0%	4.1%	-	-	0.2%	-	-
1980	89.7%	0.8%	5.2%	-	-	4.3%	-	-
1985	56.1%	24.8%	18.2%	-	-	0.9%	-	-
1990	2.1%	27.0%	70.8%	-	-	0.1%	-	-
1995	-	8.4%	91.6%	-	-	0.0%	-	-
2000	-	0.0%	99.8%	-	-	0.1%	-	-
2005	-	-	99.7%	-	-	0.3%	-	-
2010	-	-	91.0%	8.3%	-	0.7%	-	0.0%
2011	-	-	83.8%	15.4%	-	0.8%	0.1%	0.0%
2012	-	-	76.4%	22.5%	0.1%	0.9%	0.1%	0.0%
2013	-	-	67.7%	30.5%	0.6%	0.9%	0.3%	-
2014	-	-	60.9%	37.4%	0.4%	1.0%	0.3%	0.0%
2015	-	-	56.0%	41.9%	0.7%	0.9%	0.5%	0.0%
2016	-	-	48.7%	48.0%	2.3%	0.5%	0.5%	0.0%
2017	-	-	44.2%	49.7%	5.2%	0.3%	0.6%	0.0%
2018	-	-	37.7%	50.2%	10.3%	0.4%	1.4%	0.0%
2019	-	-	31.6%	52.9%	14.2%	0.1%	1.2%	0.0%
2020	-	-	26.6%	57.1%	14.0%	0.5%	1.8%	0.0%
2021	-	-	23.6%	53.4%	18.7%	1.0%	3.2%	0.0%
2022	-	-	21.0%	52.3%	20.6%	0.8%	5.2%	0.0%
2023	-	-	16.0%	50.5%	22.9%	0.8%	9.8%	0.0%
2024 (prelim)	-	-	*11.8%*	*54.6%*	*21.4%*	*0.8%*	11.4%	0.1%
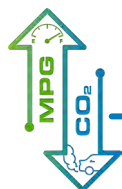
Table 4.4. Production Share by Gasoline[17] Engine Technologies

Model Year	Avg. No. of Cylinders	Displacement (CID)	Horsepower (HP)	Multi- Valve	Variable Valve Timing (VVT)	Cylinder Deactivation (CD	Turbo- charged	Non-hybrid Stop/ Start
1975	6.8	293	137	-	-	-	-	-
1980	5.6	196	105	-	-	-	-	-
1985	5.5	189	114	-	-	-	-	-
1990	5.4	185	135	23.1%	-	-	-	-
1995	5.6	196	158	35.5%	-	-	-	-
2000	5.7	200	181	44.8%	15.0%	-	1.2%	-
2005	5.8	205	209	65.5%	45.7%	0.8%	1.4%	-
2010	5.3	188	214	84.8%	83.8%	6.4%	2.6%	-
2011	5.4	193	230	85.6%	93.0%	9.5%	6.1%	-
2012	5.1	181	222	90.9%	96.5%	8.1%	7.5%	0.6%
2013	5.1	177	227	91.9%	97.4%	7.7%	13.0%	2.3%
2014	5.1	181	231	88.2%	97.6%	10.6%	13.8%	4.9%
2015	5.0	177	229	90.2%	97.2%	10.5%	14.8%	7.0%
2016	5.0	173	230	91.8%	98.0%	10.4%	19.4%	9.4%
2017	5.0	173	233	91.7%	98.1%	11.9%	23.2%	17.7%
2018	5.0	172	239	90.6%	96.4%	12.5%	29.6%	29.6%
2019	5.1	174	244	89.9%	97.2%	14.9%	29.8%	36.8%
2020	4.9	169	243	90.2%	95.8%	14.7%	34.2%	45.4%
2021	5.0	176	249	86.9%	94.4%	16.6%	31.8%	44.0%
2022	4.9	171	249	86.7%	92.5%	15.9%	35.8%	48.9%
2023	4.9	170	253	83.0%	88.0%	15.1%	37.3%	49.2%
2024 (prelim)	4.7	158	249	83.2%	87.5%	13.3%	44.4%	55.0%

[17] This table includes technology penetration rates for new vehicles with gasoline engines, including hybrids and PHEVs (except for non-hybrid stop/start, which excludes hybrids and PHEVs), as compared to all new vehicles. The values in this table are slightly lower than values elsewhere this report that include other technologies. For example, most vehicles that operate on diesel fuel are turbocharged, and when included, as in Table 4.1, will slightly increase the overall share of vehicles that are turbocharged.

Table 4.5. 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%	-	-	-	-	3.7
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
2005	6.2%	91.5%	0.1%	1.0%	1.3%	-	56.0%	37.3%	4.1%	0.2%	-	-	4.5
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%	2.9%	8.9%	-	8.1%	18.2%	56.3%	2.8%	2.6%	-	5.5
2013	3.5%	80.4%	1.4%	3.3%	11.4%	-	5.4%	12.8%	60.1%	2.8%	4.1%	-	5.6
2014	2.8%	76.7%	1.6%	2.7%	16.3%	-	2.2%	7.8%	58.4%	3.3%	8.4%	1.1%	6.0
2015	2.6%	72.3%	1.4%	2.4%	21.3%	-	1.5%	4.5%	54.2%	3.1%	9.5%	3.5%	6.0
2016	2.2%	72.3%	2.6%	1.8%	21.0%	-	1.1%	3.0%	54.9%	2.9%	11.2%	4.1%	6.0
2017	2.1%	71.5%	2.6%	2.5%	21.2%	-	1.0%	2.4%	49.0%	3.4%	14.6%	5.9%	6.1
2018	1.6%	72.8%	3.2%	2.2%	20.1%	-	1.9%	2.0%	37.6%	3.7%	19.0%	13.5%	6.5
2019	1.4%	72.1%	2.4%	2.4%	21.7%	-	1.5%	1.6%	26.1%	2.6%	27.5%	16.5%	6.8
2020	1.1%	68.3%	2.7%	3.3%	24.5%	-	1.8%	0.8%	17.3%	2.1%	28.8%	21.2%	7.1
2021	0.9%	67.0%	5.4%	5.4%	21.2%	-	3.2%	1.1%	12.2%	2.0%	32.5%	22.4%	7.0
2022	0.9%	65.2%	8.1%	5.7%	20.1%	-	5.0%	1.1%	8.7%	2.1%	33.8%	23.5%	7.1
2023	0.8%	59.9%	14.9%	5.5%	18.9%	-	9.9%	1.0%	8.3%	2.4%	29.9%	24.1%	7.1
2024 (prelim)	*0.9%*	*56.6%*	*15.9%*	*7.5%*	*19.2%*	*-*	*11.5%*	*0.8%*	*8.6%*	*2.1%*	*29.3%*	*21.0%*	*6.9*
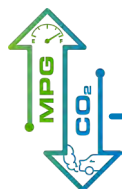
Table 4.6. Production Share by Drive Technology

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%
2005	79.2%	14.2%	6.6%	20.1%	27.7%	52.2%	53.0%	20.2%	26.8%
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	65.9%	11.2%	22.9%	10.0%	8.9%	81.0%	30.6%	9.8%	59.6%
2023	60.3%	14.9%	24.8%	9.5%	7.1%	83.4%	28.5%	10.1%	61.4%
2024 (prelim)	60.7%	12.3%	27.0%	9.1%	6.9%	84.0%	28.1%	8.9%	63.1%

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 2023 and credit trades reported to EPA as of October 1, 2024.

This report reflects the current light-duty GHG and fuel economy regulations as finalized by EPA and NHTSA, including updated standards through model year 2032 and 2031, respectively. Any applicable regulatory changes finalized by EPA and NHTSA will be included in future versions of this report.

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 all deficits to avoid non-compliance and may not report deficits for more than 3 years in a row. The general compliance process that manufacturers follow at the end of each model year is shown in Figure 5.1.

Figure 5.1. The GHG Compliance Process

1) Calculate Model Year Standards

2) Measure Model Year Performance

3) Evaluate Credits and Deficits for each Model Year
- Standards vs Performance
- Credit Transactions
- Credit Expirations

4) Determine Overall Credit Balance and Compliance Status
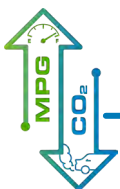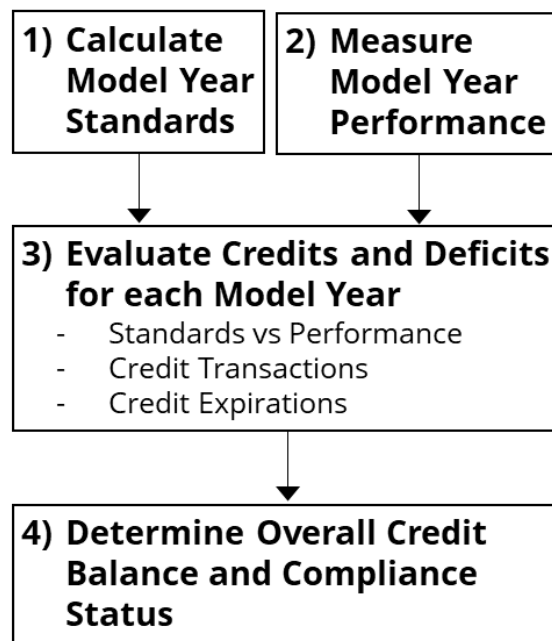
Averaging, banking, and trading (ABT) provisions have been an important part of many mobile source programs under the Clean Air Act. These provisions help manufacturers in planning and implementing a phase-in of emissions reduction technology in their production that is consistent with their unique redesign 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 2023 model year, the industry wide weighted VMT is 214,384 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.
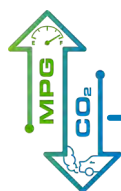
A. Footprint-Based CO$_2$ Standards

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 Appendix F for the definitions of "car" and "truck" under the regulations.

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 Porsche 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.

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 47.7 square feet in model year 2023 (the average car footprint) has a compliance CO$_2$ target of 170 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. 2012–2023 Model Year CO$_2$ Footprint Target Curves
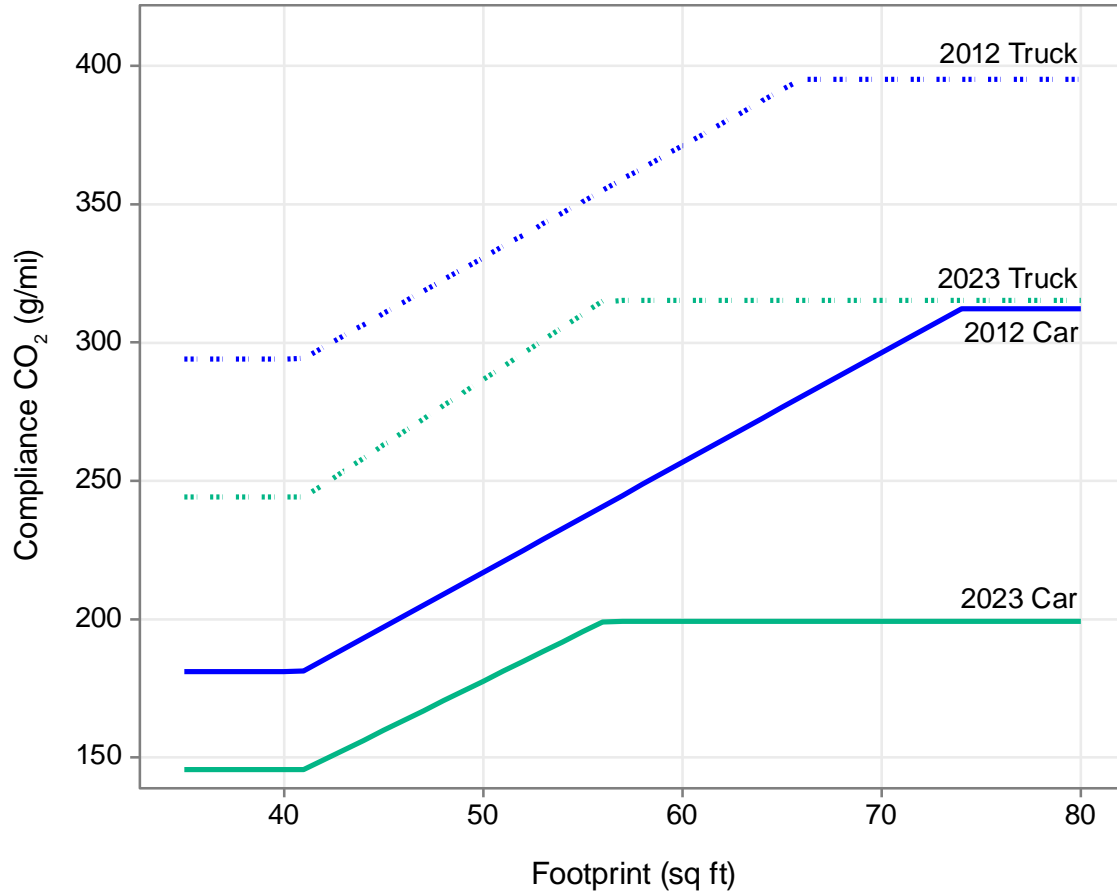
The footprint curves for the 2012 and 2023 model years are shown in Figure 5.2. The GHG targets have gradually decreased (become more stringent) from 2012 to the current 2023 levels, as defined in the regulations. Larger vehicles have higher targets, although the increases are capped beyond a certain 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
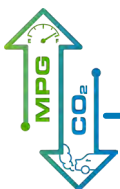
fleet according to the footprint-based approach applied to all other car and truck fleets. Each manufacturer could apply the TLAAS standards to a maximum of 100,000 vehicles, cumulative over model years 2012–2015. Mercedes, Jaguar Land Rover, Volvo, Porsche, Ferrari, Aston Martin, Lotus, and McLaren 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 that utilized 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.[18] These manufacturers submitted petitions for alternative standards for model year 2022 and beyond, and in 2024 EPA codified[19] that the applicable 2021 model year small volume manufacturer standards will continue for five additional model years, through the 2026 model year. Lotus is no longer eligible for a small volume manufacturer alternative standard as the company is now majority owned by Geely, along with Volvo.

Each manufacturer's standards for model year 2023 are shown in Table 5.1. In model year 2023, average new car footprint increased 0.5 square feet while truck footprint increased 0.1 square feet. The more stringent model year 2023 footprint targets, along with changes to footprint, resulted in a reduction of the car standard by 14 g/mi, from 183 g/mi to 170 g/mi, and the truck standard by 27 g/mi, from 260 g/mi to 234 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

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[18] 89 FR 39561, July 1, 2020.
[19] 89 FR 27927, April 18, 2024.
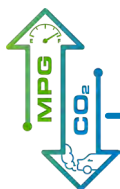
manufacturers. Overall, the effective combined car and truck standard decreased in model year 2023 by 23 g/mi, from 234 g/mi to 212 g/mi.

Table 5.1 shows the manufacturers that produced vehicles in model year 2023 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.

Table 5.1. Manufacturer Footprint and Standards for Model Year 2023

Manufacturer	Footprint (ft²)			Standards (g/mi)		
	Car	Truck	All	Car	Truck	All
Aston Martin	48.8	55.4	52.0	376	376	376
BMW	48.6	52.0	50.2	173	225	200
Ferrari	47.7	-	47.7	373	-	373
Fisker	53.8	-	53.8	191	-	191
Ford	49.2	59.2	58.2	175	253	246
GM	46.4	59.0	55.7	165	253	232
Honda	46.9	51.9	49.4	167	225	198
Hyundai	47.6	50.3	48.7	169	218	190
Jaguar Land Rover	46.5	53.5	53.4	165	231	230
Kia	46.2	50.0	47.9	164	217	190
Lucid	53.2	-	53.2	189	-	189
Mazda	44.0	47.0	46.7	160	205	201
McLaren	46.6	-	46.6	329	-	329
Mercedes	50.7	53.9	52.3	179	232	207
Mitsubishi	38.7	45.6	44.7	146	200	194
Nissan	46.6	50.6	48.4	165	219	191
Rivian	-	59.5	59.5	-	255	255
Stellantis	52.8	56.6	56.0	188	243	236
Subaru	45.0	46.2	46.0	160	202	197
Tesla	50.7	51.5	50.7	180	223	184
Toyota	46.9	52.6	50.4	167	227	206
VW	46.5	50.3	48.8	165	218	199
Volvo	48.0	51.2	50.2	170	222	206
All Manufacturers	**47.7**	**54.2**	**51.8**	**170**	**234**	**212**

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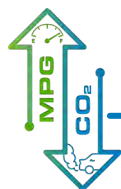
the context of the compliance regulations and are not the same as and should not be compared to the estimated real-world values reported in Sections 1–4.

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 2017–2032 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 2023 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 2023; 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.

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, Volvo leads manufacturers in the overall reduction of 2-cycle CO_2 emissions with a reduction in their average new vehicle emission rate of 119 g/mi, or 38%. Eleven manufacturers have reduced tailpipe CO_2 emissions by 10% or more. Overall, tailpipe CO_2 emissions of the entire fleet have been reduced by 53 g/mi, or about 17%, 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 82 g/mi in each of the car and truck fleets since model year 2012.
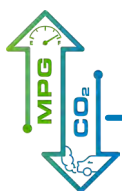
Figure 5.3. Changes in 2-Cycle Tailpipe CO_2 Emissions by Manufacturer
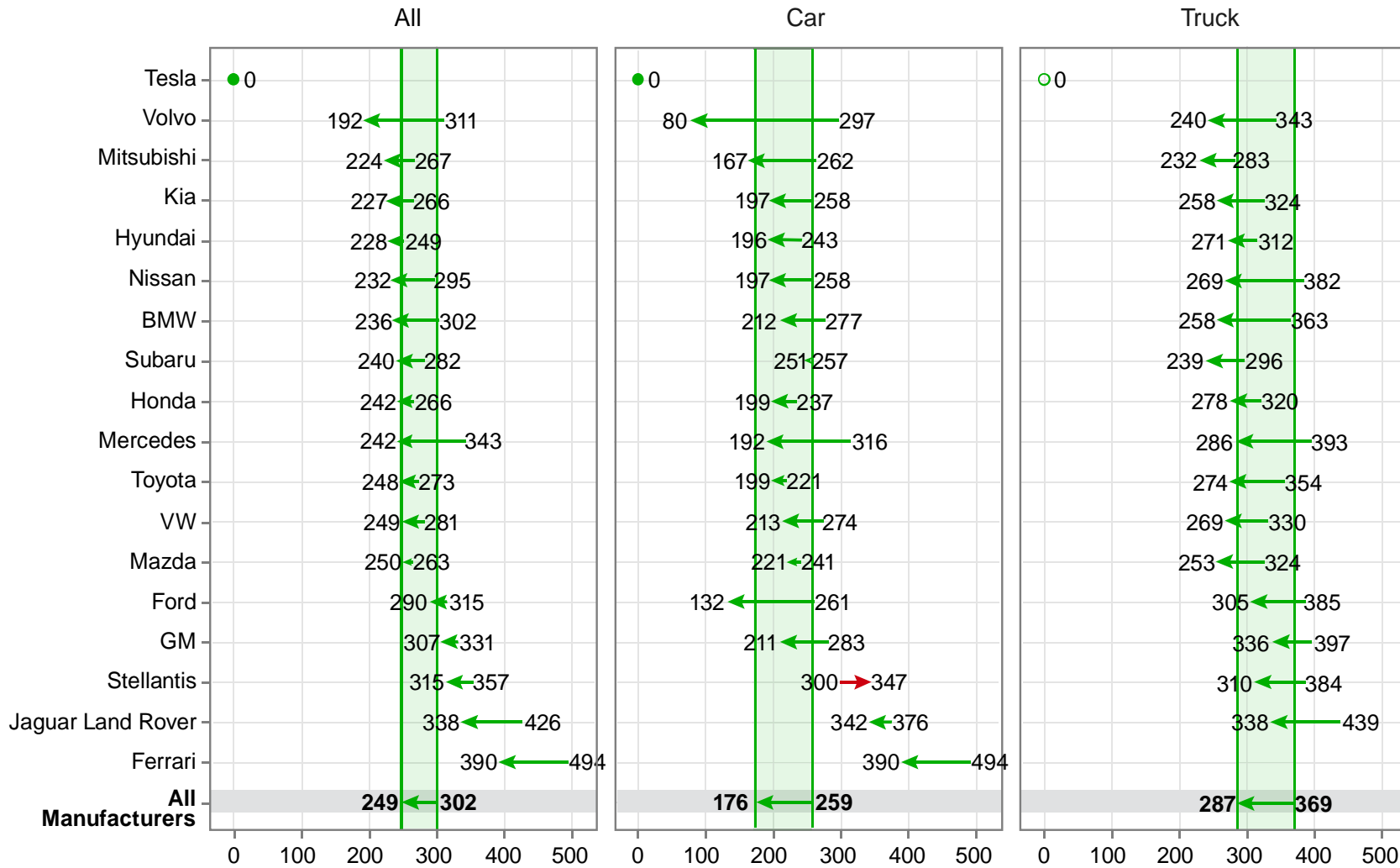
Performance Credits for Producing Alternative Fuel Vehicles

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 (BEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell electric vehicles (FCEVs), and compressed natural gas (CNG) vehicles. Multipliers allow manufacturers to increase the volume of credits created by each vehicle during the compliance process. For example, the 1.5 multiplier for 2023 model year BEVs allows manufacturers to increase the credits created by each electric or fuel cell vehicle by an additional 50%. In model years 2023 and 2024, BEVs, FCEVs, and PHEVs are eligible for production multipliers subject to a cumulative credit cap of 10 g/mi per manufacturer across both model years. Previous model years where multipliers were available did not have a cap. Advanced technology multiplier credits will be evaluated again after the 2024 model year to ensure accuracy and consistency with regards to the credit cap.

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.
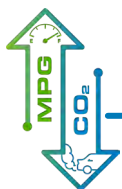
Table 5.2. Production Multipliers by Model Year

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 2023 production volume of vehicles that are in categories that qualify for model year 2023 incentives. More than 1.6 million BEVs, PHEVs, and FCEVs were produced in the 2023 model year. Of those vehicles, about 85% were BEVs, 15% were PHEVs, and less than 1% were FCEVs. Figure 4.15 in the previous section shows the overall growth in BEVs, PHEVs, and FCEVs. The impacts of the advanced technology multiplier credit are shown in Figure 5.5. Eight manufacturers reached the capped multiplier credit threshold of 10 g/mi while one, BMW, elected to take less than the maximum credit allowance, leaving room for credit generation in the 2024 model year.

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. Manufacturers that produced vehicles eligible for these incentives have resubmitted 2-cycle data to EPA, and this report uses these updated data and calculations.
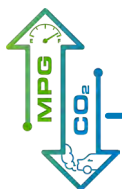
Figure 5.4. Model Year 2023 Production of BEVs, PHEVs, and FCEVs
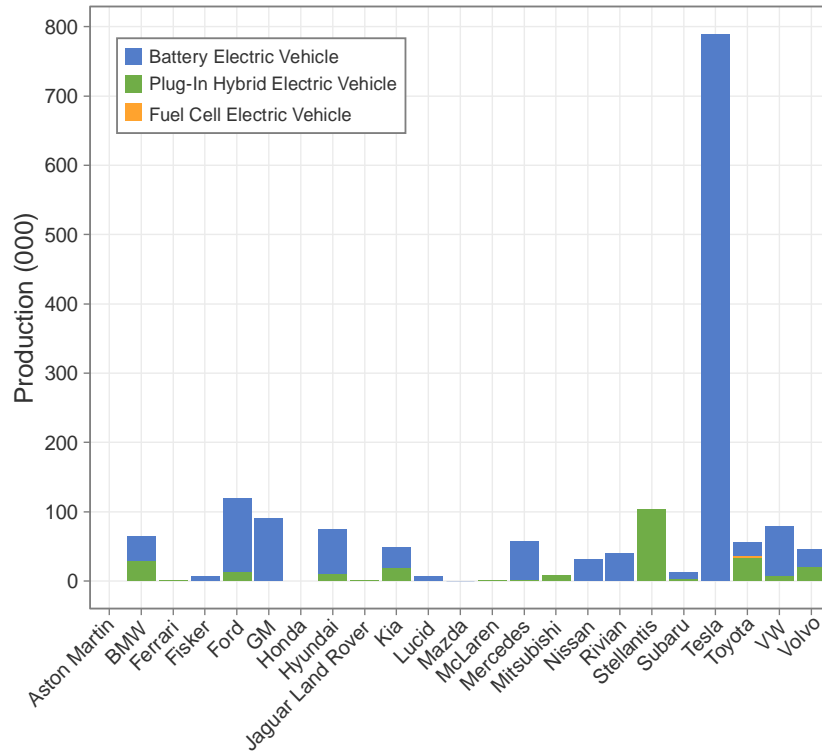
Figure 5.5. Model Year 2023 Advanced Technology Credits by Manufacturer
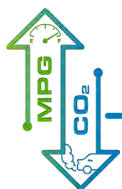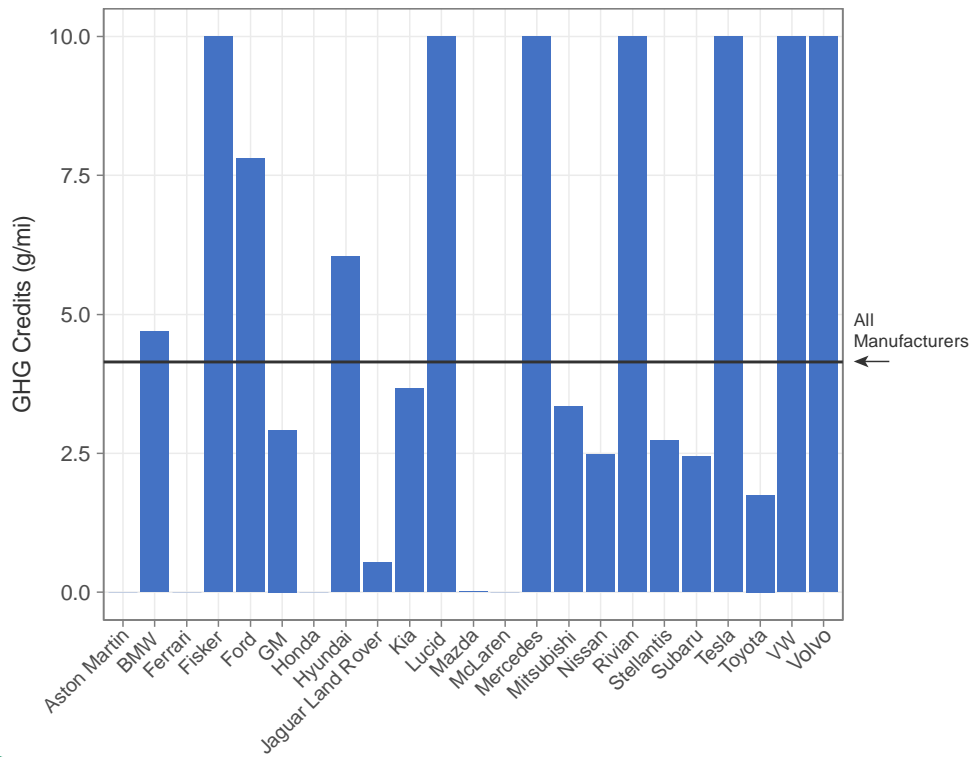
Gasoline-Ethanol Flexible Fuel Vehicles

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.[20] This value will continue to apply until EPA issues a new determination.

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

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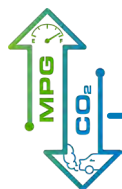
Performance Credits for Improved Air Conditioning Systems

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)[21], 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 Figure 5.6. In the nine model years since, low GWP refrigerant use has expanded to 97% of new vehicles. All manufacturers reported some type of A/C leakage credits in the 2023 model year, resulting in an overall performance credit of 15.4 g/mi for the industry.

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[21] 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.
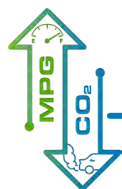
Figure 5.6. HFO-1234yf Adoption by Manufacturer
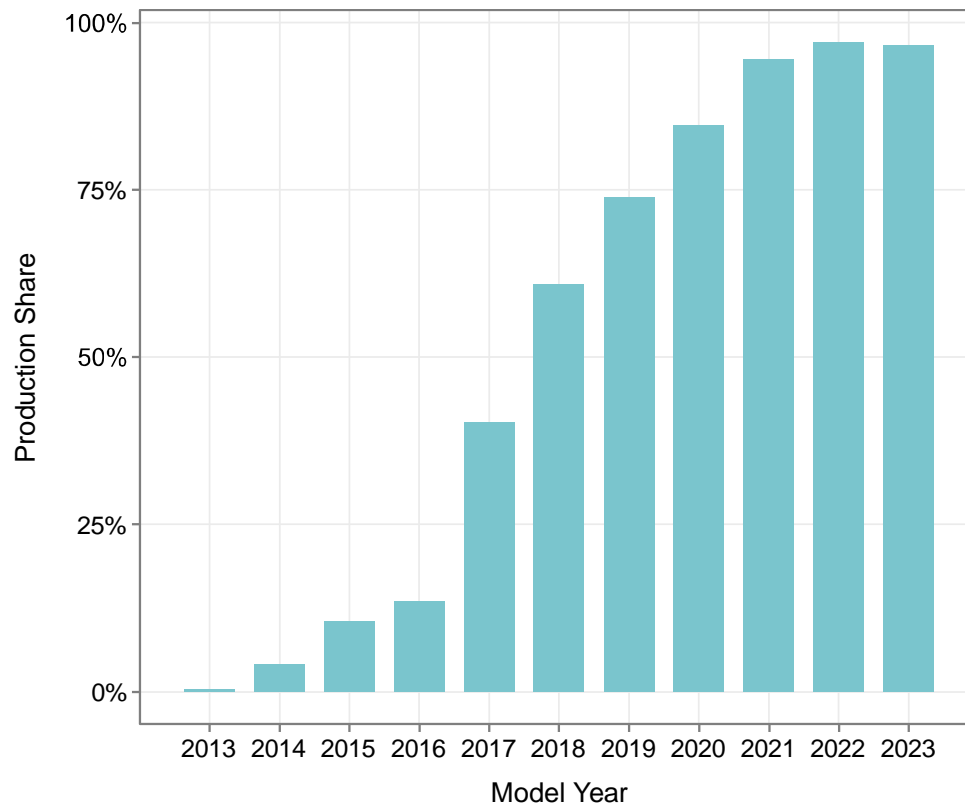
Air Conditioning Efficiency Performance Credits

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
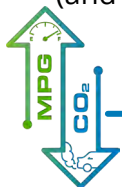
equipped with automatic climate-control systems, real-time adjustment of several aspects of the overall system can result in improved efficiency.

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 model years 2012–2016, and at 5.0 and 7.2 g/mi for cars and trucks, respectively, in model year 2017 and later. Twenty out of twenty-two manufacturers reported A/C efficiency credits in model year 2023, resulting in an average credit of 5.8 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 2023 model year. All manufacturers used the A/C credit provisions—leakage reductions, efficiency improvements, or both—as part of their compliance demonstration in the 2023 model year. Ford had the highest reported credit on a per vehicle g/mi basis, at 23.9 g/mi. Thus, A/C credits resulted in about an 8% reduction from tailpipe emissions for Ford. All manufacturers reported at least 12 g/mi of credits, and the overall industry reported an average of 21.2 g/mi of total A/C credits (5.8 g/mi from efficiency improvements and 15.4 from leakage reductions).
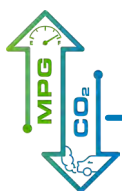
Figure 5.7. Fleetwide A/C Credits by Credit Type
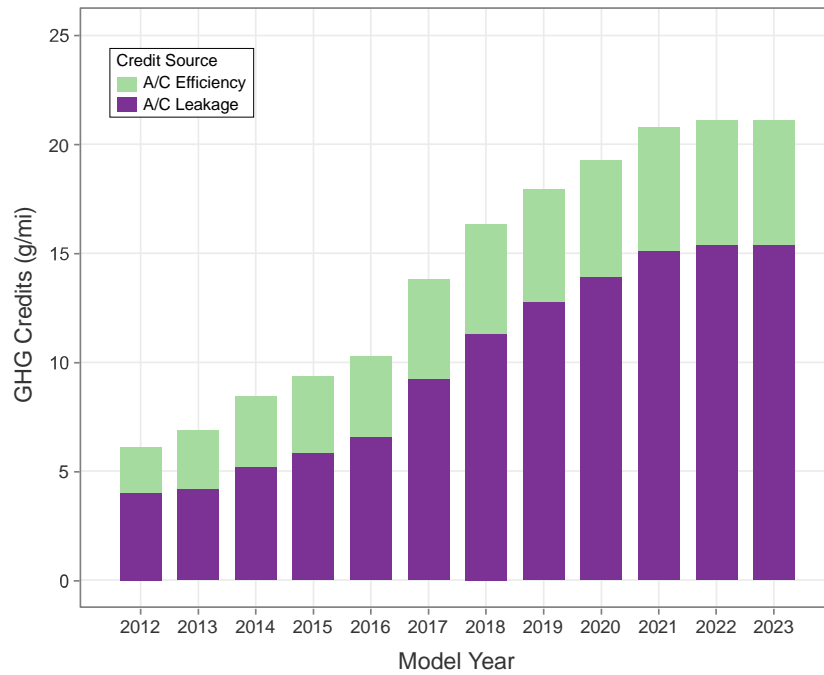
Figure 5.8. Total A/C Credits by Manufacturer for Model Year 2023
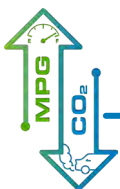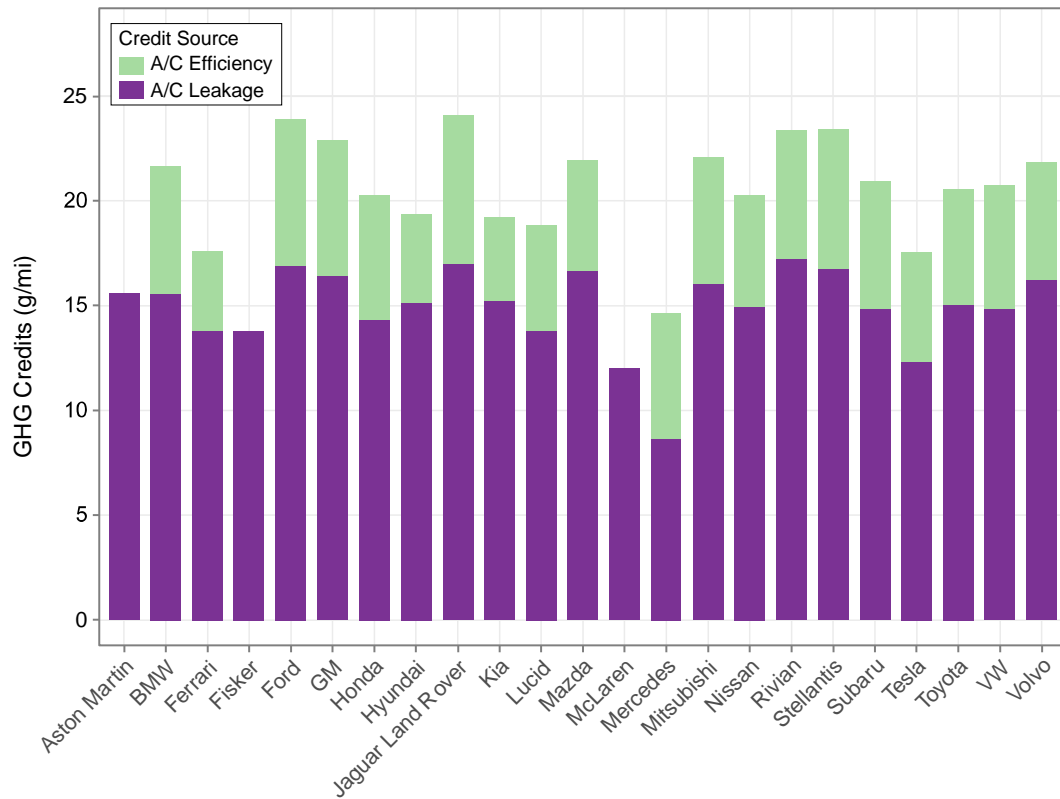
Performance Credits for "Off-Cycle" Technology

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.[22] 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 was 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 increased to 15 g/mi for model year 2023 through 2026 before reverting to 10 g/mi through model year 2030, then phasing out entirely in model year 2033. Manufacturers will no longer be able to generate credits under this method for vehicles with zero tailpipe emissions beginning in model year 2027.

Off-cycle technology credits based on the menu were widely used in model year 2023, with more than 95% of off-cycle credits generated via the menu pathway. Each of these technologies is discussed below.

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[22] See 40 CFR 86.1869-12(b).
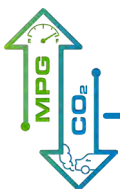
Figure 5.9. Off-Cycle Menu Technology Adoption by Manufacturer, Model Year 2023

	Active Aero	Active Cabin Vent	Active Seat Vent	Glass or Glazing	Passive Cabin Vent	Solar Coating	Active Engine Warm up	Active Trans Warm up	Stop Start	High Efficiency Alternator	High Efficiency Lighting	Solar Panels
Aston Martin	24%							34%	83%		34%	
BMW	82%	100%	21%	53%	100%		26%		84%	44%	100%	
Ferrari				96%							100%	
Fisker	100%										100%	89%
Ford	97%		18%	100%			66%	20%	68%	79%	98%	
GM	87%		32%	100%		28%	64%	29%	91%	59%	91%	
Honda	55%		12%	100%		12%	100%	48%	90%	82%	100%	
Hyundai	31%	100%	31%	100%	100%	15%	56%		66%	82%	99%	
Jaguar Land Rover	99%		67%	100%					100%	51%	100%	
Kia	17%	100%	22%	100%	100%	20%	29%	0%	42%	35%	44%	
Lucid	100%	100%	100%	17%							100%	
Mazda	93%		21%	100%	100%	6%	21%		5%	12%		
McLaren	7%						100%		100%		100%	
Mercedes		90%	43%	76%	90%	30%			38%		91%	
Mitsubishi	45%			87%					9%	78%		
Nissan	78%		10%	82%		17%	59%		43%	91%	98%	
Rivian			100%	100%							100%	
Stellantis	59%	85%	26%	100%		26%	76%		69%	48%	90%	
Subaru	44%		7%	94%				0%	71%	84%	72%	
Tesla	100%	100%		100%							100%	
Toyota	28%		12%	58%		15%	39%		50%	70%	94%	0%
VW	46%	1%	25%	90%	21%	3%	66%		81%	85%	99%	
Volvo		100%	20%	96%	100%	26%	45%		79%	63%	100%	
All Manufacturers	60%	34%	20%	90%	25%	14%	51%	10%	62%	62%	89%	0%

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 2023 vehicles. Fisker, Lucid, and Tesla all reported implementation of active aerodynamics on 100% of their new vehicles. Overall, 60% of new vehicles qualified for these credits, reducing overall fleet CO_2 emissions by 0.7 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 34% of all new vehicles in model year 2023, with six manufacturers reporting this technology on all of their vehicles. Five manufacturers
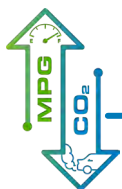
reporting using passive cabin ventilation on all model year 2023 production, and overall passive cabin ventilation had a 25% adoption rate.

Active seat ventilation was used by many manufacturers and the rate of implementation remained about the same at 20% in model year 2023. Lucid and Rivian utilized active seat ventilation in all of their model year 2023 vehicles, followed by Jaguar Land Rover at 67%. Glass or glazing technology continues to be used throughout the industry, with 90% of model year 2023 vehicles equipped with these technologies. Solar reflective coatings have been used less widely, with a penetration of 14% across new vehicles in model year 2023, and no manufacturer above 30%.

Due to the likelihood of synergistic effects among the various thermal technologies, the total credit allowed from this technology group is capped at 3.0 g/mi for cars and 4.3 g/mi for trucks. Overall, manufacturers widely adopted thermal control technologies, which reduced model year 2023 overall new vehicle fleet CO_2 emissions by 2.3 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 51% of all new vehicles, and active transmission warmup in 10% of the fleet, resulting in a CO_2 reduction of about 1.7 g/mi across the 2023 model year fleet. Honda and Stellantis led the industry in active engine warmup, with more than 75% of their new vehicles employing the technology. McLaren led the industry in active transmission warmup technologies, with 100% 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
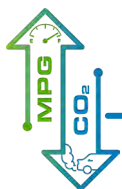
determine that the predominant operating mode of the system is the "on" setting (defaulting to "on" every time the key is turned on is one basis for such a determination). Thus, some vehicles with these systems are not eligible for credits. Credits range from 1.5 to 4.4 g/mi and depend on whether the 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 2023, 62% of new vehicles qualified for and claimed this credit, resulting in a fleetwide CO_2 reduction of about 2.3 g/mi. Eighteen manufacturers installed stop start systems on at least some of their 2023 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 0.05 g/mi for high beams 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. Most manufacturers reported wide-spread usage of high efficiency lighting in model year 2023 new vehicles, except Mazda, and Mitsubishi. Overall, in model year 2023, 89% of new vehicles implemented high efficiency lighting in some form, reducing fleetwide CO_2 emissions by 0.6 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. Fifteen manufacturers claimed menu credits for high-efficiency alternators on 62% of all new vehicles, reducing fleetwide CO_2 emissions by 0.7 g/mi. Stellantis, Jaguar Land Rover, and Toyota also claimed credits for high-efficiency alternators in model year 2023 through the alternative methodology described below.
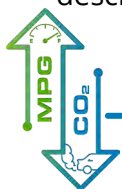
Solar Panels

Vehicles that use electric motors for propulsion, such as battery electric, plug-in hybrid electric, and hybrid electric 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. Fisker was the only manufacturer that claimed this credit in model year 2023.

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 2023, the industry achieved 8.2 g/mi of credits from the menu, based on a production weighted average of credits across all manufacturers. The effective off-cycle menu credit cap for 2023 model year was increased to 15 g/mi from 10 g/mi in the 2022 model year. Multiple manufacturers including Volvo, Jaguar Land Rover, GM, Ford, Fisker and BMW, achieved or exceeded 10 g/mi while no manufacturers exceeded the 15 g/mi off-cycle menu credit cap. The overall industry-wide value of 8.2 g/mi reflects all off-cycle menu credits submitted by manufacturers. The off-cycle menu credit cap will remain at 15 g/mile through 2026 model year then phase out to 0 g/mi in the 2033 model year.

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.[23] 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. Manufacturers will no longer be able to generate credits under this method beginning in model year 2027.

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[23] See 40 CFR 86.1869-12(c).
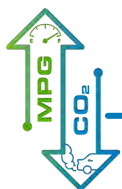
Table 5.3. Model Year 2023 Off-Cycle Technology Credits from the Menu, by Manufacturer and Technology (g/mi)

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	0.2	-	-	0.5	2.0	-	0.3	-	2.9
BMW	1.3	3.3	0.8	-	2.8	0.8	1.0	-	10.0
Ferrari	-	0.3	-	-	-	-	1.0	-	1.3
Fisker	0.8	-	-	-	-	-	1.0	12.1	13.9
Ford	1.5	2.5	2.1	0.6	2.9	1.0	0.6	-	11.2
GM	0.9	2.1	1.8	0.9	3.8	0.5	0.8	-	10.7
Honda	0.3	1.3	2.4	0.9	2.9	0.4	0.5	-	8.8
Hyundai	0.2	2.2	1.4	-	1.7	1.0	0.4	-	6.9
Jaguar Land Rover	1.6	2.7	-	-	4.4	0.6	0.5	-	9.7
Kia	0.3	2.6	1.3	0.0	1.5	0.7	0.2	-	6.6
Lucid	0.9	3.0	-	-	-	-	1.0	-	4.9
Mazda	0.7	4.0	0.7	-	0.2	0.1	-	-	5.7
McLaren	0.1	-	-	1.5	1.5	-	0.8	-	3.9
Mercedes	-	3.0	-	-	1.3	-	0.9	-	5.2
Mitsubishi	0.4	1.0	-	-	0.4	0.5	-	-	2.3
Nissan	0.7	1.2	1.4	-	1.1	1.5	0.6	-	6.5
Rivian	-	2.9	-	-	-	-	0.7	-	3.6
Stellantis	0.8	2.3	2.3	-	3.1	0.7	0.3	-	9.6
Subaru	0.2	1.3	-	0.0	2.1	0.7	0.4	-	4.7
Tesla	1.1	3.1	-	-	-	-	0.7	-	4.9
Toyota	0.2	2.6	1.2	-	1.8	0.6	0.6	0.0	7.0
Volkswagen	0.3	2.5	1.7	-	2.8	1.5	0.8	-	9.6
Volvo	-	3.6	1.3	-	3.4	1.4	1.0	-	10.7
All	**0.7**	**2.3**	**1.5**	**0.3**	**2.3**	**0.7**	**0.6**	**0.0**	**8.2**
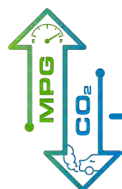
GM is the only manufacturer to date to have claimed off-cycle credits based on 5-cycle testing. These credits are for an auxiliary electric pump used on certain GM gasoline-electric hybrid vehicles to keep engine coolant circulating in cold weather while the vehicle is stopped, and the engine is off. 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 2023.

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.[24] 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. Manufacturers will no longer be able to generate credits under this method beginning in model year 2027.

The off-cycle technologies that have been approved to date under the alternative pathway include:

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

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 stop-start systems, high-efficiency lighting, infrared glass glazing, solar reflective paint, and active seat ventilation technologies. EPA is no longer accepting retroactive credit claims.

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.
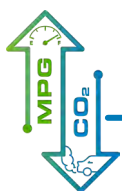
Summary of Off-Cycle Alternative Methodology Credits

Since the beginning of the light-duty GHG program, twelve manufacturers have been granted approval for alternative methodology off-cycle GHG credits using the alternative methodology pathway. Eight manufacturers requested off-cycle credits based on the approved alternative methodologies in model year 2023. Table 5.4 shows the impact of the credits submitted for model year 2023. On a total fleetwide basis, the aggregated credit is 0.4 g/mi for model year 2023.

Table 5.4. Model Year 2023 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	Active Climate Control Seats	Brushless Motors	Cold Storage Evap-orator	Total Alt. Method Credits
GM	-	-	-	-	0.1	-	0.1
Honda	-	-	-	-	-	0.7	0.7
Hyundai	0.0	0.8	-	-	-	-	0.8
Jaguar Land Rover	-	-	0.8	-	-	-	0.8
Kia	-	0.5	-	-	-	-	0.5
Mazda	0.9	-	-	-	-	-	0.9
Mitsubishi	0.7	-	-	-	-	-	0.7
Nissan	-	0.1	-	-	-	-	0.1
Stellantis	-	-	0.4	-	-	-	0.4
Subaru	-	-	-	-	0.0	-	0.0
Toyota	-	0.1	0.0	0.1	0.1	0.6	0.9
All Manufacturers	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.4**

Off-Cycle Performance Credit Summary

In total, the industry achieved 8.6 g/mi of off-cycle performance credits in model year 2023. 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 2023. Fisker achieved the highest gram per mile benefit from off-cycle credits at 13.9 g/mi, followed closely by multiple manufacturers around 10 -11 g/mi. All manufacturers that qualified for the GHG Program reported at least some off-cycle credits for model year 2023.
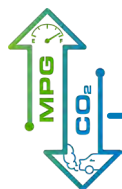
Figure 5.10. Total Off-Cycle Credits by Manufacturer for Model Year 2023
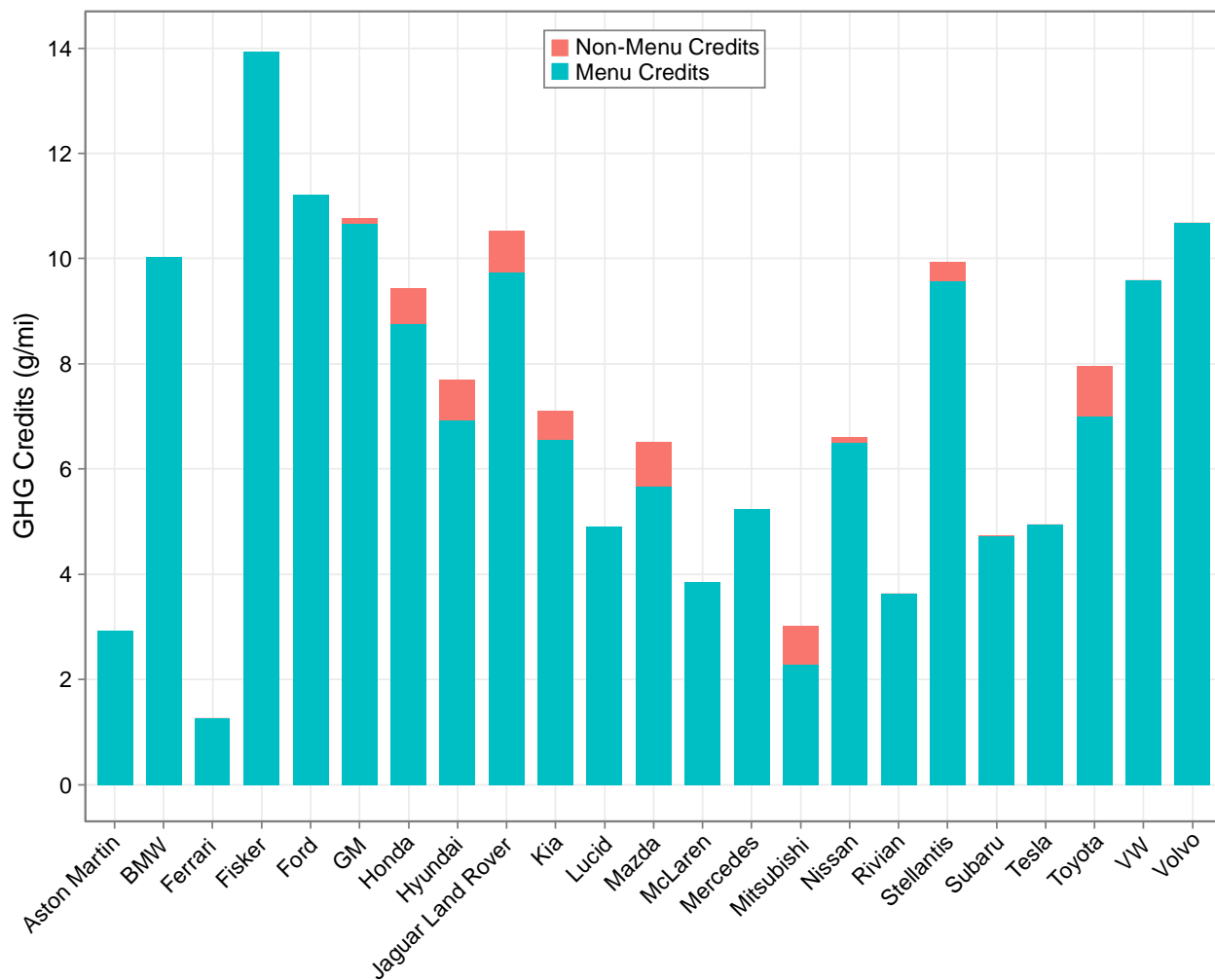
Alternative Standards for Methane and Nitrous Oxide

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 2023 model year. In aggregate, the impact of the methane and nitrous oxide flexibilities resulted in an increase in the industry-wide performance of about 0.2 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 2023, 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.
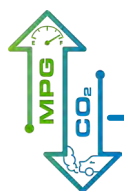
Table 5.5. Manufacturer Performance in Model Year 2023, All (g/mi)

| Manufacturer | 2-Cycle Tailpipe | Performance Credits and Adjustments | | | | | Performance Value |
		Adv. Tech	FFV	A/C	Off-Cycle	CH₄ & N₂O	
Aston Martin	394	-	-	15.6	2.9	-	375
BMW	236	4.7	-	21.7	10.0	-0.0	200
Ferrari	390	-	-	13.8	1.3	-	375
Fisker	0	10.0	-	17.6	13.9	-	-42
Ford	290	7.8	-	23.9	11.2	-0.2	248
GM	307	2.9	-	22.9	10.8	-0.5	271
Honda	242	-	-	20.3	9.4	-	212
Hyundai	228	6.0	-	19.3	7.7	-0.0	195
Jaguar Land Rover	338	0.5	-	24.1	10.5	-	303
Kia	227	3.7	-	19.2	7.1	-0.0	197
Lucid	0	10.0	-	18.8	4.9	-	-34
Mazda	250	0.0	-	22.0	6.5	-0.6	222
McLaren	291	-	-	12.0	3.9	-	275
Mercedes	242	10.0	-	14.6	5.2	-	212
Mitsubishi	224	3.3	-	22.1	3.0	-	196
Nissan	232	2.5	-	20.3	6.6	-	203
Rivian	0	10.0	-	23.4	3.6	-	-37
Stellantis	315	2.7	-	23.4	9.9	-0.2	279
Subaru	240	2.4	-	20.9	4.7	-0.0	212
Tesla	0	10.0	-	17.5	4.9	-	-32
Toyota	248	1.8	-	20.6	7.9	-0.3	218
Volkswagen	249	10.0	-	20.8	9.6	-0.0	209
Volvo	192	10.0	-	21.9	10.7	-	150
All Manufacturers	**249**	**4.1**	**-**	**21.2**	**8.6**	**-0.2**	**215**

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

| Model Year | 2-Cycle Tailpipe | Performance Credits and Adjustments | | | | | Performance Value |
		Adv. Tech	FFV	A/C	Off-Cycle	CH$_4$ & N$_2$O	
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	-0.2	262
2018	280	3.7	-	16.3	7.1	-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
2022	263	-	-	21.1	9.2	-0.2	233
2023	249	4.1	-	21.2	8.6	-0.2	215
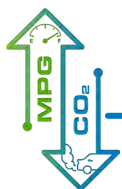
Table 5.7. Manufacturer Performance in Model Year 2023, Car (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH₄ & N₂O	
Aston Martin	364	-	-	13.8	2.9	-	347
BMW	212	-	-	18.7	6.7	-0.1	187
Ferrari	390	-	-	13.8	1.3	-	375
Fisker	-	10.0	-	17.6	13.9	-	-42
Ford	132	42.4	-	18.8	5.6	-0.0	65
GM	211	12.5	-	18.4	5.9	-	174
Honda	199	-	-	16.7	6.2	-	176
Hyundai	196	9.8	-	17.3	4.9	-0.1	164
Jaguar Land Rover	342	-	-	18.7	4.9	-	318
Kia	197	5.8	-	17.2	3.7	-0.1	170
Lucid	-	10.0	-	18.8	4.9	-	-34
Mazda	221	0.2	-	17.7	3.5	-0.4	200
McLaren	291	-	-	12.0	3.9	-	275
Mercedes	192	10.0	-	13.3	4.7	-	164
Mitsubishi	167	-	-	18.1	0.3	-	149
Nissan	197	4.8	-	17.8	4.3	-	170
Rivian	-	-	-	-	-	-	-
Stellantis	347	-	-	18.8	2.3	-0.1	326
Subaru	251	-	-	15.4	0.9	-0.1	235
Tesla	-	10.0	-	16.8	4.7	-	-32
Toyota	199	1.0	-	17.6	4.1	-0.0	176
Volkswagen	213	10.0	-	17.1	6.5	-0.0	179
Volvo	80	15.4	-	17.6	5.7	-	41
All Manufacturers	**176**	**7.0**	**-**	**17.4**	**4.8**	**-0.0**	**147**
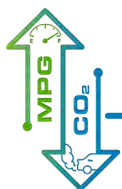
Table 5.8. Industry Performance by Model Year, Car (g/mi)

| Model Year | 2-Cycle Tailpipe | Performance Credits and Adjustments | | | | | Performance Value |
		Adv. Tech	FFV	A/C	Off-Cycle	CH$_4$ & N$_2$O	
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	4.5	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
2022	197	-	-	17.3	6.0	0.0	174
2023	176	7.0	-	17.4	4.8	0.0	147
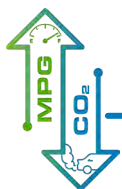
Table 5.9. Manufacturer Performance in Model Year 2023, Truck (g/mi)

Manufacturer	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH$_4$ & N$_2$O	
Aston Martin	421	-	-	17.2	2.9	-	401
BMW	258	9.0	-	24.4	13.0	(0.0)	212
Ferrari	-	-	-	-	-	-	-
Fisker	-	-	-	-	-	-	-
Ford	305	4.6	-	24.4	11.7	(0.2)	264
GM	336	-	-	24.3	12.2	(0.6)	300
Honda	278	-	-	23.3	12.2	-	243
Hyundai	271	0.9	-	22.1	11.5	-	237
Jaguar Land Rover	338	0.5	-	24.2	10.6	-	303
Kia	258	1.4	-	21.4	10.7	-	224
Lucid	-	-	-	-	-	-	-
Mazda	253	-	-	22.4	6.9	(0.7)	224
McLaren	-	-	-	-	-	-	-
Mercedes	286	10.0	-	15.8	5.7	-	254
Mitsubishi	232	3.8	-	22.6	3.4	-	202
Nissan	269	-	-	22.8	9.0	-	237
Rivian	-	10.0	-	23.4	3.6	-	(37)
Stellantis	310	3.1	-	24.1	11.1	(0.2)	272
Subaru	239	2.8	-	21.7	5.3	-	209
Tesla	-	10.0	-	23.8	6.9	-	(41)
Toyota	274	2.1	-	22.1	10.0	(0.4)	240
Volkswagen	269	10.0	-	22.8	11.3	(0.0)	225
Volvo	240	7.7	-	23.7	12.8	-	196
All Manufacturers	**287**	**2.6**	**-**	**23.2**	**10.6**	**(0.2)**	**251**
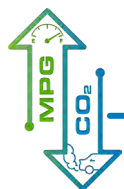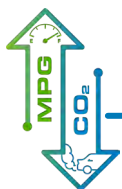
Table 5.10. Industry Performance by Model Year, Truck (g/mi)

Model Year	2-Cycle Tailpipe	Performance Credits and Adjustments					Performance Value
		Adv. Tech	FFV	A/C	Off-Cycle	CH$_4$ & N$_2$O	
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	-0.3	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
2022	297	-	-	23.1	10.8	-0.3	263
2023	287	2.6	-	23.2	10.6	-0.2	251

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
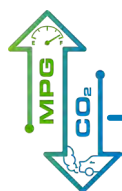
overall manufacturer standard, and performance value, from the underlying passenger car and truck data. Figure 5.11 illustrates the performance of all manufacturers in model year 2023, compared to their effective overall standards.

Of the 23 manufacturers that produced vehicles in model year 2023, eight were below their overall effective standards, and generated net credits (accounting for credits and deficits from each manufacturer's car and truck fleets). Fifteen manufacturers were above their standards and generated net deficits in model year 2023. 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 2023
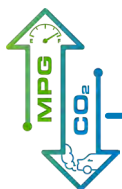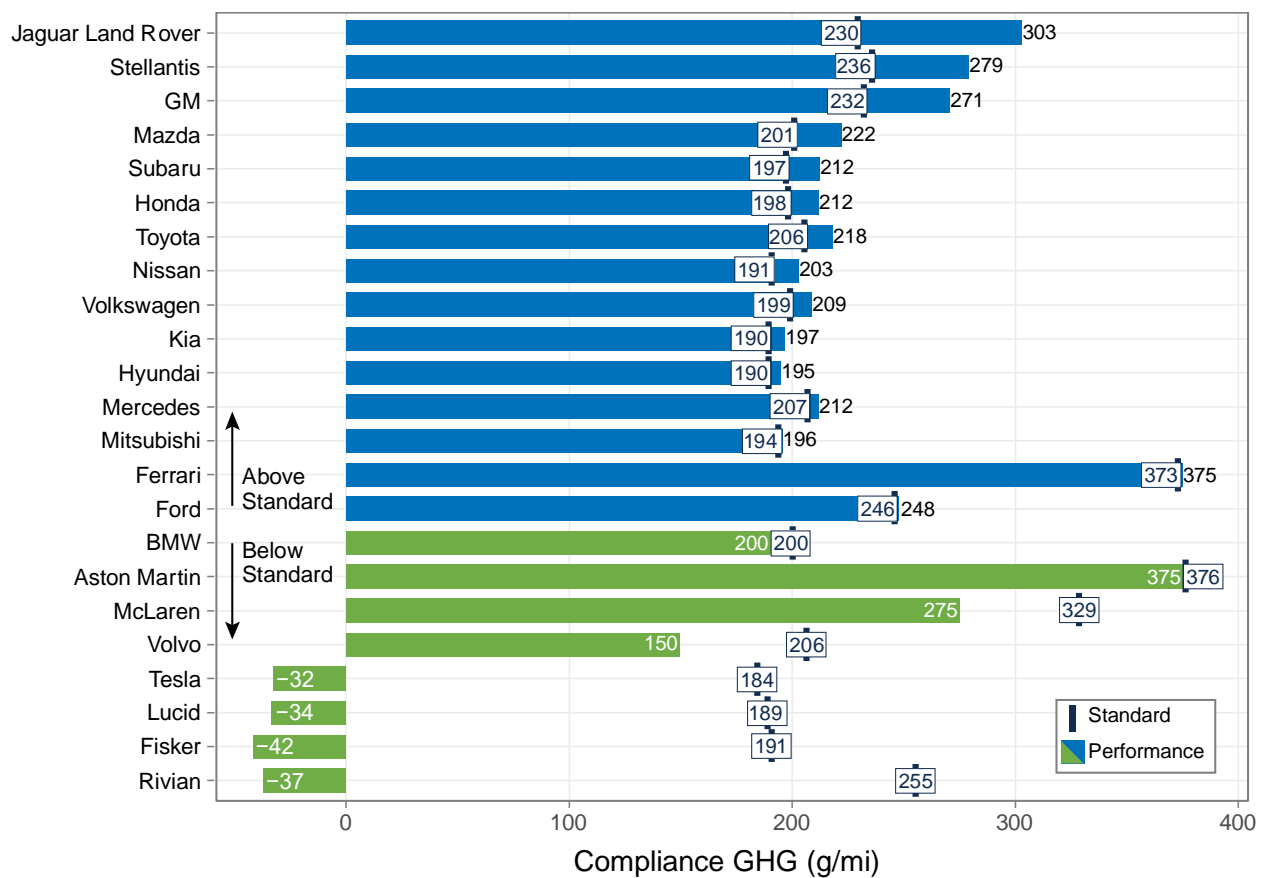
In model year 2023, four manufacturers generated credits from their truck fleets, while fifteen generated deficits. Nine manufacturers generated credits with their car fleets, compared to 13 that generated deficits.[25] Table 5.11 through Table 5.16 provide a summary of the standards, manufacturer performance, and the credits and deficits generated by each manufacturer's car and truck fleets for model year 2023 and for the aggregated industry for model years 2009–2023 (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 – all of which will be discussed later in this section. The tables showing combined car and truck, or overall industry values, are aggregated from the underlying car and truck data.

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[25] Not all manufacturers have both a car and truck fleet. Four manufacturers (Ferrari, Fisker, Lucid, and McLaren) did not produce trucks in model year 2023, and one (Rivian) did not produce cars.

Table 5.11. Credits Earned by Manufacturers in Model Year 2023, All

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	375	376	-1	2,417	397
BMW	200	200	-1	349,611	37,895
Ferrari	375	373	2	3,413	-1,289
Fisker	-42	191	-233	6,895	313,070
Ford	248	246	1	1,540,119	-406,987
GM	271	232	38	2,132,177	-17,767,927
Honda	212	198	14	1,003,728	-2,877,872
Hyundai	195	190	5	990,102	-1,031,926
Jaguar Land Rover	303	230	73	97,472	-1,602,600
Kia	197	190	7	893,905	-1,287,359
Lucid	-34	189	-223	6,745	293,307
Mazda	222	201	21	341,605	-1,628,396
McLaren	275	329	-54	1,159	12,188
Mercedes	212	207	5	302,914	-306,509
Mitsubishi	196	194	2	89,507	-45,058
Nissan	203	191	11	998,235	-2,385,123
Rivian	-37	255	-292	39,151	2,582,415
Stellantis	279	236	43	1,201,130	-11,538,248
Subaru	212	197	15	519,743	-1,764,790
Tesla	-32	184	-217	789,720	33,896,698
Toyota	218	206	12	2,158,030	-5,457,268
Volkswagen	209	199	10	605,163	-1,244,913
Volvo	150	206	-57	123,459	1,512,529
All Manufacturers	**215**	**212**	**4**	**14,196,400**	**-10,697,766**

Table 5.12. Total Credits Earned by Model Year, 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	-15,370,662	2023
2018	253	252	1	16,259,539	-3,204,647	2024
2019	253	246	7	16,139,407	-23,247,116	2024
2020	244	239	6	13,720,942	-17,093,797	2025
2021	239	238	1	13,811,848	-2,738,562	2026
2022	233	234	-1	12,859,584	3,025,361	2027
2023	215	212	4	14,196,400	-10,697,766	2028
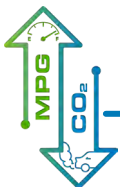
Table 5.13. Credits Earned by Manufacturers in Model Year 2023, Car

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	347	376	-29	1,245	6,988
BMW	187	173	14	179,271	-478,511
Ferrari	375	373	2	3,413	-1,289
Fisker	-42	191	-233	6,895	313,070
Ford	65	175	-110	149,284	3,197,512
GM	174	165	9	556,762	-1,002,694
Honda	176	167	9	500,159	-882,174
Hyundai	164	169	-5	603,283	587,022
Jaguar Land Rover	318	165	153	1,818	-54,455
Kia	170	164	6	493,781	-612,459
Lucid	-34	189	-223	6,745	293,307
Mazda	200	160	40	38,579	-301,443
McLaren	275	329	-54	1,159	12,188
Mercedes	164	179	-15	153,791	450,218
Mitsubishi	149	146	3	11,903	-6,093
Nissan	170	165	5	547,817	-530,386
Rivian	-	-	-	-	-
Stellantis	326	188	138	182,429	-4,914,868
Subaru	235	160	75	69,987	-1,022,583
Tesla	-32	180	-212	719,920	29,740,011
Toyota	176	167	9	820,732	-1,492,386
Volkswagen	179	165	14	236,582	-665,238
Volvo	41	170	-129	40,710	1,022,704
All Manufacturers	**147**	**170**	**-23**	**5,326,265**	**23,658,441**

Table 5.14. Total Credits Earned by Model Year, Car

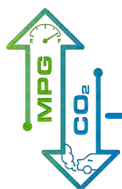| Model Year	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)	Credit Expiration
2009					58,018,752	2014
2010					50,856,700	2021
2011					8,831,637	2021
2012	249	267	-18	8,657,393	30,484,967	2021
2013	240	261	-21	9,747,624	39,249,608	2021
2014	236	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	2,999,670	2023
2018	204	209	-6	7,800,403	8,647,205	2024
2019	203	198	4	7,170,630	-5,822,099	2024
2020	194	189	4	6,029,845	-5,025,051	2025
2021	179	185	-6	5,119,934	5,974,761	2026
2022	174	183	-9	4,748,244	8,702,083	2027
2023	147	170	-23	5,326,265	23,658,441	2028
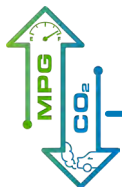
Table 5.15. Credits Earned by Manufacturers in Model Year 2023, Truck

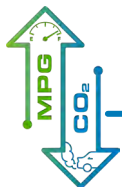| Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Standard Exceedance (g/mi)	Production	Credits Generated (Mg)
Aston Martin	401	376	25	1,172	-6,591
BMW	212	225	-13	170,340	516,406
Ferrari	-	-	-	-	-
Fisker	-	-	-	-	-
Ford	264	253	11	1,390,835	-3,604,499
GM	300	253	47	1,575,415	-16,765,233
Honda	243	225	18	503,569	-1,995,698
Hyundai	237	218	19	386,819	-1,618,948
Jaguar Land Rover	303	231	72	95,654	-1,548,145
Kia	224	217	7	400,124	-674,900
Lucid	-	-	-	-	-
Mazda	224	205	19	303,026	-1,326,953
McLaren	-	-	-	-	-
Mercedes	254	232	22	149,123	-756,727
Mitsubishi	202	200	2	77,604	-38,965
Nissan	237	219	18	450,418	-1,854,737
Rivian	-37	255	-292	39,151	2,582,415
Stellantis	272	243	29	1,018,701	-6,623,380
Subaru	209	202	7	449,756	-742,207
Tesla	-41	223	-264	69,800	4,156,687
Toyota	240	227	13	1,337,298	-3,964,882
Volkswagen	225	218	7	368,581	-579,675
Volvo	196	222	-26	82,749	489,825
All Manufacturers	**251**	**234**	**17**	**8,870,135**	**-34,356,207**

Table 5.16. Total Credits Earned by Model Year, 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	-18,370,332	2023
2018	292	286	6	8,459,136	-11,851,852	2024
2019	288	279	9	8,968,777	-17,425,017	2024
2020	279	272	7	7,691,097	-12,068,746	2025
2021	270	265	4	8,691,914	-8,713,323	2026
2022	263	260	3	8,111,340	-5,676,722	2027
2023	251	234	17	8,870,135	-34,356,207	2028

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 Teragrams (Tg)[26] 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 were usable through the 2021 model year. After model year 2021 any remaining unused model year 2010 or 2011 credits expired. Manufacturers can no longer generate early credits. The distribution of early credits earned by manufacturer is shown in Figure 5.12. More details of the early credit program can be found in the "Early Credits Report," which was released by EPA in 2013.[27]

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[26] 1 Teragram = 1 million Megagrams.
[27] 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.
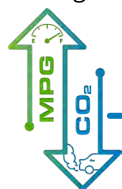
Figure 5.12. Early Credits by Manufacturer
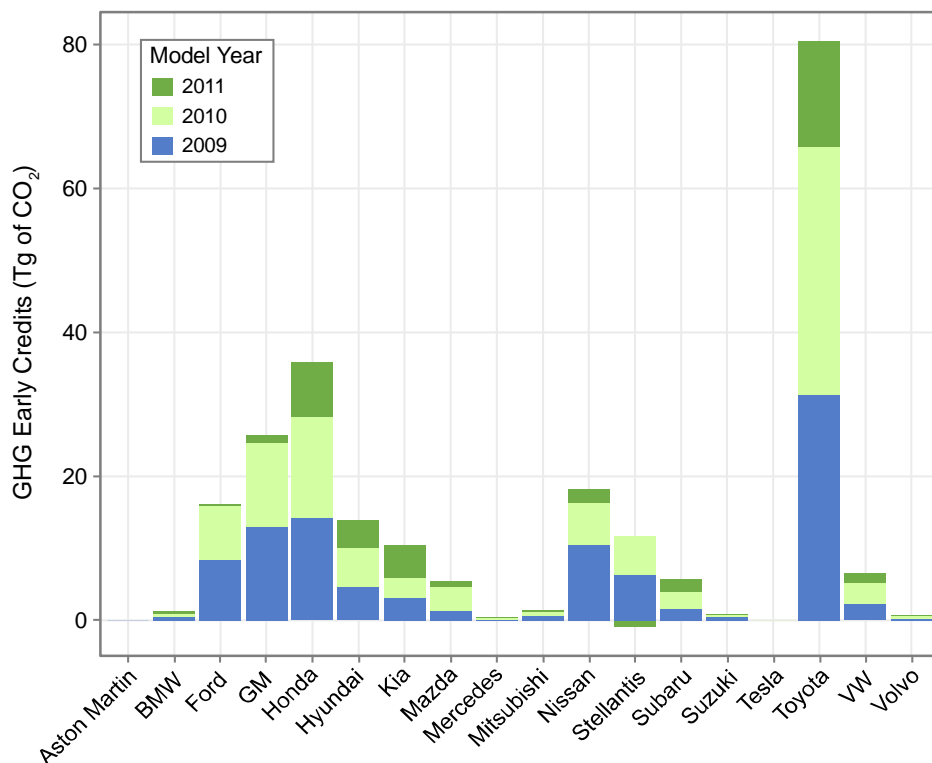
Expiration and Forfeiture of Credits

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, 69 Tg of credits expired.

At the end of model year 2021, all unused credits from model years 2010 to 2016 expired. These expiring credits totaled 39 Tg. At the end of model year 2023, all unused credits from model years 2017 expired, which totaled another 0.5 Tg. The remaining credits that currently exist, or are generated in future years, will expire according to the schedule defined by the GHG Program, and shown in Table 5.17.
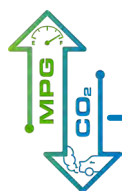
Table 5.17 Credit Expiration Schedule

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.

Pursuant to a resolution with General Motors regarding in-use verification program ("IUVP") testing results for carbon-related exhaust emissions ("CREE") on GM vehicles originally certified with EPA before EPA's implementation of drive-cycle metric regulatory requirements, GM agreed to voluntarily recalculate its GHG credit balance by retiring 49,067,347 Mg of GM's GHG credits. GM recalculated its GHG credit balances and submitted the updated results in GM's most recently filed GHG report. Those adjustments are reflected in this report.

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 fifteen manufacturers selling credits, twenty manufacturers purchasing credits, and more than 140 credit transactions occurring since the inception of the program. Twenty-six total manufacturers have made credit transactions, with nine manufacturers both selling and buying credits. 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 1, 2024, about 270 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.
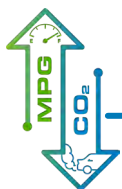
Manufacturers can purchase or sell credits generated in any model year. The model year the credits were generated in remains important, as those credits must be used, and will expire, according to the model year in which they were originally created. Figure 5.13 also shows the distribution of credits 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
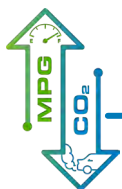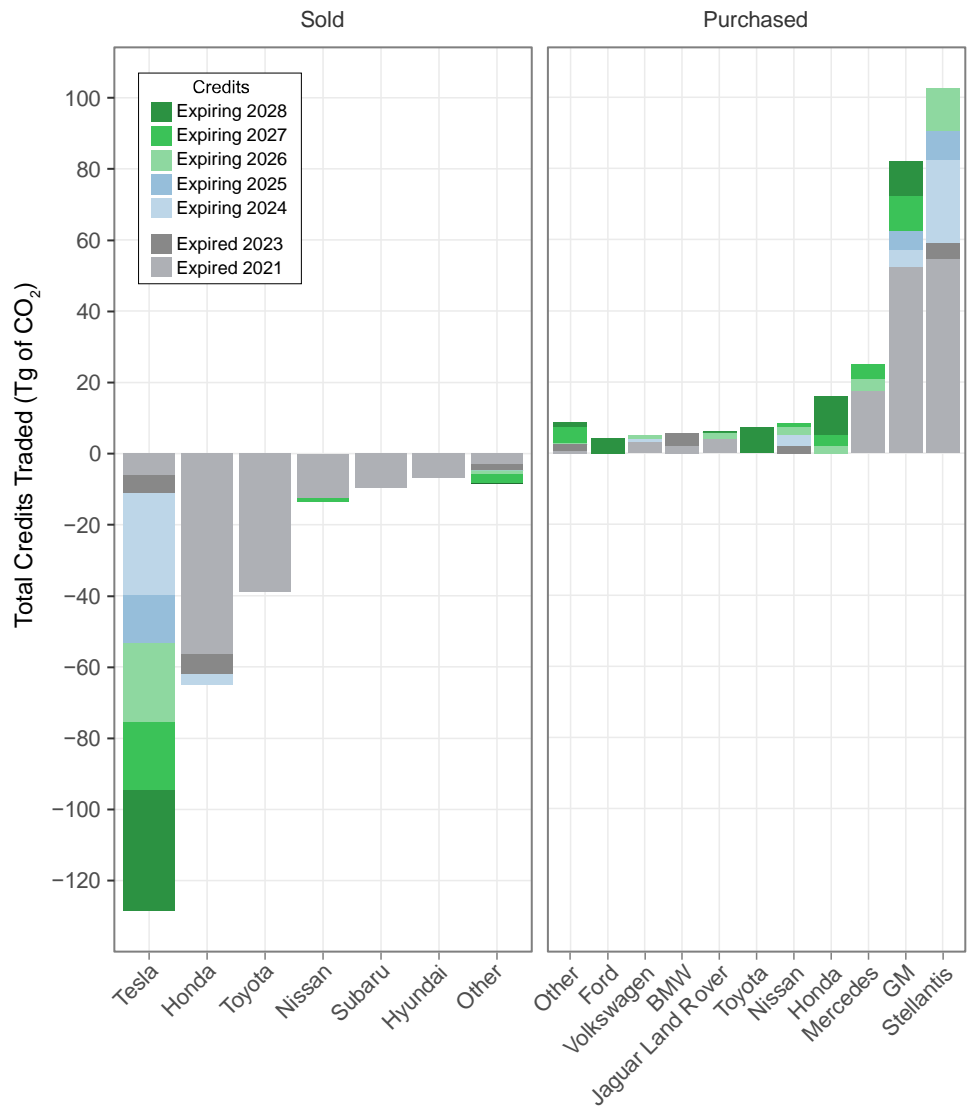
D. GHG Program Credit Balances

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. Manufacturers that end any model year with a deficit have up to three years to offset all deficits to avoid non-compliance and may not report deficits for more than 3 years in a row. In addition, 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 2021, 2022, and 2023. The manufacturer's truck fleets did not generate any credits or deficits in model years 2021 or 2022 but generated a deficit of 500,000 Mg in 2023. Because the oldest credits are applied first, credits generated in model year 2021 are the first credits applied towards the 2023 truck deficit, then 2022 and 2023 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 2022, and 300,000 Mg of credits from model year 2023 to bank for future use.

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

	Model Year 2021	Model Year 2022	Model Year 2023
Generated Truck Credits	0	0	-500,000
Generated Car Credits	300,000	300,000	300,000
Applied to 2023 Deficits	-300,000	-200,000	
Remaining Credits	**0**	**100,000**	**300,000**
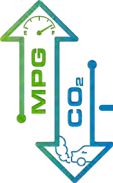
The complete credit and deficit accounting for each manufacturer also includes the impact of credits earned as part of the early credit program, credit trades, credit forfeitures, and credit expirations over the full span of the GHG program. The detailed deficit offset calculations for each manufacturer 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 2023 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 2023, deficits from model year 2020 or prior would be considered non-compliant.

Figure 5.14 shows the credit balance of all manufacturers after model year 2023 including the breakdown of expiration dates, and the distribution of deficits, by age of the deficit. All but three manufacturers ended the 2023 model year with a positive credit balance and are thus in compliance with model year 2023 and all previous years of the GHG program. Volkswagen and Mazda ended model year 2023 with a deficit and must offset their deficits by the model year 2026 reporting period to remain in compliance. Kia ended model year 2023 with a deficit, which is their third straight model year reporting a deficit. Kia must offset all deficits by the model year 2024 reporting period to remain in compliance.

The breakdown of each manufacturer's final model year 2023 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 2012–2023, 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 sum 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.
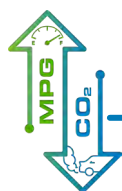
Figure 5.14. Manufacturer Credit Balance After Model Year 2023
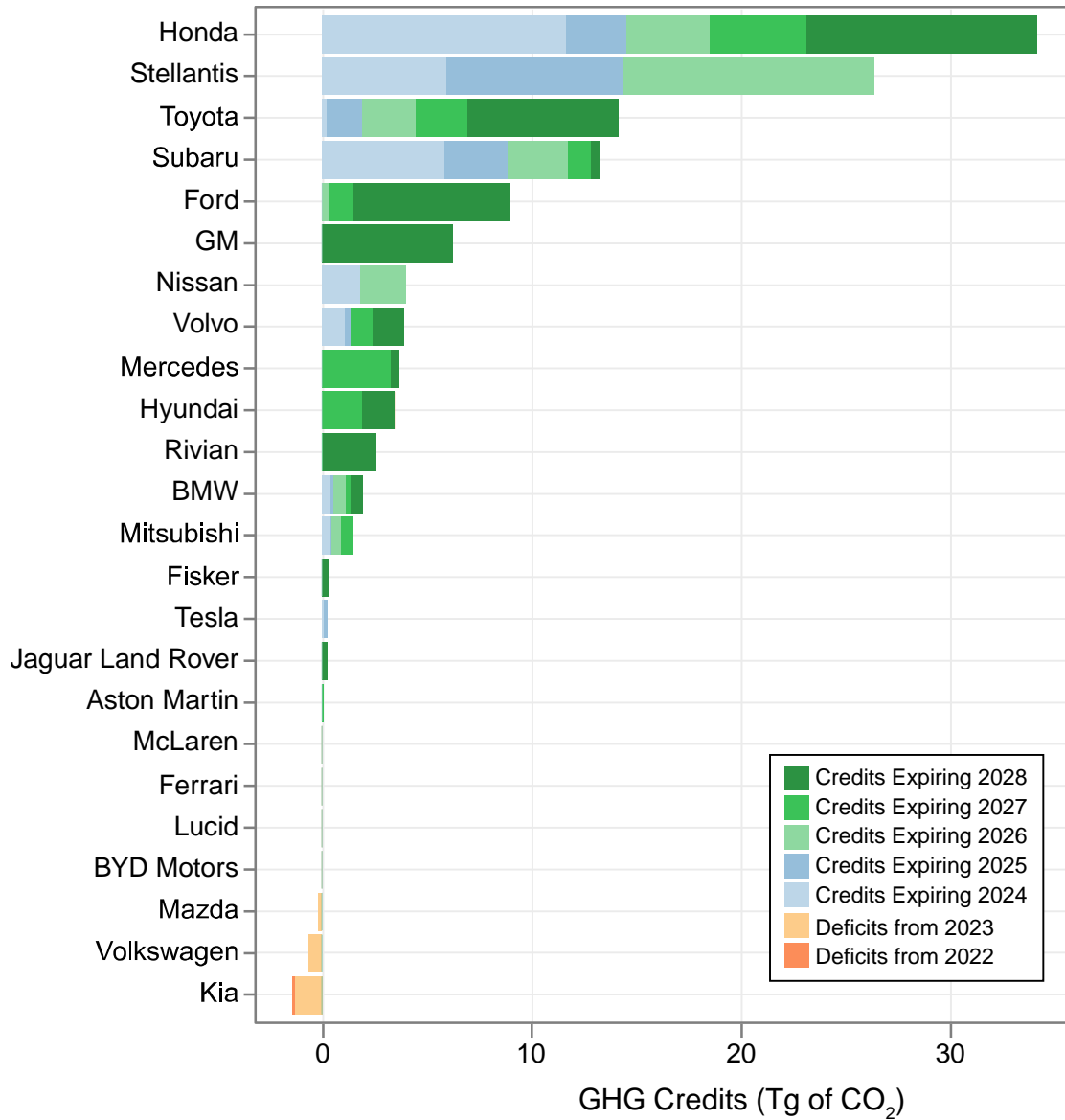
Table 5.19. Final Credit Balance by Manufacturer for Model Year 2023 (Mg)

Manufacturer	Early Credits Earned 2009-2011	Net Credits Earned 2012-2021	Net Credits Earned 2023	Credits Expired	Credits Forfeited	Credits Purchased or Sold	Final 2023 Credit Balance
Aston Martin	3,332	-16,262	397	-	-	75,844	63,311
BMW	1,251,522	-2,939,278	37,895	-135,125	-	3,719,709	1,934,723
BYD Motors	-	5,568	-	-5,400	-	-	168
Coda	-	7,251	-	-	-	-7,251	-
Ferrari	-	-179,094	-1,289	-80,667	-	268,700	7,650
Fisker	-	-	313,070	-	-	-	313,070
Ford	16,116,453	1,526,263	-406,987	-12,552,071	-	4,254,634	8,938,292
GM	25,788,547	-34,850,134	-17,767,927	-11,558	-49,067,347	82,161,795	6,253,376
Honda	35,842,334	65,991,437	-2,877,872	-15,872,556	-	-48,950,245	34,133,098
Hyundai	14,007,495	-1,883,691	-1,031,926	-4,579,410	-169,775	-2,871,951	3,470,742
Jaguar Land Rover	-	-4,219,278	-1,602,600	-10,128	-	6,055,028	223,022
Karma	-	84,597	-	-56,011	-	-28,586	-
Kia	10,444,192	-8,309,552	-1,287,359	-2,362,882	-123,956	235,000	-1,404,557
Lotus	-	-3,147	-	-	-	3,147	-
Lucid	-	158,161	293,307	-	-	-451,161	307
Mazda	5,482,642	1,100,402	-1,628,396	-5,097,987	-	-32,199	-175,538
McLaren	-	-45,769	12,188	-	-	45,769	12,188
Mercedes	378,272	-21,264,100	-306,509	-	-28,416	24,927,713	3,706,960
Mitsubishi	1,449,336	1,060,174	-45,058	-1,135,814	-	157,119	1,485,757
Nissan	18,131,200	6,084,234	-2,385,123	-12,695,612	-	-5,098,348	4,036,351
Porsche	-	426,439	-	-	-426,439	-	-
Rivian	-	1,385,539	2,582,415	-	-	-1,367,801	2,600,153
Stellantis	10,827,083	-75,475,341	-11,538,248	-	-	102,569,367	26,382,861
Subaru	5,755,171	19,430,268	-1,764,790	-917,606	-	-9,221,991	13,281,052
Suzuki	876,650	-183,097	-	-265,311	-	-428,242	-
Tesla	49,772	94,733,320	33,896,698	-1,858	-	-128,402,297	275,635
Toyota	80,435,498	21,534,118	-5,457,268	-50,620,615	-	-31,762,431	14,129,302
Volkswagen	6,613,985	-9,321,246	-1,244,913	-1,442,571	-219,419	5,000,000	-614,164
Volvo	730,187	2,696,520	1,512,529	-78,996	-85,163	-851,322	3,923,755
All Manufacturers	234,183,671	57,534,302	-10,697,766	-107,922,178	-50,120,515	-	122,977,514

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

Manufacturer	Final 2023 Credit Balance	Credits Expiring in 2024	Credits Expiring in 2025	Credits Expiring in 2026	Credits Expiring in 2027	Credits Expiring in 2028	Model Year 2023 Deficits	Model Year 2022 Deficits
Aston Martin	63,311	-	5,350	5,489	45,484	6,988	-	-
BMW	1,934,723	420,467	117,904	582,705	297,241	516,406	-	-
BYD Motors	168	168	-	-	-	-	-	-
Coda	-	-	-	-	-	-	-	-
Ferrari	7,650		-	-	-	3,700	-	-
Fisker	313,070	-	-	-	-	313,070	-	-
Ford	8,938,292	-	-	367,875	1,118,271	7,452,146	-	-
GM	6,253,376	-	-	-	-	6,253,376	-	-
Honda	34,133,098	11,658,284	2,868,950	4,005,904	4,599,960	11,000,000	-	-
Hyundai	3,470,742	-	-	-	1,883,720	1,587,022	-	-
Jaguar Land Rover	223,022	-	-	-	-	223,022	-	-
Karma	-	-	-	-	-	-	-	-
Kia	(1,404,557)	-	-	-	-	-	-1,287,359	-117,198
Lotus	-	-	-	-	-	-	-	-
Lucid	307	-	-	-	307	-	-	-
Mazda	(175,538)	-	-	-	-	-	-175,538	-
McLaren	12,188	-	-	-	-	12,188	-	-
Mercedes	3,706,960	-	-	-	3,256,742	450,218	-	-
Mitsubishi	1,485,757	392,525	56,866	476,697	559,669	-	-	-
Nissan	4,036,351	1,785,335	-	2,231,845	19,171	-	-	-
Porsche	-	-	-	-	-	-	-	-
Rivian	2,600,153	-	-	-	17,738	2,582,415	-	-
Stellantis	26,382,861	5,938,974	8,443,887	12,000,000	-	-	-	-
Subaru	13,281,052	5,822,837	3,041,737	2,859,900	1,118,214	438,364	-	-
Suzuki	-	-	-	-	-	-	-	-
Tesla	275,635	53,704	208,003	13,928	-	-	-	-
Toyota	14,129,302	209,503	1,666,470	2,592,586	2,460,743	7,200,000	-	-
Volkswagen	(614,164)	-	-	-	-	-	-614,164	-
Volvo	3,923,755	1,095,257	215,898	71	1,100,000	1,512,529	-	-
All Manufacturers	**122,977,514**	**27,377,054**	**16,625,065**	**25,137,000**	**16,477,260**	**39,551,444**	**-2,077,061**	**-117,198**

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 2023, the overall industry GHG performance fell 18 g/mi to 215 g/mi, while the standard fell 23 g/mi to 212 g/mi. As a result, the overall industry performance was above the standard, and the industry generated 11 Tg of deficits. The overall industry emerged from model year 2023 with a bank of 123 Tg of GHG credits available for future use, after offsetting all deficits, as seen in Figure 5.15.

The credits available at the end of model year 2023 will expire according to the schedule defined by the GHG Program and detailed in Table 5.20. An active credit market has allowed manufacturers to purchase credits to demonstrate compliance, with fifteen manufacturers selling credits, twenty manufacturers purchasing credits, and approximately 140 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 2023 model year.
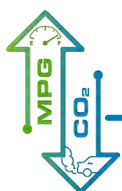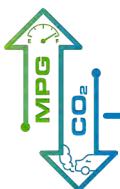
Figure 5.15. Industry Performance and Standards, Credit Generation and Use
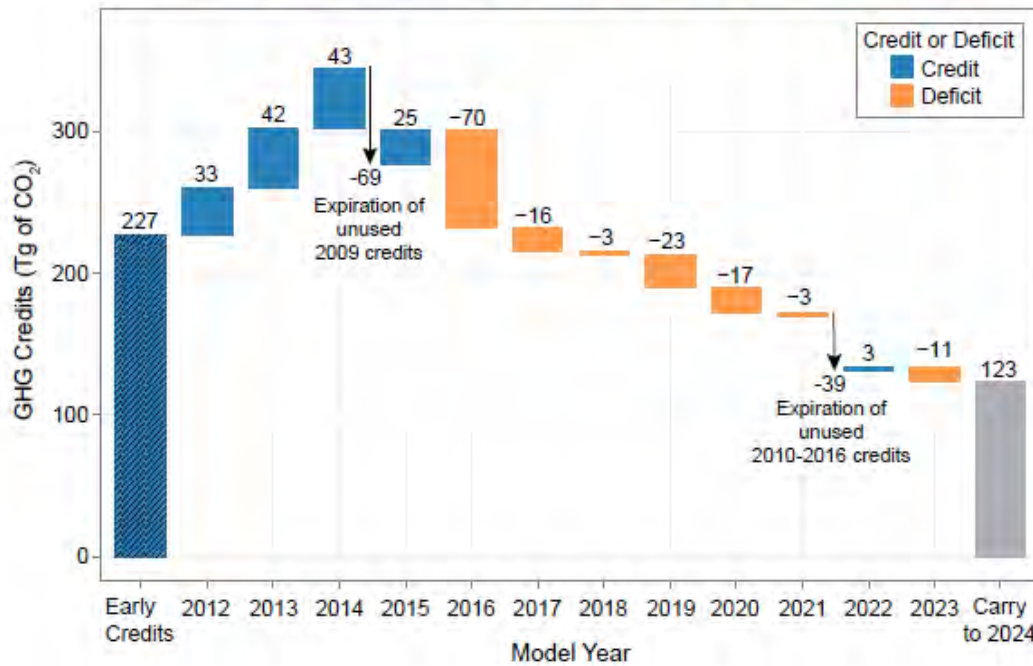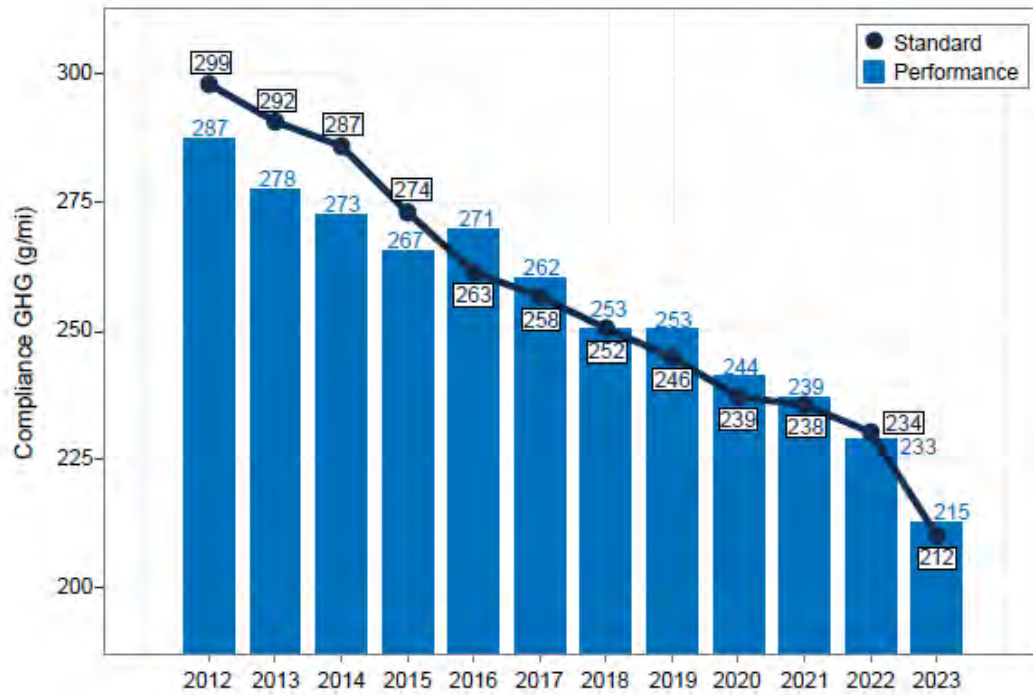
Appendices: Methods and Additional Data

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 https://one.nhtsa.gov/cafe_pic/home. 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 2032 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 2024 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.

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 2022 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
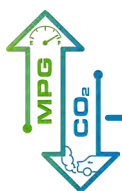
report, the preliminary values from the previous year are updated to reflect the final values. This allows a comparison to gauge the accuracy of preliminary projections.

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 ten 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	26.4	26.0	-0.4
2023	26.9	27.1	+0.2
2024 (prelim)	28.0		
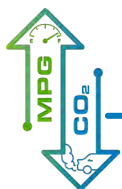
B. Harmonic Averaging of Fuel Economy Values

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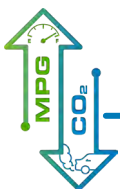
The following equation illustrates the use of harmonic averaging to obtain the correct mathematical result for the fuel economy example above:

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

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

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

(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.)

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.
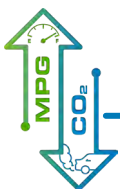
C. Fuel Economy and CO_2 Metrics

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[28] 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:

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[28] 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.
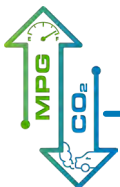
1. The GHG regulations require a car and truck weighting based on a slightly higher lifetime vehicle miles traveled (VMT) for trucks. The 2-cycle fuel economy values do not account for this difference.
2. The GHG regulations allow manufacturers to use an optional compliance approach, which adds nitrous 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
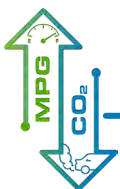
and higher acceleration) that an average driver will encounter. City and highway results are weighted 43% / 57%, consistent with fleetwide driver activity data.

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 2024 Toyota Prius. 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 is 83 mpg, the highway fuel economy is 78 mpg, and the combined 2-cycle value is 80 mpg.

Using the 5-cycle methodology, the Toyota Prius has a vehicle fuel economy label value of 57 mpg city and 56 mpg highway. On the vehicle label, these values are harmonically
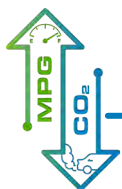
averaged using a 55% city / 45% highway weighting to determine a combined value of 57 mpg. The estimated real-world fuel economy for the Prius, which is the set of values used in calculations for this report, has the same city and highway fuel economy as the label, but the 43% city and 57% highway weighting leads to a combined value of 56 mpg, which is one mpg less than the values found on the label.

Table C.1. Fuel Economy Metrics for the Model Year 2024 Toyota Prius

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	80	83	78
Label	Consumer information to compare individual vehicles	55% / 45%	5-cycle	57	57	56
Estimated Real-World	Best estimate of real-world performance	43% / 57%	5-cycle	56	57	56

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.
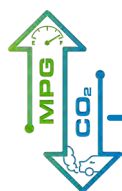
D. Historical Changes in the Database and Methodology

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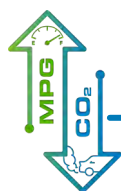
Model year 1986–2010: The 2006 5-cycle methodology and 43% City / 57% Highway Weighting

In 2006, EPA established a major change to the fuel economy label calculations by introducing the 5-cycle methodology[29]. 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.[30] 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.

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[29] See 71 Federal Register 77872, December 27, 2006.
[30] See 71 Federal Register 77883-77886, December 27, 2006.
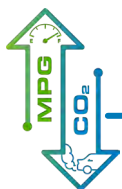
For vehicles that were eligible to use the 2006 derived 5-cycle methodology, the following equations were used to convert 2-cycle city and highway fuel economy values to label economy values. These equations were based on the relationship between 2-cycle and 5-cycle fuel economy data for the industry 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.[31] 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.

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[31] See 71 Federal Register 77904, December 27, 2006.

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.[32] This 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:
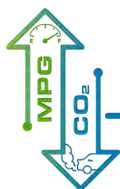
$$\text{Label CITY} = \frac{1}{\left(0.004091 + \frac{1.1601}{\text{2CYCLE CITY}}\right)}$$

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

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. 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. See Appendix C for more information.

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[32] See https://www.epa.gov/fueleconomy/basic-information-fuel-economy-labeling and
http://iaspub.epa.gov/otaqpub/display_file.jsp?docid=35113&flag=1
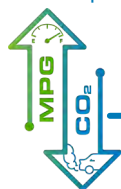
Figure D.1. Estimated Real-World versus 2-Cycle Fuel Economy since Model Year 1975
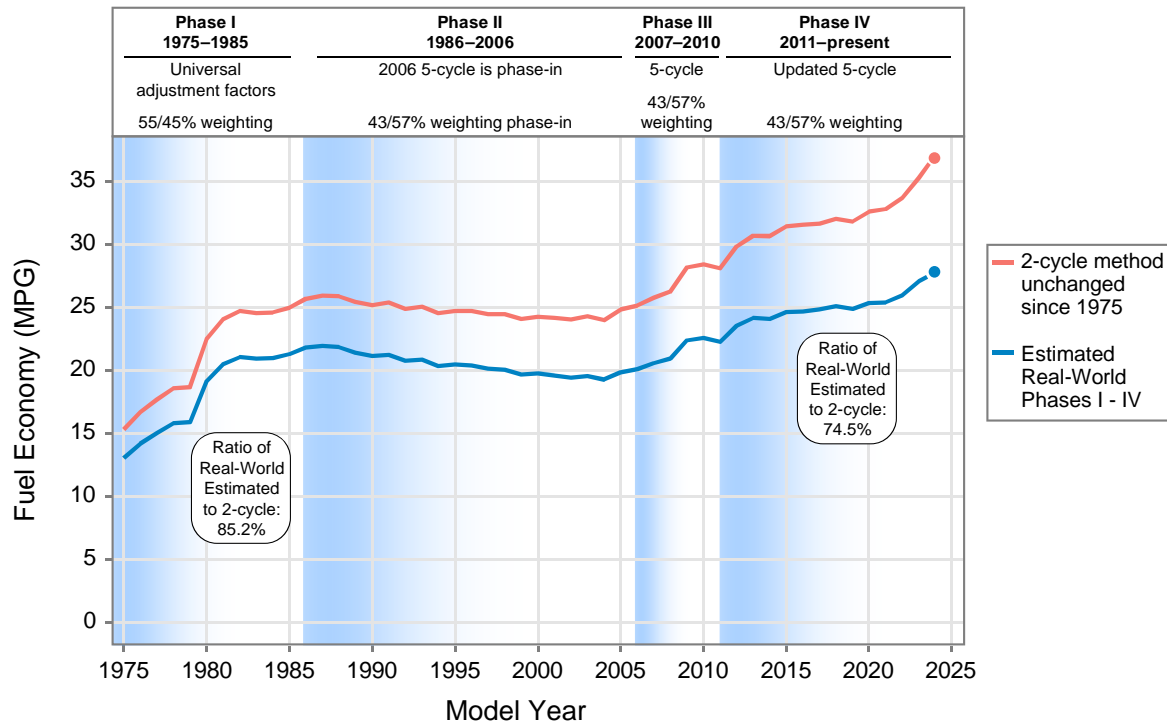
Other Database Changes

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.
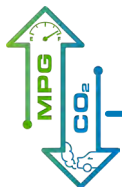
Addition of Alternative Fuel Vehicles

Data from alternative fuel vehicles are integrated into the overall database, beginning with MY 2011 data. These vehicles include electric vehicles, plug-in hybrid electric 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 light truck category to the passenger 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
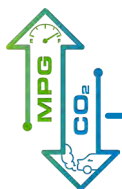
previous manufacturer definitions where necessary to preserve the integrity of compliance data as they were accrued.

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.
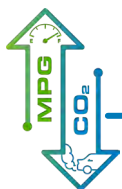
E. Electric Vehicle and Plug-In Hybrid Metrics

Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) have continued to gain market share. Overall market penetration of these vehicles is projected to reach 15% production share in model year 2024. This section addresses some of the technical metrics used both to quantify BEV and PHEV operation and to integrate data from these vehicles with gasoline and diesel vehicle data.

BEVs operate using only energy stored in a battery from external charging. PHEVs blend BEV 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 a BEV) and a gasoline internal combustion engine. There are generally three ways that a PHEV can operate:

- Charge-depleting electric-only mode – The vehicle operates like a BEV, using only energy stored in the battery to propel the vehicle.

- Charge-depleting 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 – The vehicle has exhausted the stored energy in the battery and relies on the gasoline internal combustion engine. In this mode, the vehicle will operate much like a strong hybrid.

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

This section discusses BEV and PHEV metrics for several example model year 2024 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 BEVs and PHEVs when operating only on electricity, as well as the total electricity plus gasoline range for PHEVs. The average range of new BEVs is increasing, as shown in Section 4, and many BEVs are approaching the range of an average gasoline vehicle.[33] 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 2024 Example BEV and PHEV Powertrain and Range

Manufacturer	Model	Fuel or Power-train	Electric Range (miles)	Total Range (miles)	Utility Factor
Ford	F-150 Lightning Platinum	BEV	300	300	-
GM	Equinox EV AWD	BEV	285	285	-
Hyundai	Ioniq 6 LR AWD 18" wheels	BEV	316	316	-
Nissan	Leaf SV	BEV	212	212	-
Tesla	Model 3 LR AWD	BEV	342	342	-
BMW	XM	PHEV	31	300	0.60
Stellantis	Pacifica Hybrid	PHEV	32	520	0.61
Toyota	Prius Prime SE	PHEV	45	600	0.71
Volvo	XC60 T8 AWD Recharge	PHEV	36	560	0.64

Determining the electric range of PHEVs is complicated if the vehicle is capable of operating in blended modes. For PHEVs like the Toyota Prius Prime SE, which cannot operate in blended mode, the electric range represents the estimated range operating in electric only mode. However, for PHEVs that operate in a blended mode, the electric range represents the estimated range of the vehicle operating in either electric only *or* blended mode, due to the design of the vehicle. For example, the Volvo XC60 Recharge uses electricity stored in its battery and a small amount of gasoline to achieve an alternative fuel range of 35 miles. Most 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

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[33] 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/.
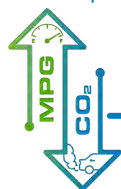
speeds, and air conditioning or heater operation) would likely cause these vehicles to operate in a blended mode instead of an all-electric mode.

Table E.1 also introduces the concept of a utility factor. The utility factor is directly related to the electric range for PHEVs and is a projection, on average, of the percentage of miles that will be driven using electricity (in electric-only and blended modes) by an average driver. The model year 2024 Prius Prime SE, for example, has a utility factor of 0.71, i.e., it is expected that, on average, the Prius Prime SE will operate 71% of the time on electricity and 29% of the time on gasoline. The label utility factor calculations are based on the SAE methodology J2841 that EPA has adopted for fuel economy labeling (SAE 2010).

Table E.2 shows five energy-related metrics for model year 2024 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 2024 Example EV and PHEV Fuel Economy Label Metrics

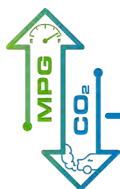| Manufacturer | Model | Fuel or Power-train | Charge Depleting | | | Charge Sustaining | Overall Fuel Economy (mpge) |
			Electricity (kW-hrs/ 100 miles)	Gasoline (gallons/ 100 miles)	Fuel Economy (mpge)	Fuel Economy (mpg)	
Ford	F-150 Lightning Platinum	BEV	51	N/A	66	N/A	66
GM	Equinox EV AWD	BEV	35	N/A	96	N/A	96
Hyundai	Ioniq 6 LR AWD	BEV	28	N/A	121	N/A	121
Nissan	Leaf SV	BEV	31	N/A	109	N/A	109
Tesla	Model 3 LR AWD	BEV	26	N/A	130	N/A	130
BMW	XM	PHEV	73	0.0	46	14	24
Stellantis	Pacifica Hybrid	PHEV	41	0.0	82	30	48
Toyota	Prius Prime SE	PHEV	26	0.0	127	52	89
Volvo	XC60 T8 AWD Recharge	PHEV	50	0.1	63	28	44
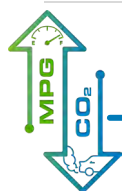
The fourth column in Table E.2 gives electricity consumption rates for BEVs and PHEVs during charge depleting operation in units of kilowatt-hours per 100 miles (kW-hrs/100 miles). As shown on the vehicle label, the electricity consumption rate is based on the amount of electricity required from an electric outlet to charge the vehicle and includes wall-to-vehicle charging losses. The values for all of the BEVs and PHEVs reflect the electricity consumption rate required to operate the vehicle in either electric-only or blended mode operation. PHEVs that are capable of operating in a blended mode may also consume some gasoline in addition to electricity. Any additional gasoline used is shown in the fifth column. For example, the Volvo XC60 Recharge consumes 50 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 109 mpge.[34] Because the Volvo XC60 Recharge consumes both electricity and gasoline over the alternative fuel range of 35 miles, the charge depleting fuel economy of 63 mpge includes both the electricity and gasoline consumption, at a rate of 50 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

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[34] 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.

introduced in Table E.1. For EVs, the overall fuel economy in the last column is equal to the charge depleting fuel economy, as EVs can only operate in a charge depleting mode.

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

Table E.3. Model Year 2024 Example EV and PHEV Label Tailpipe CO_2 Emissions Metrics

Manufacturer	Model	Fuel or Powertrain	Tailpipe CO_2 (g/mile)
Ford	F-150 Lightning Platinum	BEV	0
GM	Equinox EV AWD	BEV	0
Hyundai	Ioniq 6 LR AWD 18" wheels	BEV	0
Nissan	Leaf SV	BEV	0
Tesla	Model 3 LR AWD	BEV	0
BMW	XM	PHEV	244
Stellantis	Pacifica Hybrid	PHEV	119
Toyota	Prius Prime SE	PHEV	50
Volvo	XC60 T8 AWD Recharge	PHEV	122

Table E.4 accounts for the "upstream" CO_2 emissions associated with the production and distribution of electricity used in BEVs 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 a BEV 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
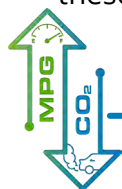
coal is used with no CO_2 emissions control) or very low CO_2 emissions (for example, if renewable processes with minimal fossil energy inputs are used).

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. Natural gas plants currently 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 high 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 2024 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 Platinum	BEV	132	211	340	45	124	253
GM	Equinox EV AWD	BEV	91	146	235	31	86	175
Hyundai	Ioniq 6 AWD 18"	BEV	73	116	188	18	61	133
Nissan	Leaf SV	BEV	80	128	206	33	81	159
Tesla	Model 3 LR AWD	BEV	67	107	173	15	55	121
BMW	XM	PHEV	419	488	599	315	383	495
Stellantis	Pacifica Hybrid	PHEV	214	254	318	140	179	243
Toyota	Prius Prime SE	PHEV	111	139	186	63	92	139
Volvo	XC60 T8 AWD Recharge	PHEV	236	286	368	164	214	295
Average Sedan/Wagon			**280**	**280**	**280**	**224**	**224**	**224**

Based on data from EPA's eGRID power plant database,[35] and accounting for additional greenhouse gas emissions impacts for feedstock processing upstream of the power plant,[36] EPA estimates that the electricity CO_2 emission factors for various regions of the

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[35] United States Environmental Protection Agency (EPA). 2024. "Emissions & Generation Resource Integrated Database (eGRID), 2022" Washington, DC: Office of Atmospheric Programs, Clean Air Markets Division. Available from EPA's eGRID web site: https://www.epa.gov/egrid.

[36] Argonne National Laboratory 2024. GREET_1_2023rev1 Model. greet.es.anl.gov.
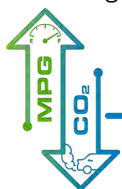
country vary from 260 g CO_2/kW-hr in California to 670 g CO_2/kW-hr in the Midwest (Illinois and Missouri), with a national average of 416 g CO_2/kW-hr. Emission rates for small regions in upstate New York and Alaska have lower electricity upstream CO_2 emission rates than California. However, California is a good surrogate for the "low" end of the range because California is a leading market for current BEVs and PHEVs. Initial sales of electric vehicles have been largely, though not exclusively, focused in regions of the country with power plant CO_2 emissions factors lower than the national average, such as California, New York, and other coastal areas. Accordingly, in terms of CO_2 emissions, EPA believes that the current "sales-weighted average" vehicle operating on electricity in the near term will likely fall somewhere between the low end of this range and the national average.[37]

The fourth through sixth columns in Table E.4 provide the range of tailpipe plus *total* upstream CO_2 emissions for BEVs and PHEVs based on regional electricity emission rates. For comparison, the average model year 2024 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 BEVs is shown in the following example for the model year 2024 Nissan Leaf SV:

- 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 241 g/kW-hr, 5.1%, and 9.3%, respectively).

- Determine the regional upstream emission factor (for California 226 g/kW-hr / (1–0.051) * (1+0.093) = 260 g CO_2/kW-hr)[38]

- Multiply by the range of Low (California = 260g CO_2/kW-hr), Average (National Average = 416 g CO_2/kW-hr), and High (Midwest = 670 g CO_2/kW-hr) electricity upstream CO_2 emission rates, which yields a range for the Leaf of 80-206 grams CO_2/mile.

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[37] To estimate the upstream greenhouse gas emissions associated with operating a BEV or PHEV in a specific geographical area, use the emissions calculator at www.fueleconomy.gov/feg/Find.do?action=bt2.

[38] 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.
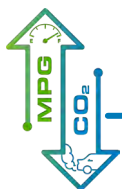
The tailpipe plus total upstream CO_2 emissions values for PHEVs include the upstream CO_2 emissions due to electricity operation and both the tailpipe and upstream CO_2 emissions due to gasoline operation, using the utility factor discussed above to weight the values for electricity and gasoline operation. The tailpipe plus total upstream CO_2 emissions values for the average car are the average projected real-world model year 2024 car tailpipe CO_2 emissions multiplied by 1.25 to account for upstream emissions due to gasoline production.

The values in columns four through six are tailpipe plus *total* upstream CO_2 emissions. As mentioned, all of the gasoline and diesel vehicle CO_2 emissions data in the rest of this report refer only to tailpipe emissions and do not reflect the upstream emissions associated with gasoline or diesel production and distribution. Accordingly, in order to equitably compare the overall relative impact of BEVs and PHEVs with tailpipe emissions of petroleum-fueled vehicles, EPA uses the metric "tailpipe plus *net* upstream emissions" for BEVs and PHEVs. The net upstream emissions value for a BEV is equal to the total upstream emissions for the BEV 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 BEV and PHEV regulatory compliance with the 2012–2016 light-duty vehicle GHG emissions standards for the production of BEVs and PHEVs beyond a threshold; however, those thresholds were never exceeded.

For each BEV 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 BEVs 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 Nissan 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 2024 CO_2 footprint curve, the
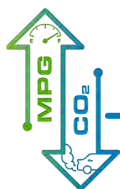
5-cycle tailpipe GHG emissions for a Leaf-sized gasoline vehicle meeting its compliance target would be close to 189 grams/mi, with upstream emissions of one-fourth of this value, or 47 g/mi. The net upstream emissions value for a Leaf is determined by subtracting this value, 47 g/mi, from the total (tailpipe + total upstream). The result is a range for the tailpipe plus net upstream value of 33–159 g/mile as shown in Table E.4, with a more likely sales-weighted value in the 33-81 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 BEVs and PHEVs

Determining metrics for BEVs 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 to compare the vehicle with other vehicles. 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.
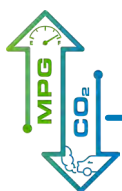
The utility factors that are used for fleetwide calculations are somewhat different than those used to create label values. For label values, multi-day individual utility factors (MDIUF) are used to incorporate "a driver's day to day variation into the utility calculation." For fleetwide calculations, 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.
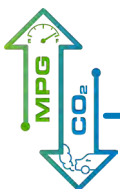
F. Regulatory Car and Truck Definitions

Under EPA's light-duty GHG regulations and NHTSA's fuel economy standards, new vehicles are separated into two distinct regulatory classes, passenger cars and light trucks. Each regulatory class has separate and unique GHG and fuel economy standards. The regulatory definitions of passenger vehicles (cars) and light trucks (trucks) are located in the U.S. Department of Transportation's (USDOT) National Highway Traffic Safety Administration's (NHTSA) CAFE regulations (code of federal regulations: 49 CFR 523.5). NHTSA's regulatory definitions are based in part on statutory definitions included in the Energy Policy and Conservation Act of 1975 and the Energy Independence and Security Act of 2007 (codified at 49 USC 32901). EPA references regulatory definitions for the light-duty GHG program (code of federal regulations: 40 CFR 86.1818-12).

Figure F.1 shows the generalized decision tree for determining if a vehicle is a car or a truck under the regulatory definitions, for model year 2012 and later vehicles. First, vehicles that are above 10,000 gross vehicle weight rating (GVWR), or above 8,500 GVWR and not considered a MDPV are excluded from EPA's light-duty GHG regulations and CAFE. If the vehicle is below 8,500 pounds GVWR or an MDPV, then a vehicle can qualify as a light truck based on the vehicle's functionality or off-road capabilities. Any light-duty vehicles that do not meet the above functionality or off-road requirements are considered cars for regulatory purposes.

Note that Figure F.1, and the description of car and truck regulations presented here, are an overview of the regulatory definitions. They should not be considered a guidance document or used for compliance purposes. Any compliance related questions as to the car or truck classifications of specific vehicles should be referred directly to the agencies.
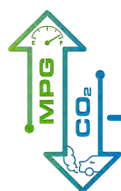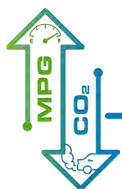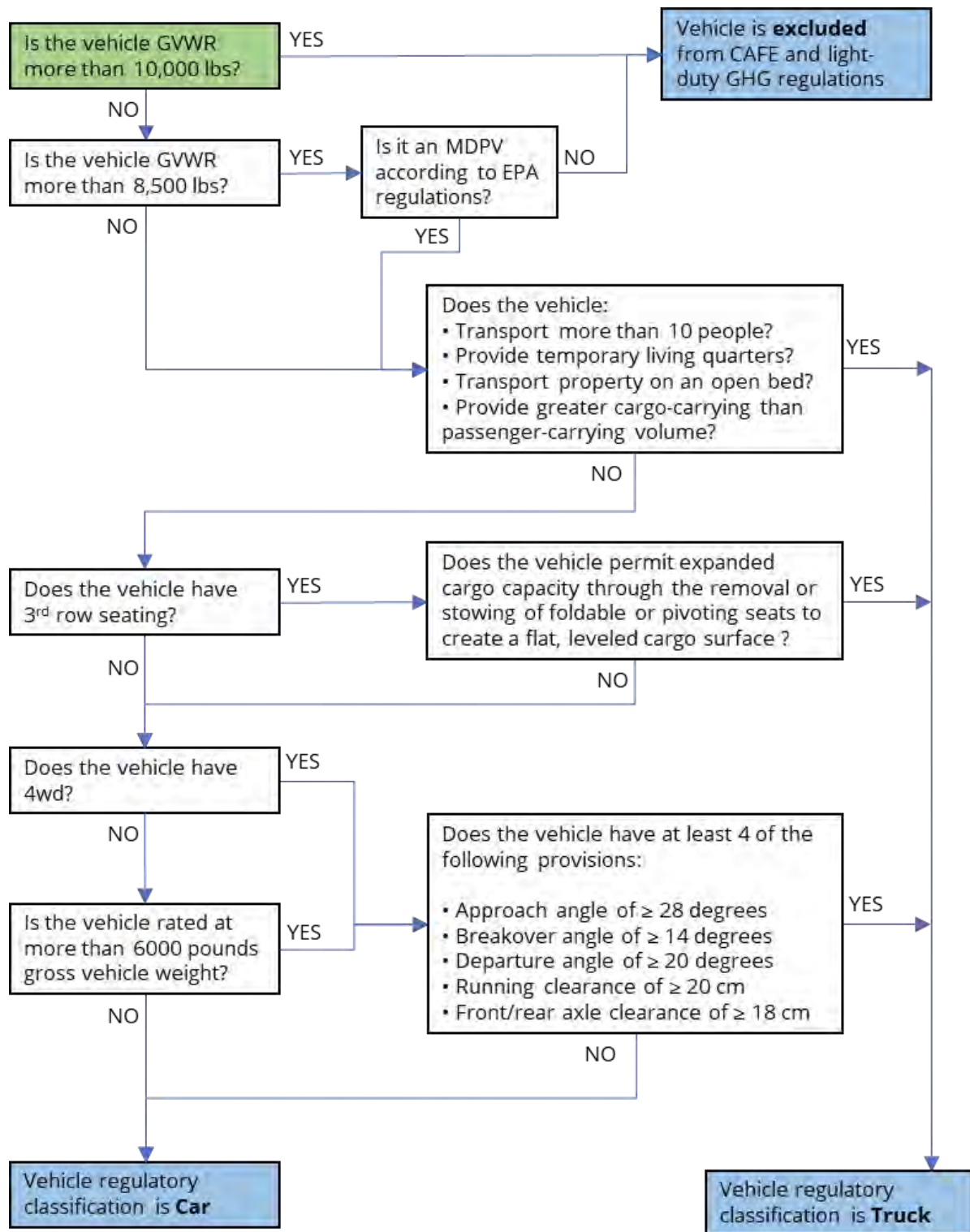
Figure F.1. Regulatory Car or Truck Flow Chart

Is the vehicle GVWR more than 10,000 lbs? — YES → Vehicle is **excluded** from CAFE and light-duty GHG regulations

NO ↓

Is the vehicle GVWR more than 8,500 lbs? — YES → Is it an MDPV according to EPA regulations? — NO →

NO ↓   YES ↓

Does the vehicle:
• Transport more than 10 people?
• Provide temporary living quarters?
• Transport property on an open bed?
• Provide greater cargo-carrying than passenger-carrying volume? — YES →

NO ↓

Does the vehicle have 3rd row seating? — YES → Does the vehicle permit expanded cargo capacity through the removal or stowing of foldable or pivoting seats to create a flat, leveled cargo surface ? — YES →

NO ↓   NO ↓

Does the vehicle have 4wd? — YES →

NO ↓

Is the vehicle rated at more than 6000 pounds gross vehicle weight? — YES → Does the vehicle have at least 4 of the following provisions:

• Approach angle of ≥ 28 degrees
• Breakover angle of ≥ 14 degrees
• Departure angle of ≥ 20 degrees
• Running clearance of ≥ 20 cm
• Front/rear axle clearance of ≥ 18 cm — YES →

NO ↓   NO ↓

Vehicle regulatory classification is **Car**

Vehicle regulatory classification is **Truck**

G. Naming Conventions for Electrified Vehicles

This report identifies several electrification technologies currently being deployed on new vehicles. In accordance with EPA's light-duty GHG rulemaking[39], this report uses the following conventions to identify specific vehicle technology types and groupings. These relationships are also depicted in Figure G.1.

Figure G.1. Electrification Groupings of Vehicles
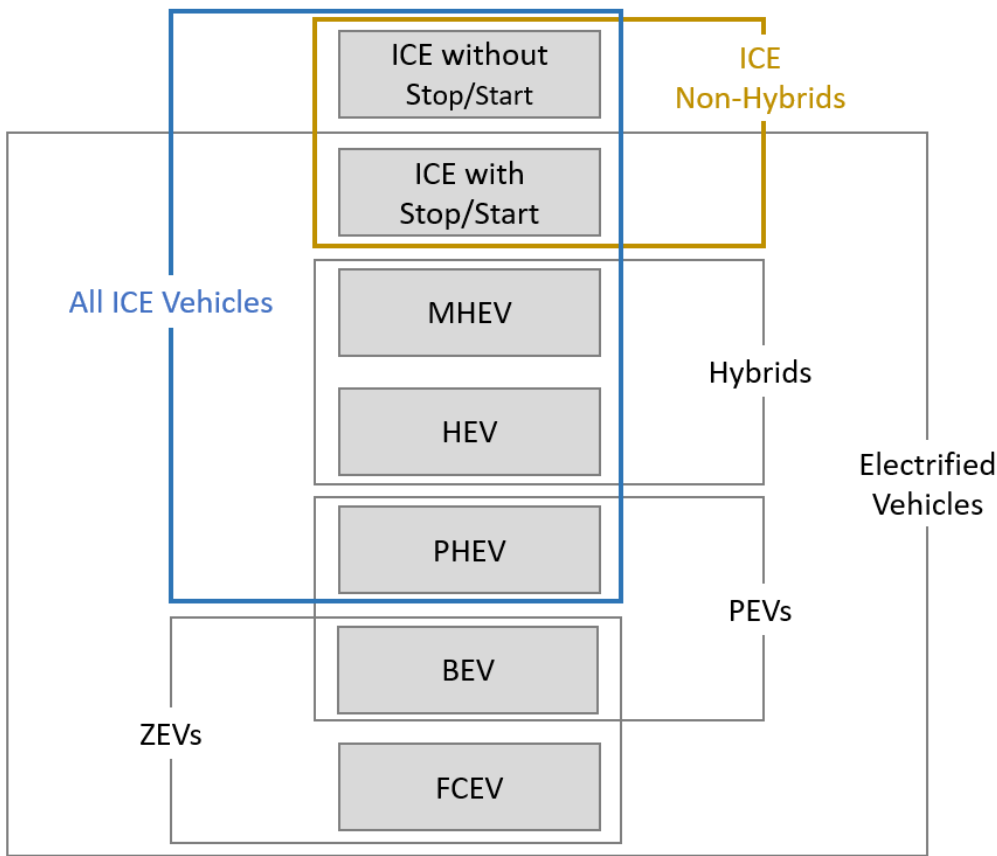
The technology categories are:

- **Internal Combustion Engine (ICE) Vehicle:** These vehicles are powered by an internal combustion engine, in which energy released from the combustion of fuel is used to power the vehicle. ICE vehicles included in the report include those powered by gasoline, diesel, and compressed natural gas (CNG).

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[39] 89 FR 27842
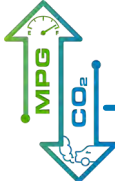
- **ICE with Stop/Start:** These vehicles have technology that can turn off the internal combustion engine when the vehicle is stopped and very quickly restart the engine when the driver releases the brake pedal.
- **Mild Hybrid Electric Vehicle (MHEV):** These vehicles generally have an electric motor and battery that can assist the engine with moving the vehicle forward at launch, stop-start systems, and regenerative braking capabilities. However, their electrical system cannot directly propel the vehicle. For the purposes of this report, new vehicles with a 48V or less electrical system and have an internal combustion engine are classified as "mild" hybrids.
- **Strong Hybrid Electric Vehicle (HEV):** These vehicles generally have a larger motor and battery that can temporarily power the vehicle without engaging the engine and may be able to capture more energy from regenerative braking than a mild hybrid. For the purposes of this report, new vehicles equipped with an electrical system more than 48V and an internal combustion engine are classified as "strong" hybrids.
- **Plug-in Hybrid Electric Vehicle (PHEV):** These vehicles have both a battery that can be charged from an external electrical source and an internal combustion and operate on electricity until the battery is depleted or cannot meet driving needs.
- **Battery Electric Vehicle (BEV):** These vehicles operate solely from energy stored in an onboard battery that can be charged from external electrical source. The energy from the battery is used to power one or more electric motors to propel the vehicle.
- **Fuel Cell Electric Vehicle (FCEV):** These vehicles use a fuel cell stack to create electricity from an onboard fuel source (usually hydrogen), which then powers one or more electric motors to propel the vehicle.

In addition to the specific technology categories above, this report uses the following technology groupings:

- **All ICE Vehicles:** Any vehicle that includes an internal combustion engine.
- **ICE Non-Hybrids:** Any vehicle that relies on an internal combustion engine but is not a hybrid vehicle.
- **Electrified vehicles:** Any vehicle with powertrain electrification, including stop/start, MHEVs, HEVs, PHEVs, and BEVs.
- **Hybrids:** refers collectively to HEVs and MHEVs.
- **Plug-in Electric Vehicle (PEV):** Vehicles that can operate on grid electricity, including BEVs and PHEVs.
- **Zero-Emission Vehicle (ZEV):** Vehicles with zero tailpipe emissions, including BEVs and FCEVs
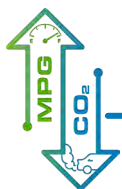
H. Authors and Acknowledgments

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