The 2018 EPA Automotive Trends Report:

Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975

MPG CO_2

United States Environmental Protection Agency

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

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1. Introduction

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

EPA has collected data on every new light-duty vehicle model sold in the United States since 1975, either from testing performed by EPA at the National Vehicle Fuel and Emissions Laboratory in Ann Arbor, Michigan, or directly from manufacturers using official EPA test procedures. These data are collected to support several important national programs, including EPA criteria pollutant and GHG standards, the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) Corporate Average Fuel Economy (CAFE) standards, and vehicle Fuel Economy and Environment labels. These data comprise the most comprehensive database of its kind. The analysis and data drawn from this extensive resource are presented here to provide as much information to the public as possible.

A. What's New This Year

- This report includes content previously included in two separate EPA reports, the *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report* and the *Greenhouse Gas Emission Standards for Light-Duty Vehicles Manufacturer Performance Report*. These reports were combined to provide a more comprehensive analysis in a single resource.
- 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. We encourage readers to visit our website at https://www.epa.gov/automotive-trends and explore the data. EPA plans to continue to add content and tools on the web to allow transparent access to public data.
- In 2016, Nissan purchased a controlling share of Mitsubishi. Based on this change, NHTSA took initial action requiring Nissan and Mitsubishi to be combined into a single corporate entity for compliance under the CAFE program (which EPA would follow for the GHG program). Consequently, all Nissan and Mitsubishi data are combined in this report as "Nissan-Mitsubishi," except where necessary to maintain the integrity of historical compliance data. However, this process is not yet complete. If, in fact,

Nissan and Mitsubishi are treated differently for compliance in the 2017 model year, EPA will revise this report to reflect that policy.

The overall long-term trends in the light-duty automotive industry since 1975 are explored in Section 2. Section 3 focuses on trends in vehicle parameters such as vehicle type, weight, horsepower, acceleration, and footprint. Section 4 examines industry trends by engine and transmission technologies. The status of manufacturer compliance with the GHG standards is now included in Section 5. Additional data and methodology discussions are included in the appendices. This report supersedes all previous reports and should not be compared to past reports.

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 the model year 2017 manufacturer definitions determined by EPA and NHTSA for implementation of the GHG emission standards and CAFE program. For simplicity, many tables throughout the report show only the 13 manufacturers that produced at least 150,000 vehicles in the 2017 model year. These manufacturers account for approximately 98% of all production. Table 1.1 lists the 13 manufacturers and their associated makes, along with an "other" category that captures the remaining manufacturers.

Table 1.1. Manufacturer Definitions

Manufacturer	Makes in the U.S. Market
BMW	BMW, Mini, Rolls Royce
FCA	Alfa Romeo, Chrysler, Dodge, Fiat, Jeep, Maserati, Ram
Ford	Ford, Lincoln, Roush, Shelby
GM	Buick, Cadillac, Chevrolet, GMC
Honda	Acura, Honda
Hyundai	Genesis, Hyundai
Kia	Kia
Mazda	Mazda
Mercedes	Maybach, Mercedes, Smart
Nissan-Mitsubishi	Infiniti, Mitsubishi, Nissan
Subaru	Subaru
Toyota	Lexus, Scion, Toyota
Volkswagen	Audi, Bentley, Bugatti, Lamborghini, Porsche, Volkswagen
Other[1]	Aston Martin, BYD, Ferrari, Jaguar, Land Rover, Lotus, McLaren, Tesla, Volvo

[1] Only vehicle brands produced in model year 2017 are shown. There are many other manufacturers and brands captured in the "other" category over the course of this report.

When a manufacturer grouping changes under the GHG and CAFE programs, EPA makes the same change in this report. For the analysis of estimated real-word CO_2 emission and fuel economy trends in Sections 1 through 4, EPA applies the current manufacturer definitions to all prior model years. 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.

C. Fuel Economy and CO_2 Metrics in this Report

This report presents current and historic data that provide a comprehensive overview of the automotive industry. The report does not examine future model years, and past performance does not necessarily predict future industry trends. All data for model years 1975 through 2017 are **final** and based on official data submitted to EPA and NHTSA as part of the regulatory process. In some cases (not for manufacturer compliance), this report will show data for model year 2018, which are **preliminary** and based on data provided to EPA by automakers prior to the model year. All data in this report are based on production volumes delivered for sale in the U.S. by model year (MY). The model year production volumes may vary from other publicized data based on calendar year sales.

The 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 demonstrating compliance with CAFE. For consistency, EPA also adopted these tests for the GHG regulations. 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 credits and other flexibilities that manufacturers can use towards meeting their emissions standards.

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

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

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

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

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

2. Fleetwide Trends Overview

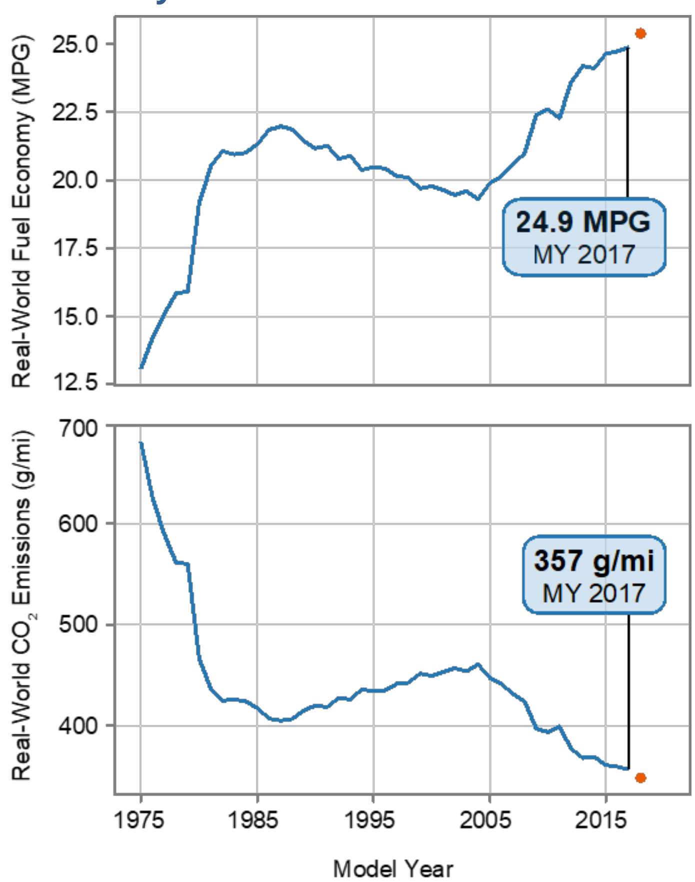
The automotive industry has made strong progress towards lower tailpipe CO_2 emissions and higher fuel economy in recent years. This section provides an update on the estimated real-world tailpipe CO_2 emissions and fuel economy for the overall fleet, and for manufacturers based on final model year 2017 data. The unique, historical data on which this report is based also provide an important backdrop for evaluating the more recent performance of the industry. Using that data, this section will also explore basic fleetwide trends in the automotive industry since EPA began collecting data in model year 1975.

A. Overall Fuel Economy and CO_2 Trends

In model year 2017, the industry achieved record low new vehicle CO_2 emissions and record high fuel economy, as shown in Figure 2.1. Average estimated real-world CO_2 tailpipe emissions fell by 3 g/mi to 357 g/mi, while estimated real-world fuel economy increased 0.2 mpg to 24.9 mpg compared to the previous year.[2] Over the last thirteen years, CO_2 emissions and fuel economy have improved eleven times and worsened twice.

The preliminary average estimated real-world fuel economy of all new model year 2018 vehicles is projected to increase again, to 25.4 mpg with corresponding average CO_2 emissions of 348 g/mi. If achieved, these values will be record levels and an improvement over model year 2017.

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



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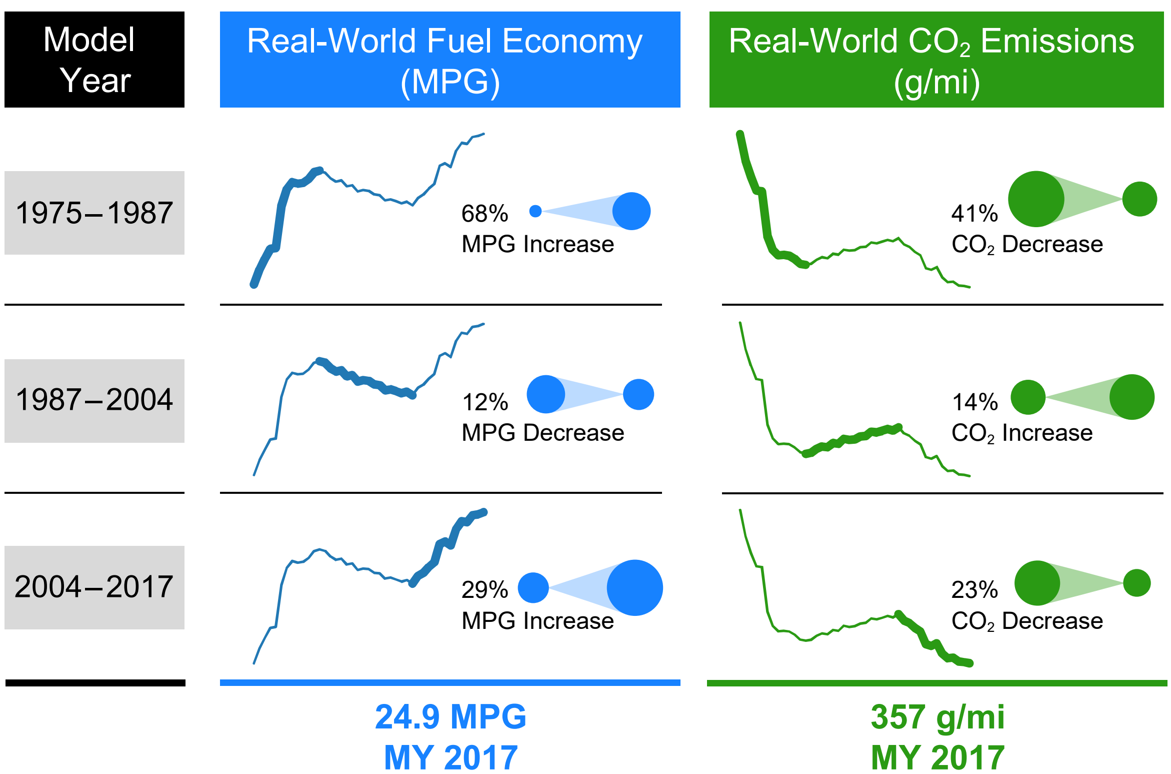
[2] EPA uses unrounded values to calculate all values in the text, figures, and tables in this report. This approach results in the most accurate data but may lead to small apparent discrepancies due to rounding. However, the data are in fact correct.

The preliminary model year 2018 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.

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 1975–2017. Over this timeframe there have been three basic phases: 1) a rapid improvement of fuel economy between 1975 and 1987, 2) a period of slowly decreasing fuel economy through 2004, and 3) increasing fuel economy through the current model year. Vehicle CO_2 emissions, which are generally inversely related to fuel economy,[3] have followed the opposite pattern over the same timeframe.

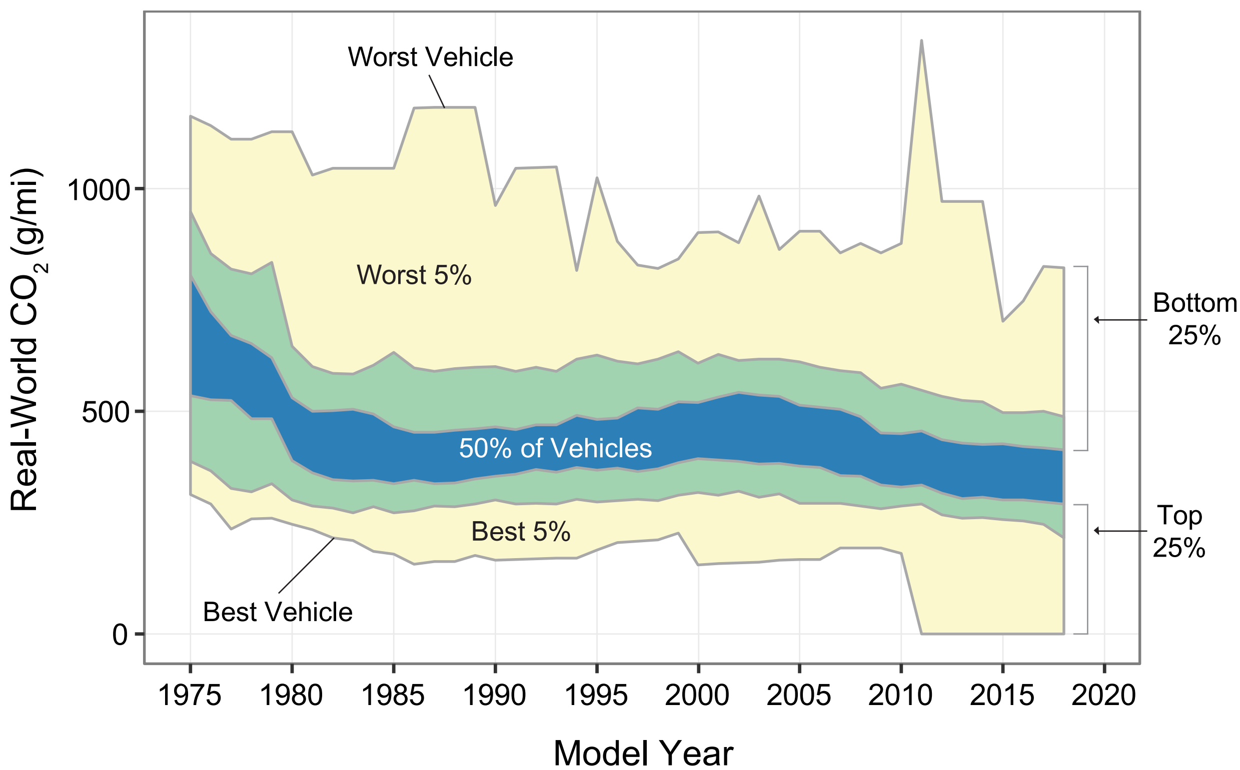
Figure 2.2. Trends in Fuel Economy and CO_2 Emissions Since Model Year 1975



[3] Fuel economy and CO_2 emissions are inversely related for gasoline and diesel vehicles, but not for electric vehicles (which have zero tailpipe emissions). If electric vehicles begin to capture a larger market share, the overall relationship between fuel economy and tailpipe CO_2 emissions will change.

Another way to look at CO_2 emissions over time is to examine how the distribution has changed. Figure 2.3 shows the production-weighted distribution of estimated real-world CO_2 emissions by model year. Since 1975, half of the total vehicle production for each model year has been within a narrow band of about 120 g/mi, or less than 10 miles per gallon. For model year 2018, that band, encompassing more than 50% of all production, spans from about 300–415 g/mi or 20–30 miles per gallon. The lowest CO_2-emitting vehicles have all been hybrids or electric vehicles since the first hybrid was introduced in model year 2000.

Figure 2.3. Distribution of New Vehicle CO_2 Emissions by Model Year[4]



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. For example, the estimated real-world fuel economy for a 1980s vehicle in the Trends database is somewhat higher than it would be if the same vehicle were being produced today as the methodology for calculating these values has changed over time to reflect estimated real-world vehicle operation. These changes are small for most vehicles, but larger for very high fuel economy

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

vehicles. See Appendix C and D for a detailed explanation of fuel economy metrics and their changes over time.

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

B. Manufacturer Fuel Economy and CO_2 Emissions

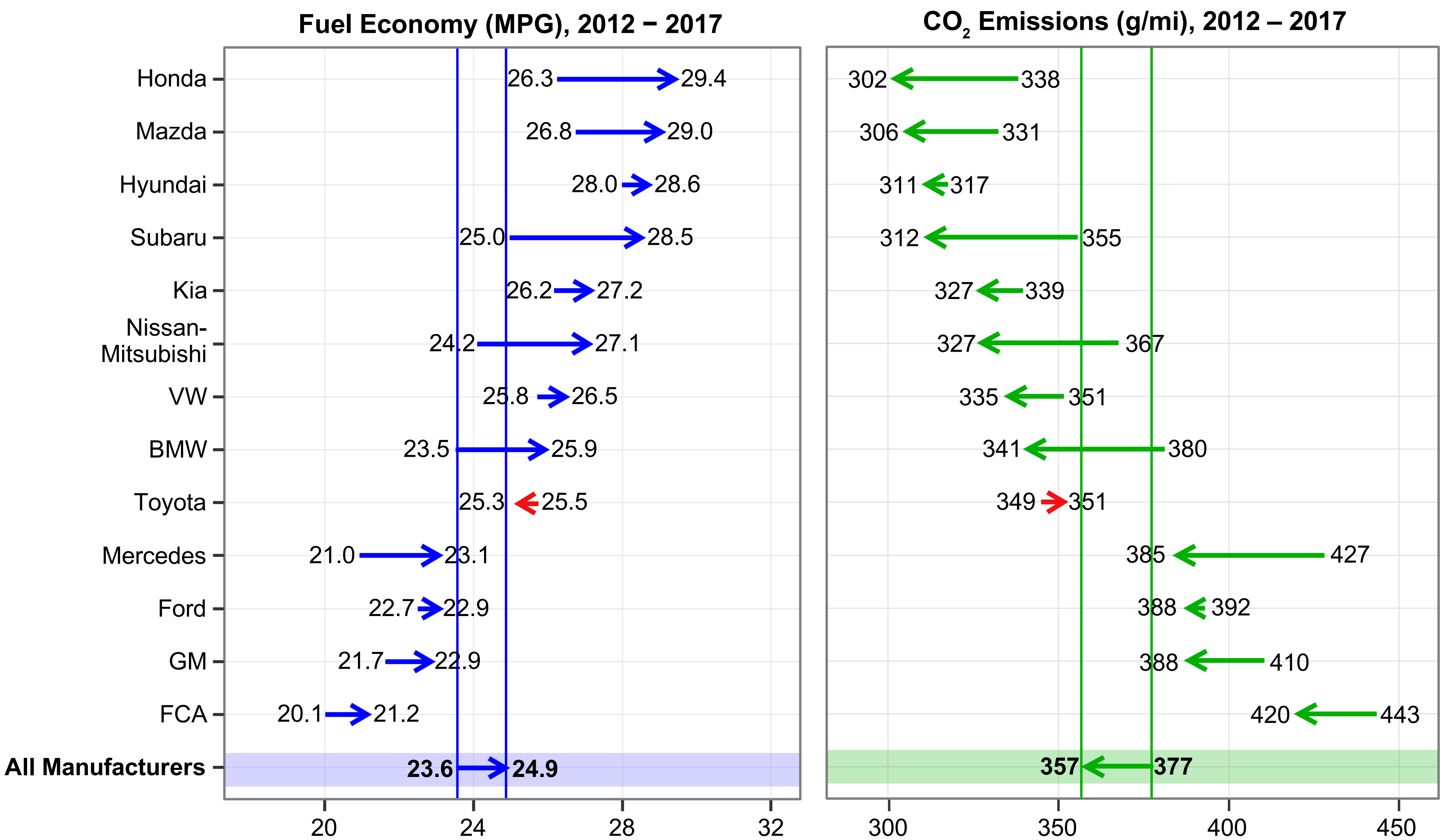
Along with the overall industry, most manufacturers have significantly improved new vehicle CO_2 emissions and fuel economy in recent years. Figure 2.4 shows the change in fuel economy and CO_2 emissions from model year 2012 to model year 2017 for the thirteen largest manufacturers. This five-year span covers the model years for which the combined EPA GHG and NHTSA CAFE regulations have been in place. It also approximately represents a redesign cycle, or the amount of time before a vehicle is significantly updated, so it is likely that most vehicles have undergone design changes in this period.

Of these thirteen manufacturers, all except for Toyota improved CO_2 emissions and fuel economy. Subaru had the largest decrease in CO_2 emissions during this period, reducing emissions by 43 g/mi. Mercedes had the next largest reduction at 42 g/mi, followed by Nissan-Mitsubishi at 40 g/mi. Subaru also had the largest improvement in fuel economy at 3.5 mpg, followed by Honda at 3.1 mpg and Nissan-Mitsubishi at 2.9 mpg. Overall, the industry improved CO_2 emissions by 21 g/mi (about 5%) and fuel economy by 1.3 mpg (about 6%) between model year 2012 and 2017.

In model year 2017, Honda led the industry overall with the lowest average new vehicle CO_2 emissions and highest fuel economy. Honda also improved more than any other manufacturer in model year 2017, decreasing new vehicle CO_2 emissions by 13 g/mi to 302 g/mi, and increasing fuel economy by 1.2 mpg to 29.4 mpg. Mazda and Hyundai had the second and third lowest CO_2 emissions, respectively. FCA had the highest new vehicle average CO_2 emissions and lowest fuel economy of the large manufacturers, followed by GM and Ford.

Seven of the thirteen manufacturers increased fuel economy and decreased CO_2 between model year 2016 and 2017. The preliminary model year 2018 data project a similar trend, with seven of thirteen manufacturers improving. The manufacturer-specific data for the last three model years are shown in Table 2.2.

Figure 2.4. Manufacturer Estimated Real-World Fuel Economy and CO_2 in Model Year 2012 and 2017



While each manufacturer has taken a different path towards improving CO_2 emissions and fuel economy, the overall result has driven the improving industry-wide trend since model year 2005. The vehicle attributes and technologies that have led to this improvement are further analyzed in the next two sections of this report, respectively.

The Department of Justice and EPA have reached settlements with Volkswagen and Fiat Chrysler Automobiles based on the sale of certain diesel vehicles equipped with devices to defeat the vehicles' emission control systems. This report includes the original fuel economy and GHG certification values of these vehicles, as EPA believes this is a reasonable representation of how these vehicles were expected to perform. The affected vehicles are certain model year 2009 to 2016 diesel vehicles from Volkswagen and 2014 to 2016 diesel vehicles from Fiat Chrysler Automobiles, and account for less than 1% of production in all affected years. For more information about these investigations, please see https://www.epa.gov/vw or https://www.epa.gov/fca.

Table 2.1. Estimated Real-World CO_2, Fuel Economy and Key Parameters

Model Year	Production (000)	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Mfr. with Highest Fuel Economy (mpg)	Mfr. with Lowest Fuel Economy (mpg)	Overall Vehicle with Highest Fuel Economy[5]			Gasoline (Non-Hybrid) Vehicle with Highest Fuel Economy	
						Vehicle	Real-World FE (mpg)	Engine Type	Gasoline Vehicle	Real-World FE (mpg)
1975	10,224	681	13.1	Honda	Ford	Honda Civic	28.3	Gas	Honda Civic	28.3
1980	11,306	466	19.2	VW	Ford	VW Rabbit	40.3	Diesel	Nissan 210	36.1
1985	14,460	417	21.3	Honda	Mercedes	GM Sprint	49.6	Gas	GM Sprint	49.6
1990	12,615	420	21.2	Hyundai	Mercedes	GM Metro	53.4	Gas	GM Metro	53.4
1995	15,145	434	20.5	Honda	FCA	Honda Civic	47.3	Gas	Honda Civic	47.3
2000	16,571	450	19.8	Hyundai	FCA	Honda Insight	57.4	Hybrid	GM Metro	39.4
2001	15,605	453	19.6	Hyundai	FCA	Honda Insight	56.3	Hybrid	Honda Civic	37.3
2002	16,115	457	19.5	Honda	FCA	Honda Insight	55.6	Hybrid	Honda Civic	35.9
2003	15,773	454	19.6	Honda	Ford	Honda Insight	55.0	Hybrid	Honda Civic	35.5
2004	15,709	461	19.3	Honda	Ford	Honda Insight	53.5	Hybrid	Honda Civic	35.3
2005	15,892	447	19.9	Honda	Ford	Honda Insight	53.3	Hybrid	Honda Civic	35.1
2006	15,104	442	20.1	Mazda	Ford	Honda Insight	53.0	Hybrid	Toyota Corolla	32.3
2007	15,276	431	20.6	Toyota	Mercedes	Toyota Prius	46.2	Hybrid	Toyota Yaris	32.6
2008	13,898	424	21.0	Hyundai	Mercedes	Toyota Prius	46.2	Hybrid	Smart Fortwo	37.1
2009	9,316	397	22.4	Toyota	FCA	Toyota Prius	46.2	Hybrid	Smart Fortwo	37.1
2010	11,116	394	22.6	Hyundai	Mercedes	Honda FCX	60.2	FCV	Smart Fortwo	36.8
2011	12,018	399	22.3	Hyundai	Mercedes	BMW Active E	100.6	EV	Smart Fortwo	35.7
2012	13,449	377	23.6	Hyundai	FCA	Nissan i-MiEV	109.0	EV	Toyota iQ	36.8
2013	15,198	368	24.2	Hyundai	FCA	Toyota IQ	117.0	EV	Toyota iQ	36.8
2014	15,512	369	24.1	Mazda	FCA	BMW I3	121.3	EV	Mitsubishi Mirage	39.5
2015	16,739	361	24.6	Mazda	FCA	BMW I4	121.3	EV	Mitsubishi Mirage	39.5
2016	16,267	359	24.7	Mazda	FCA	BMW I5	121.3	EV	Mazda Mazda 2	37.1
2017	17,011	357	24.9	Honda	FCA	Hyundai Ioniq	132.6	EV	Mitsubishi Mirage	41.5
2018 (prelim)	-	*348*	*25.4*	*Honda*	*FCA*	*Hyundai Ioniq*	*132.6*	*EV*	*Mitsubishi Mirage*	*40.1*

[5] 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 2.2. Manufacturer Estimated Real-World Fuel Economy and CO_2 Emissions for Model Year 2016–2018

	MY 2016 Final		MY 2017 Final				*MY 2018 Preliminary*	
Manufacturer	**Real-World FE (mpg)**	**Real-World CO_2 (g/mi)**	**Real-World FE (mpg)**	**FE Change from MY 2016 (mpg)**	**Real-World CO_2 (g/mi)**	**CO_2 Change from MY 2016 (g/mi)**	***Real-World FE (mpg)***	***Real-World CO_2 (g/mi)***
BMW	25.5	349	25.9	0.4	341	-7	*26.2*	*336*
FCA	21.5	413	21.2	-0.4	420	7	*21.9*	*406*
Ford	22.8	389	22.9	0.0	388	-1	*22.7*	*392*
GM	22.4	397	22.9	0.5	388	-8	*23.3*	*380*
Honda	28.2	315	29.4	1.2	302	-13	*29.5*	*300*
Hyundai	28.8	309	28.6	-0.2	311	2	*27.9*	*318*
Kia	26.2	338	27.2	0.9	327	-11	*27.7*	*319*
Mazda	29.6	301	29.0	-0.5	306	5	*28.7*	*312*
Mercedes	23.7	376	23.1	-0.6	385	9	*23.7*	*374*
Nissan-Mitsubishi	27.8	318	27.1	-0.7	327	9	*26.8*	*329*
Subaru	28.1	317	28.5	0.4	312	-5	*28.4*	*313*
Toyota	25.0	355	25.3	0.3	351	-4	*26.0*	*341*
VW	26.6	334	26.5	-0.2	335	2	*25.1*	*353*
All Manufacturers	**24.7**	**359**	**24.9**	**0.2**	**357**	**-3**	***25.4***	***348***

3. Vehicle Attributes

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

A. Vehicle Class and Type

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

Pickup trucks, vans, and minivans are all considered trucks under the regulatory definitions, while sedans, coupes, and wagons are generally classified as cars. Sport utility vehicles (SUVs) however, fall into both categories. Based on the CAFE and GHG regulatory definitions, all two-wheel drive SUVs under 6,000 pounds GVW are classified as cars, while most SUVs that have four-wheel drive or are above 6,000 pounds GVW are considered trucks. SUV models that are less than 6,000 pounds GVW can have both car and truck variants, with two-wheel drive versions classified as cars and four-wheel drive versions classified as trucks.

As the fleet has changed over time, the line drawn between car and truck classes has also evolved. This report uses the current regulatory car and truck definitions, and these changes have been propagated back throughout the historical data.

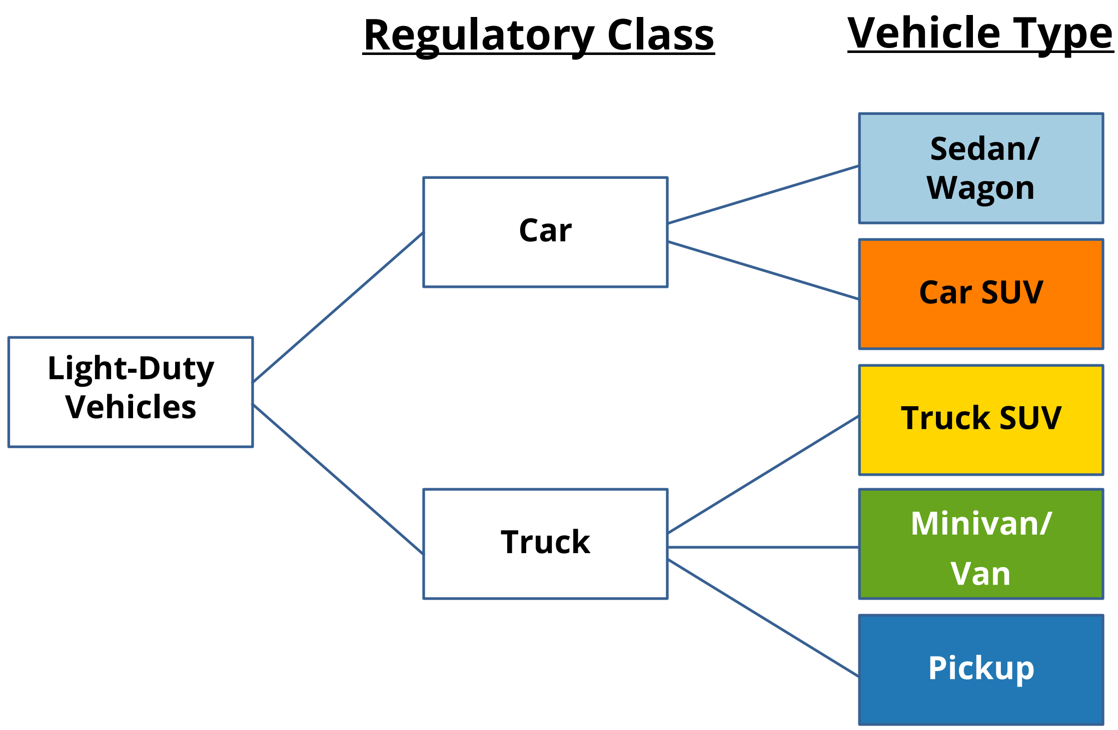
This report further separates the car and truck regulatory classes into five vehicle type categories based on their body style classifications under the fuel economy labeling program. The regulatory car class is divided into two vehicle types: sedan/wagon and car SUV. The sedan/wagon vehicle type includes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

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

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, including 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 for model years 1975-2017. In 1975, more than 80% of vehicles produced were sedans/wagons, with the remaining 20% made up mostly of pickups and vans. Pickups have remained relatively consistent over the timeframe of this report, and in model year 2017 represented 12% of vehicle production. Minivan and van production peaked in model year 1995, making up 11% of the market, but they have since fallen out of favor (down to 4% of market share) and are being replaced by SUVs. By model year 2017, truck SUVs reached a record high 32% of production and car SUVs remained at a record 12% of production. Sedans/wagons captured only 41% of the market, about half of the market share they held in model year 1975.

In model year 2017, 53% of the fleet are cars and 47% are trucks. This is a significant change from 1975, when 81% of all production was sedans/wagons. In Figure 3.2, the dashed line between the car SUVs and truck SUVs shows the split in car and truck regulatory class.

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

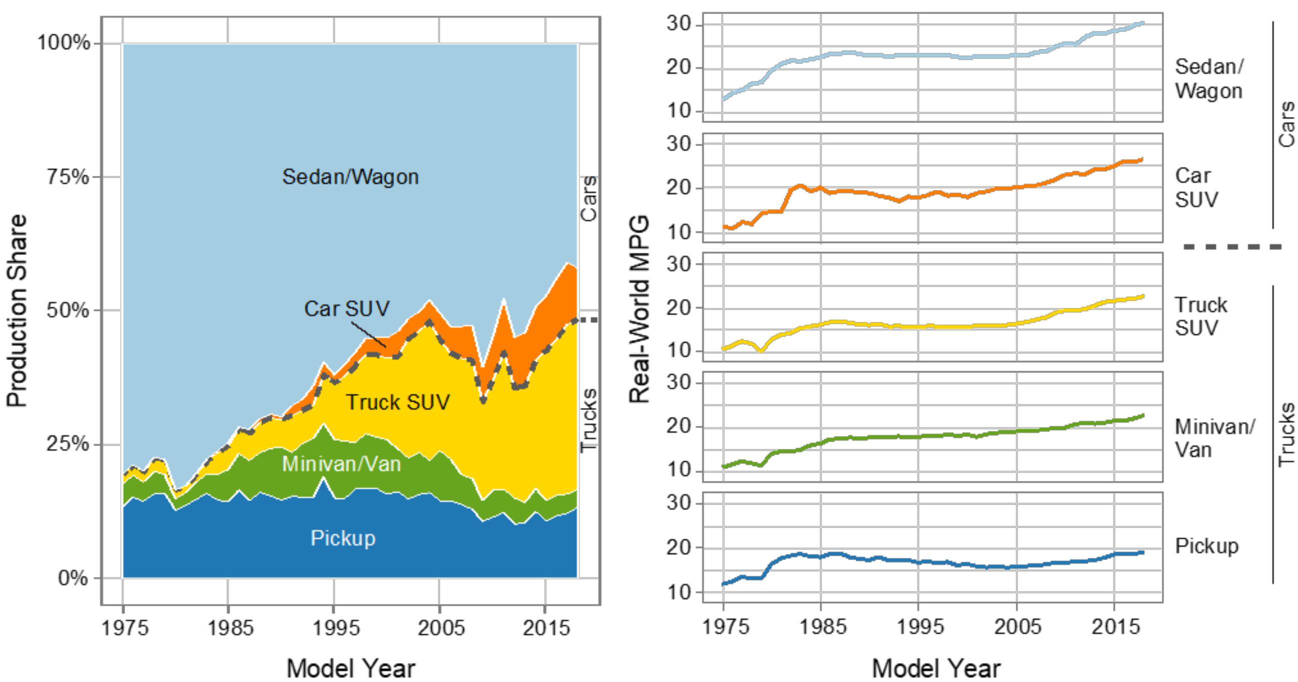


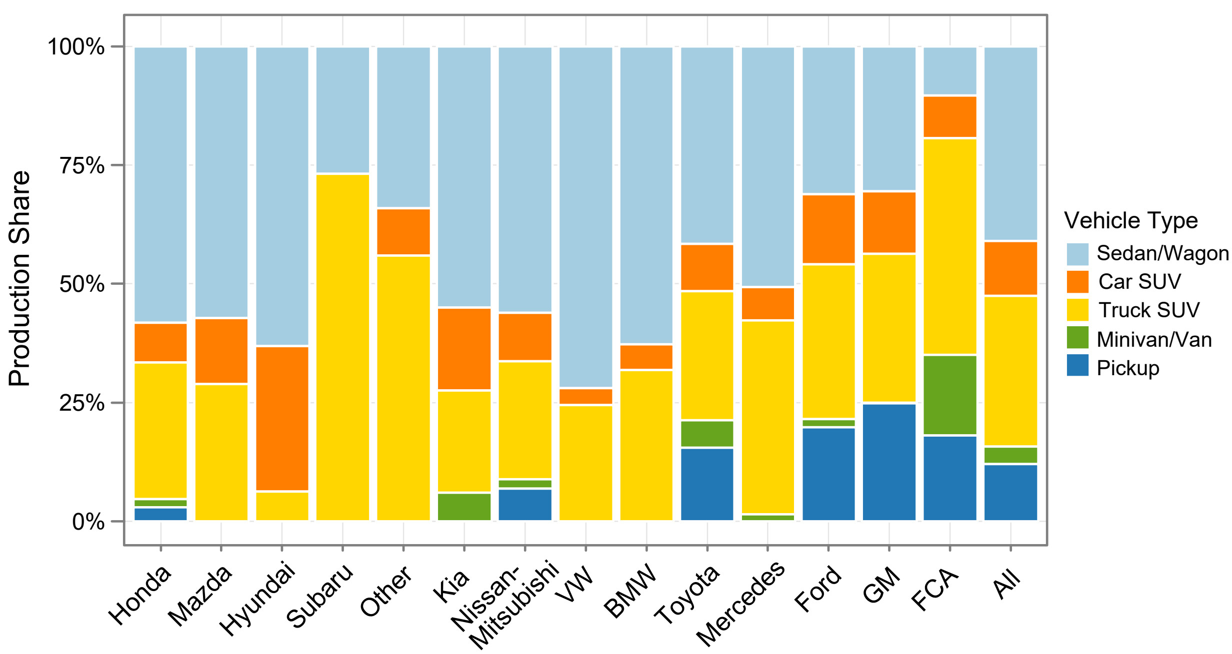
Figure 3.2 also shows estimated real-world fuel economy for each vehicle type since 1975. Fuel economy has improved for each of the five vehicle types for several years, and all are

at or near record fuel economy and CO_2 emissions levels in model year 2017. Sedans/wagons had the highest overall fuel economy, and the biggest year-over-year improvement in model year 2017. With a 1 mpg increase, new sedans/wagons achieved over 30 mpg for the first time in history, more than double the 13.5 mpg average in model year 1975. The fuel economy of car SUVs remained at a record 26.2 mpg. Truck SUVs increased 0.1 mpg to a record 22.4 mpg, minivans/vans increased 0.6 mpg to 22.2 mpg, and pickups held constant near a record high at 18.9 mpg. In the preliminary model year 2018 data, all five vehicle types are expected to further improve fuel economy by 0.4 to 0.7 mpg.

Vehicle Type by Manufacturer

The model year 2017 production breakdown by vehicle type for each manufacturer is shown in Figure 3.3. There are clear variations in production distribution by manufacturer. Over 70% of VW's production was sedans/wagons, which is the highest of any manufacturer. For other vehicle types, Hyundai had the highest percentage of car SUVs at 31%, Subaru had the highest percentage of truck SUVs at 73%, GM had the highest percentage of pickups at 25%, and FCA had the highest percentage of minivan/vans at 17%.

Figure 3.3. Vehicle Type Distribution by Manufacturer for Model Year 2017



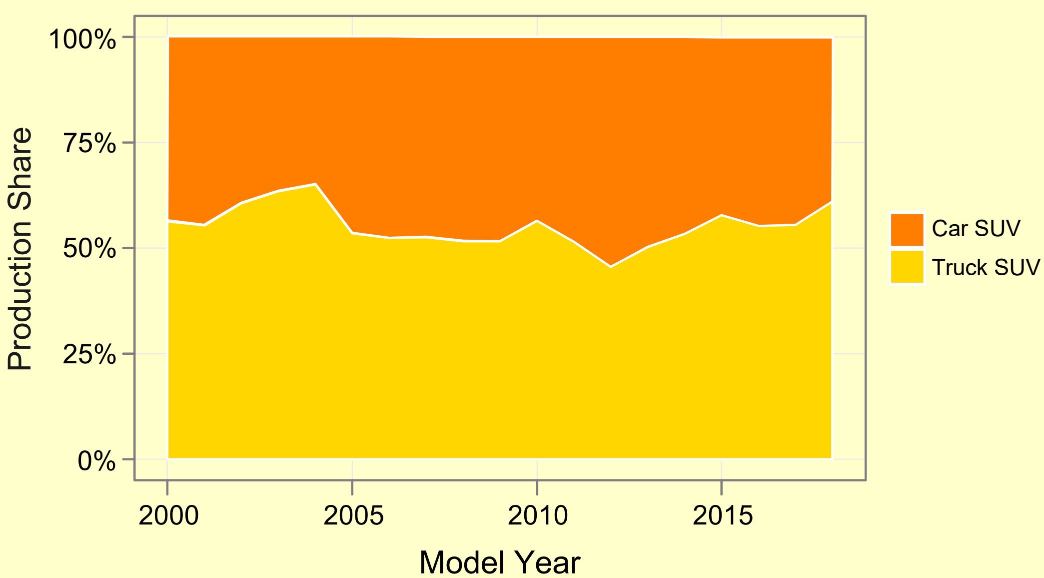
SUV Classification

Over the last 30 years, the production share of SUVs in the United States has increased in all but six years and now accounts for more than 40% of all vehicles produced (see Figure 3.2). This includes both the car and truck SUV vehicle types.

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

This report does not track GVW, but instead tracks weight using inertia weight classes, where inertia weight is the weight of the empty vehicle, plus 300 pounds (see weight discussion on the next page). Figure 3.4 shows the breakdown of SUVs into the car and truck categories over time for vehicles with an inertia weight of 4,000 pounds or less. Vehicles in the 4,500-pound inertia weight class and higher were excluded, as these vehicles generally exceed 6,000 pounds GVW and are classified as trucks. The relative percentage of SUVs with an inertia weight of 4,000 pounds or less that meet the current regulatory truck definition has stayed relatively constant over time, suggesting that there has not been a shift in vehicle design to make these vehicles fall into the car or truck regulatory category.

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



B. Vehicle Weight

Vehicle weight is a fundamental vehicle attribute, both because it can be related to utility functions such as vehicle size and features, and because higher weight, other things being equal, will increase CO_2 emissions and decrease fuel economy. All Trends vehicle weight data 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 from model year 1975 through 2018 for all new vehicles by vehicle type. From model year 1975 to 1981, average vehicle weight dropped 21%, from nearly 4,060 pounds per vehicle to about 3,200 pounds; this was likely driven by both increasing fuel economy standards (which, at the time, were universal standards, and not based on any type of vehicle attribute) and higher gasoline prices.

From model year 1981 to model year 2004, the trend reversed, and average new vehicle weight began to slowly but steadily climb. By model year 2004, average new vehicle weight had increased 28% and reached a new high at 4,111 pounds per vehicle, in part because of the increasing truck share. Since model year 2004, new vehicle weight has been relatively flat, although a new high was briefly reached in model year 2011, at 4,126 pounds. Average model year 2017 weight was 4,093, which is up 58 pounds from model year 2016. The preliminary model year 2018 data suggest that weight will be up 1 pound, or essentially unchanged.

In model year 1975, the average weight of each of the five vehicle types varied by only 215 pounds, or about 5% of the average new vehicle. However, by model year 2018 that range is expected to be about 1,650 pounds, or 40% of the average new vehicle weight. In 1975 the average new sedan/wagon outweighed the average new pickup by about 45 pounds, but by model year 2018 a new average pickup will outweigh the average new sedan/wagon by about 1,650 pounds. The weight of an average new sedan/wagon has fallen 13% since model year 1975, while the weight of an average new pickup has increased 29%. It is interesting to note that the average new pickup truck weight fell by 320 pounds in model

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

year 2015, which is the year the redesigned Ford F-150 changed to a largely aluminum body to reduce weight.

Figure 3.5. Average New Vehicle Weight by Vehicle Type

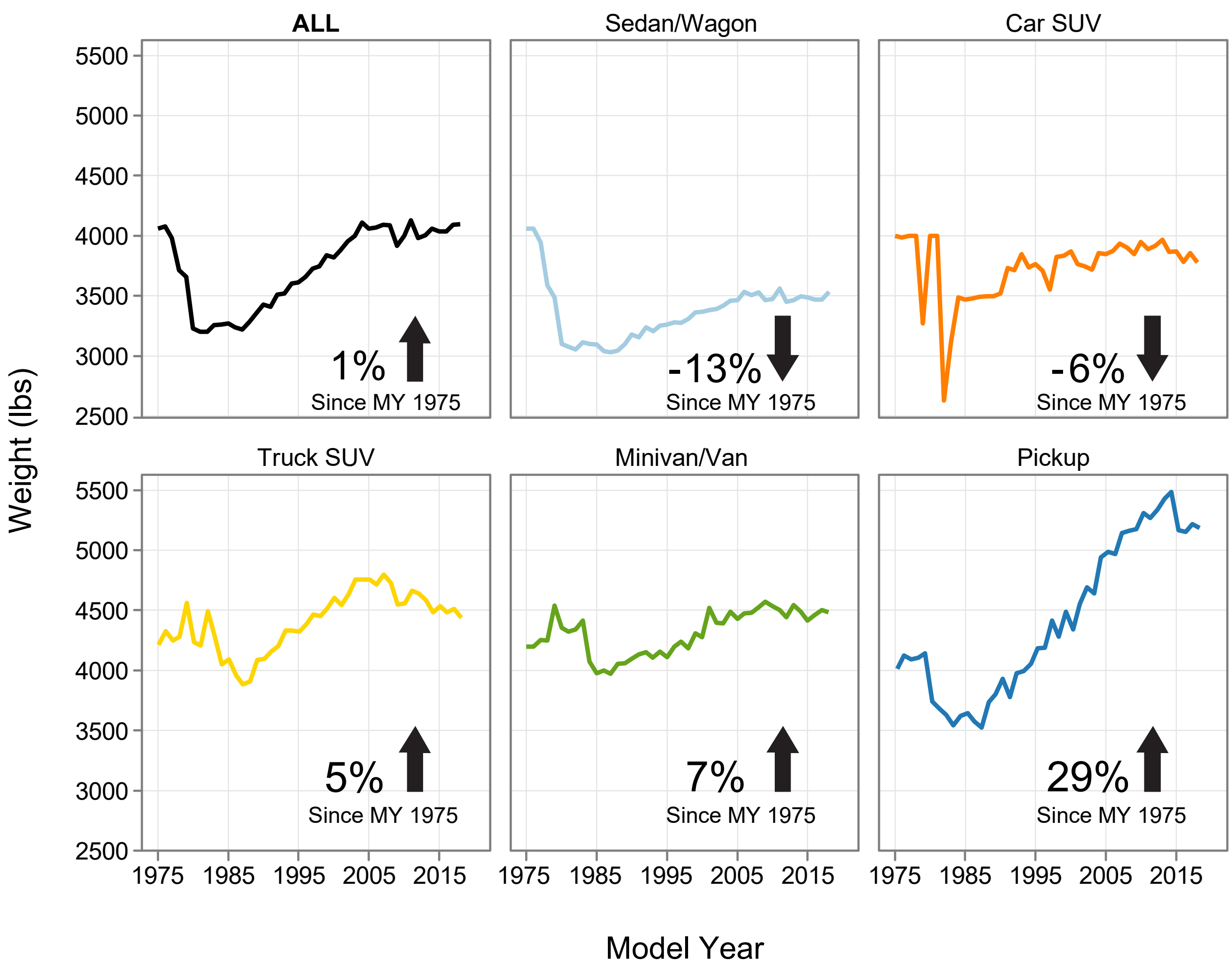
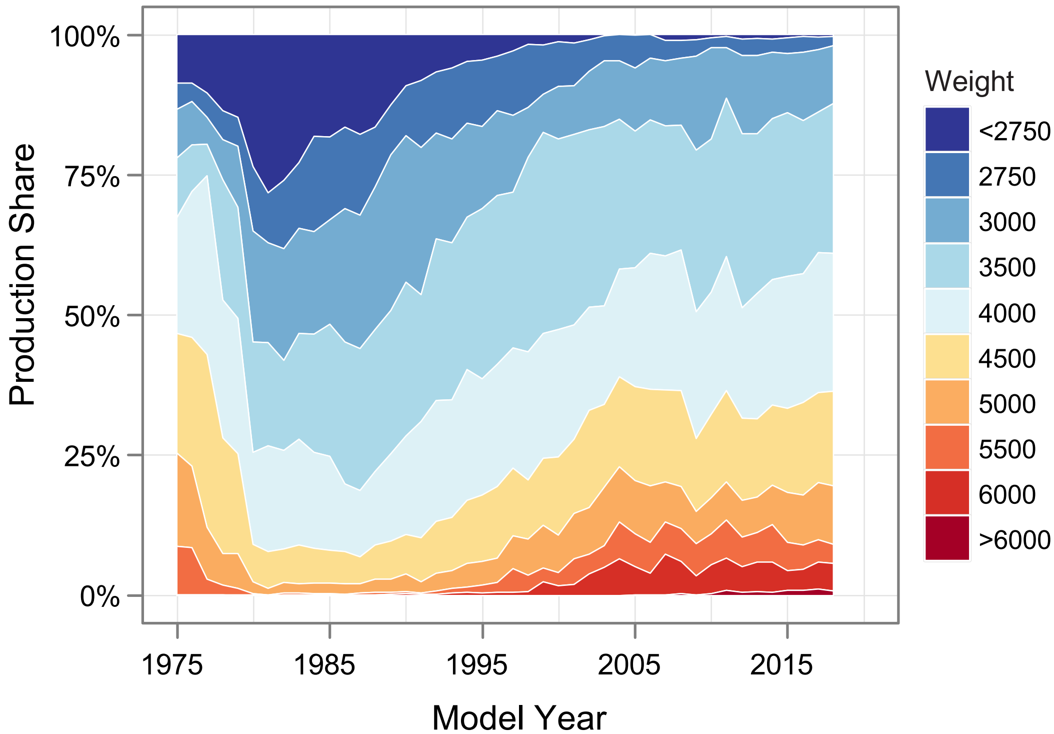


Figure 3.6 shows the annual production share of different inertia weight classes for new vehicles since model year 1975. In model year 1975 there were significant sales in all the weight classes from <2,750 pounds to 5,500 pounds. In the early 1980s the largest vehicles disappeared from the market and 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 in the 5,500-pound inertia weight class, whereas the heaviest vehicles today are all trucks.

Figure 3.6. Inertia Weight Class Distribution by Model Year



Vehicle Weight and CO_2 Emissions

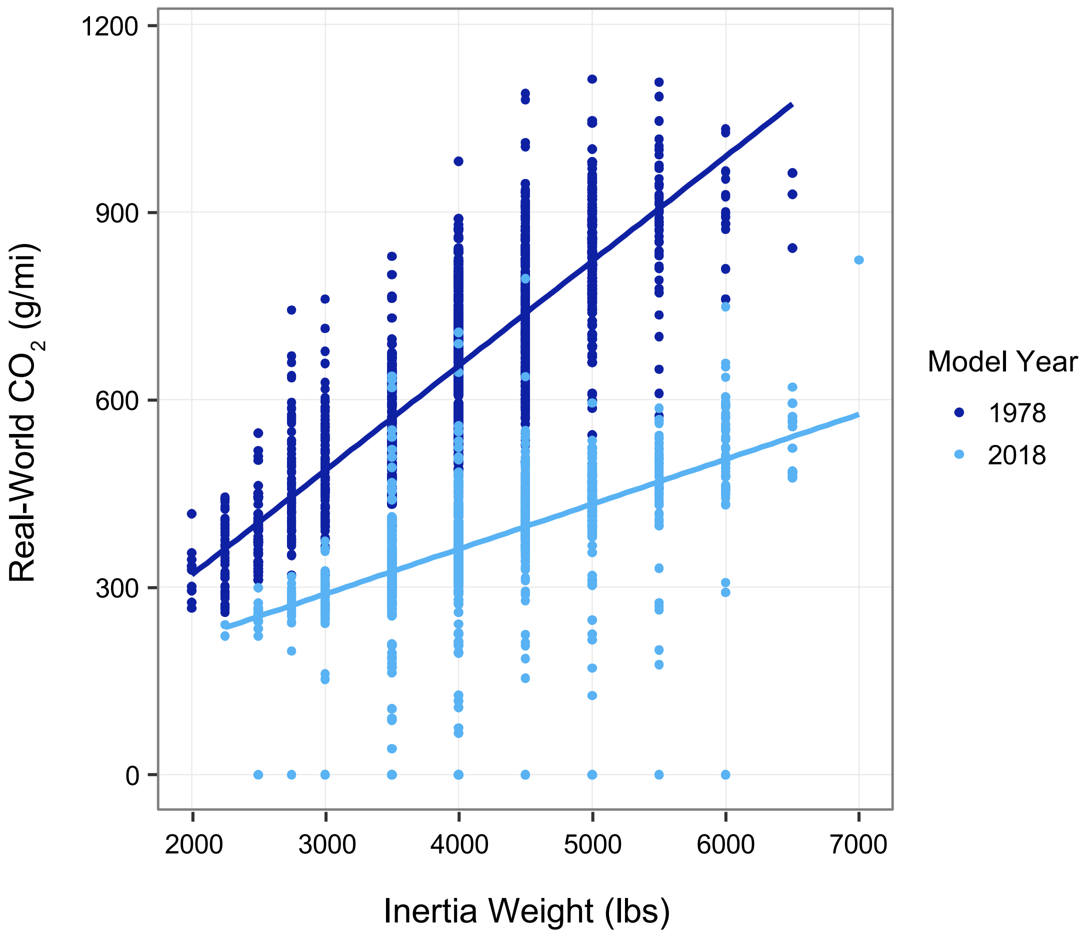
Heavier vehicles require more energy to move than lower-weight vehicles and, if all other factors are the same, will have lower fuel economy and higher CO_2 emissions. The wide array of technology available in modern vehicles complicates this comparison, but it is still useful to evaluate the relationship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

Figure 3.7 shows estimated real-world CO_2 emissions as a function of vehicle inertia weight for model year 1978[8] and model year 2018. On average, CO_2 emissions increase linearly with vehicle weight for both model years, although the rate of change as vehicles get heavier is different between model year 2018 and 1978. At lower weights, vehicles from model year 2018 produce about 33% lower CO_2 emissions than those from 1978. The difference between model year 2018 and 1978 increases for heavier vehicles, as the heaviest model year 2018 vehicles produce about 50% lower CO_2 emissions than those

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

from 1978. Electric vehicles, which do not produce any tailpipe CO_2 emissions regardless of weight, are visible along the 0 g/mi axis of Figure 3.7. As more electric vehicles are introduced into the market, the relationship between average vehicle CO_2 emissions and inertia weight will continue to evolve.

Figure 3.7. Relationship of Inertia Weight and CO_2 Emissions



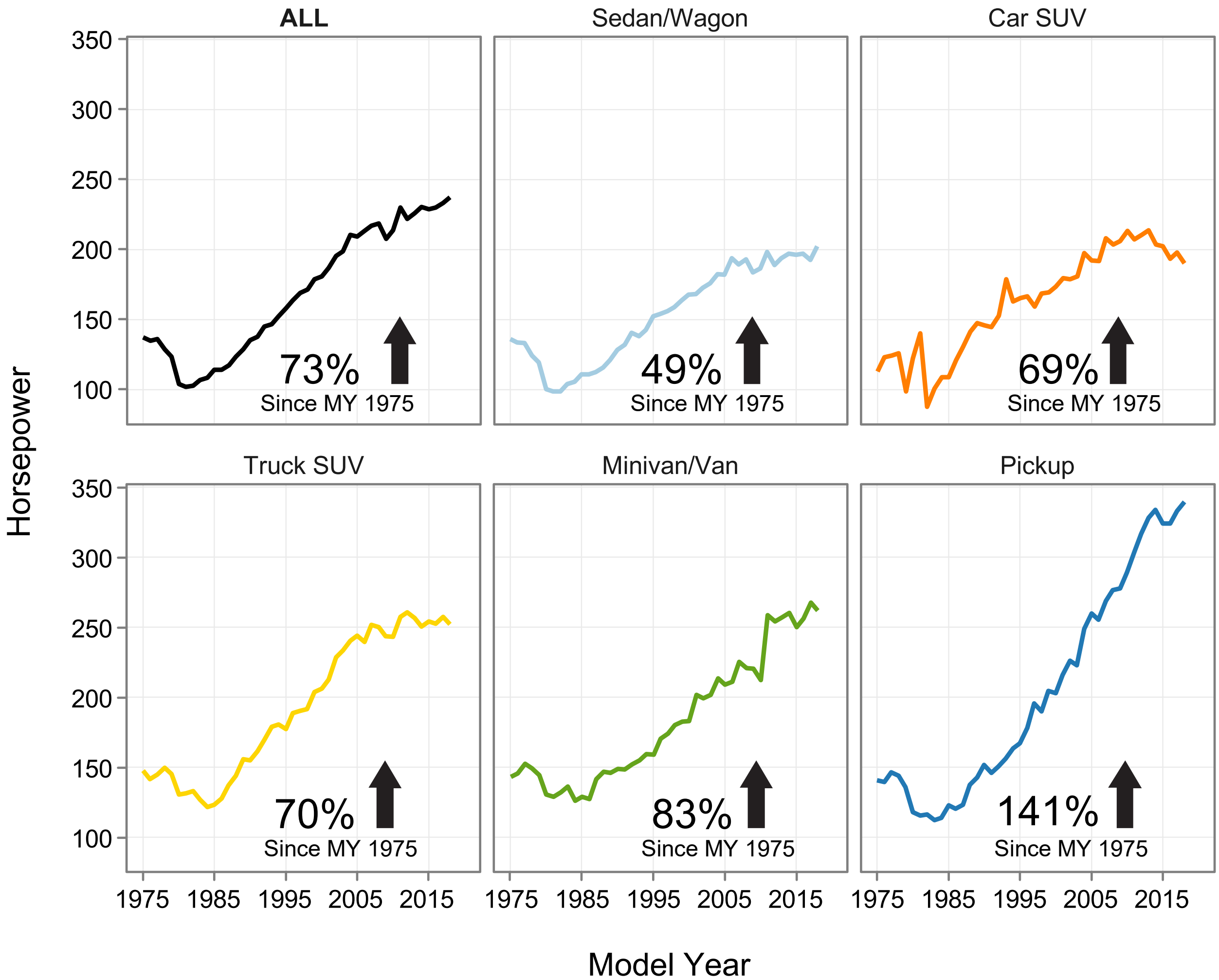
C. Vehicle Power

Vehicle power, measured in horsepower (HP), has changed dramatically since model year 1975. The average new vehicle in model year 2017 produced 70% more power than a new vehicle in model year 1975, and almost 130% more power than an average new vehicle in model year 1981. In the early years of this report, horsepower fell, from an average of 137 HP in model year 1975 to 102 HP in model year 1981. Since model year 1981 however, horsepower has increased nearly every year. The average new vehicle HP is at a record high, increasing from 230 HP in model year 2016 to 233 HP in model year 2017. The preliminary value for model year 2018 is 237 HP, which would be another record-high for horsepower.

Vehicle Power by Vehicle Type

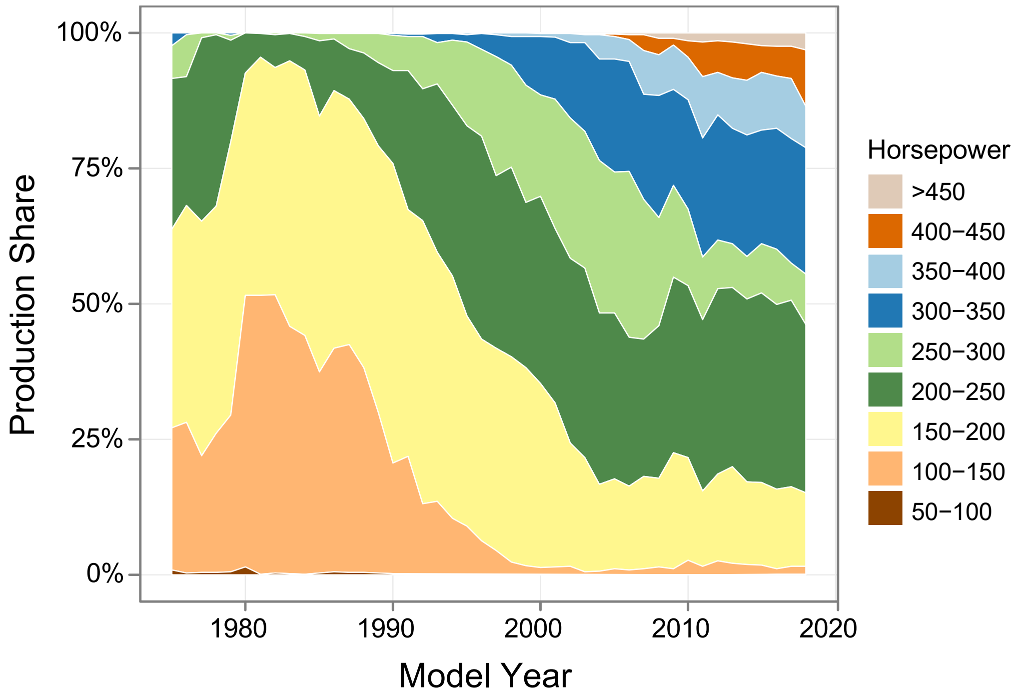
As with weight, the changes in horsepower are also quite different among vehicle types. The sedan/wagon, car SUV, and truck SUV categories have all had at least a 49% increase in horsepower since model year 1975, but horsepower in these vehicle types appears to be leveling off. However, pickup truck horsepower is up 141% since model year 1975 and does not appear to be slowing down. Horsepower for minivans/vans is up 83% and appears to still be increasing.

Figure 3.8. Average New Vehicle Horsepower by Vehicle Type



The distribution of horsepower over time has shifted significantly towards vehicles with more horsepower, as show in Figure 3.9. In the early 1980s, more than half of all new vehicles had 100 to 150 HP, and very few had more than 200 HP. The average model year 2018 vehicle is projected to have more than 230 HP, and very few vehicles have less than 150 HP. Vehicles with more than 300 HP are projected to make up about 40% of new vehicle production, and vehicles with more than 350 HP are projected to make up about 25% of new vehicle production. The maximum horsepower for an individual vehicle is now well over 1,000 HP.

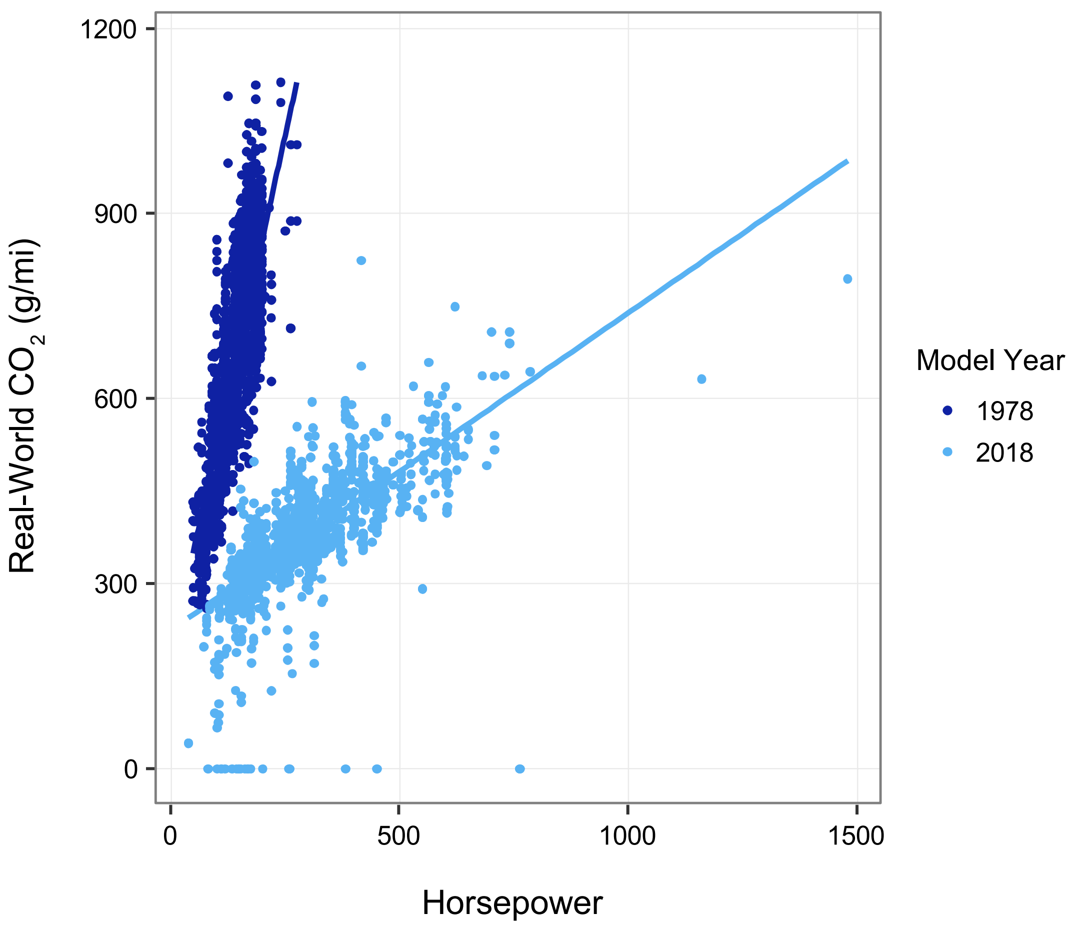
Figure 3.9. Horsepower Distribution by Model Year



Vehicle Power and CO_2 Emissions

The relationship between vehicle power, CO_2 emissions, and fuel economy has become more complex as new technology and vehicles have emerged in the marketplace. In the past, higher power generally increased CO_2 emissions and decreased fuel economy, especially when new vehicle production relied exclusively on gasoline and diesel internal combustion engines. As shown in Figure 3.10, model year 1978 vehicles with increased horsepower generally had increased CO_2 emissions. Model year 2018 vehicles nearly all have lower CO_2 emissions than their model year 1978 counterparts with the same amount of power. However, the relationship between horsepower and CO_2 emissions is different in model year 2018. As vehicle horsepower increases, so do CO_2 emissions but at a much-reduced rate compared to model year 1978. Technology improvements, including turbocharged engines and hybrid packages, have reduced the incremental CO_2 emissions associated with increased power. Electric vehicles are present along the 0 g/mi line in Figure 3.10 because they produce no tailpipe CO_2 emissions, regardless of horsepower, further complicating this analysis for modern vehicles.

Figure 3.10. Relationship of Horsepower and CO_2 Emissions



Vehicle Acceleration

Vehicle acceleration is closely related to vehicle horsepower. As new vehicles have increased horsepower, the corresponding ability of vehicles to accelerate has also increased. The most common vehicle acceleration metric, and one of the most recognized vehicle metrics overall, is the time it takes a vehicle to accelerate from 0 to 60 miles per hour, also called the 0-to-60 time. Data on 0-to-60 times are not directly submitted to EPA but are calculated for most vehicles using vehicle attributes and calculation methods developed by MacKenzie and Heywood (2012).[9] Data are obtained from external sources for hybrids and electric vehicles.

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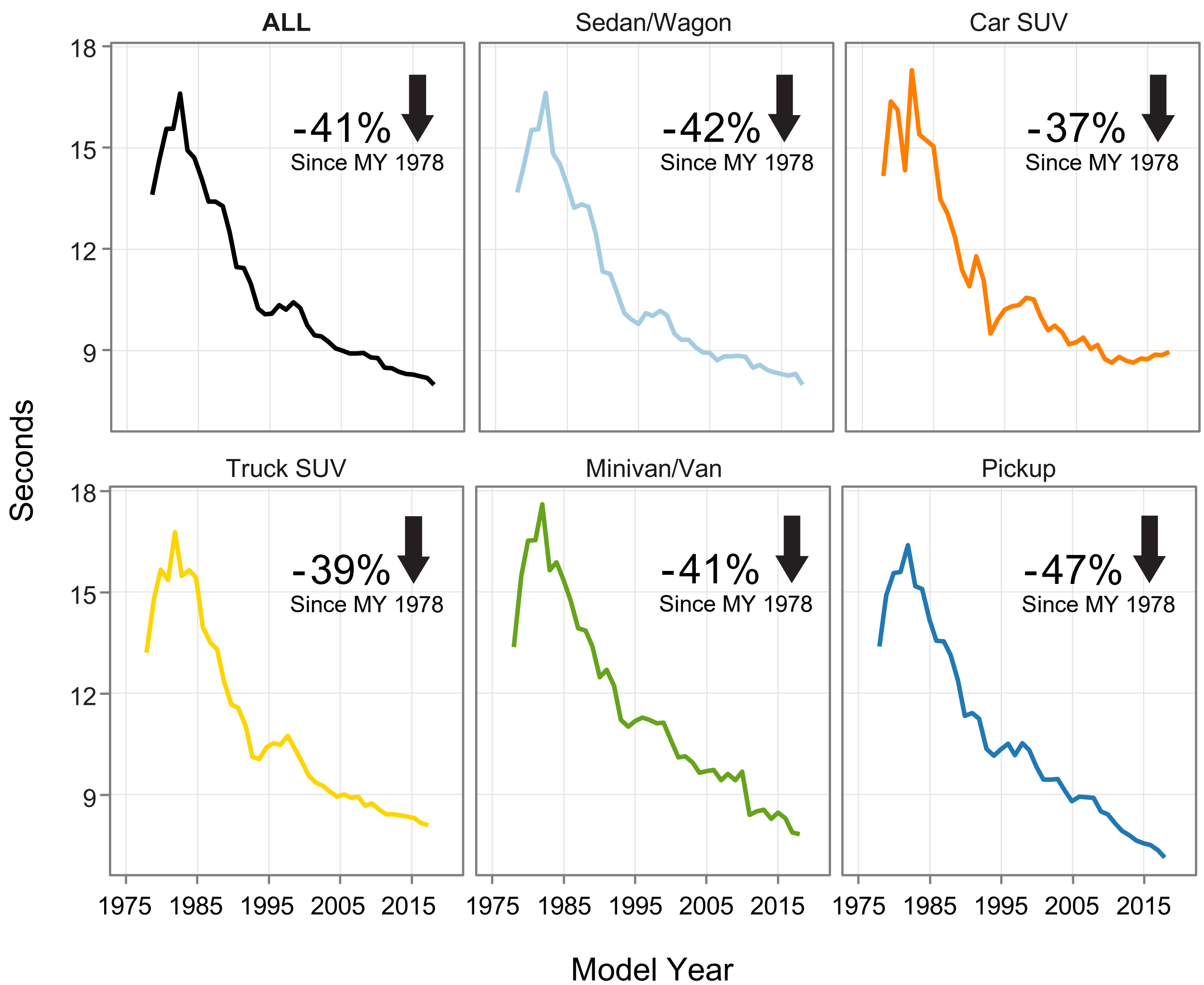
[9] MacKenzie, D. Heywood, J. 2012. Acceleration performance trends and the evolving relationship among power, weight, and acceleration in U.S. light-duty vehicles: A linear regression analysis. Transportation Research Board, Paper NO 12-1475, TRB 91st Annual Meeting, Washington, DC, January 2012.

Since the early 1980s, there has been a clear downward trend in 0-to-60 times. Figure 3.11 shows the average new vehicle 0-to-60 time from model year 1978 to model year 2018. The average new vehicle in model year 2018 is projected to have a 0-to-60 time of 8.0 seconds, which is the fastest average 0-to-60 time since the database began in 1975 and is approaching half of the average 0-to-60 times of the early 1980s.

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



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

D. Vehicle Footprint

Vehicle footprint is a very important attribute since it is the basis for the current CO_2 emissions and fuel economy standards. Footprint is the product of wheelbase times average track width (the area defined by where the centers of the tires touch the ground). This report provides footprint data beginning with model year 2008, though it is important to highlight that footprint data from model years 2008–2010 were aggregated from various sources, some independent of official automaker data, and EPA has less confidence in the consistency and precision of this 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 2017. EPA projects footprint data for the preliminary model year 2018 fleet based on footprint values for existing models from previous years and footprint values for new vehicle designs available through public sources.

Vehicle Footprint by Vehicle Type

Figure 3.12 shows overall new vehicle and vehicle type footprint data since model year 2008. Between model year 2008 and 2017, the overall average footprint increased 2%, from 48.9 to 49.8 square feet. The overall average is influenced by the trends within each vehicle type, as well as the mix of new vehicles produced and the market shift toward larger vehicles. Within each of the five vehicle types, footprint increased for all vehicle types between model year 2008 and 2017. Car SUVs increased 0.3 square feet (0.6%), truck SUVs increased 0.7 square feet (1.4%), sedan/wagons increased 0.9 square feet (2.1%), minivan/vans increased 1.5 square feet (2.8%), and pickups increased 1.8 square feet (2.8%). The distribution of footprints across all new vehicles, as shown in Figure 3.13, also shows only slight changes over time. More than 60% of all vehicles have footprints of 40–50 square feet. Projected data for model year 2018 show overall footprint will increase slightly to 50.0 square feet.

Figure 3.12. Footprint by Vehicle Type for Model Year 2008–2018

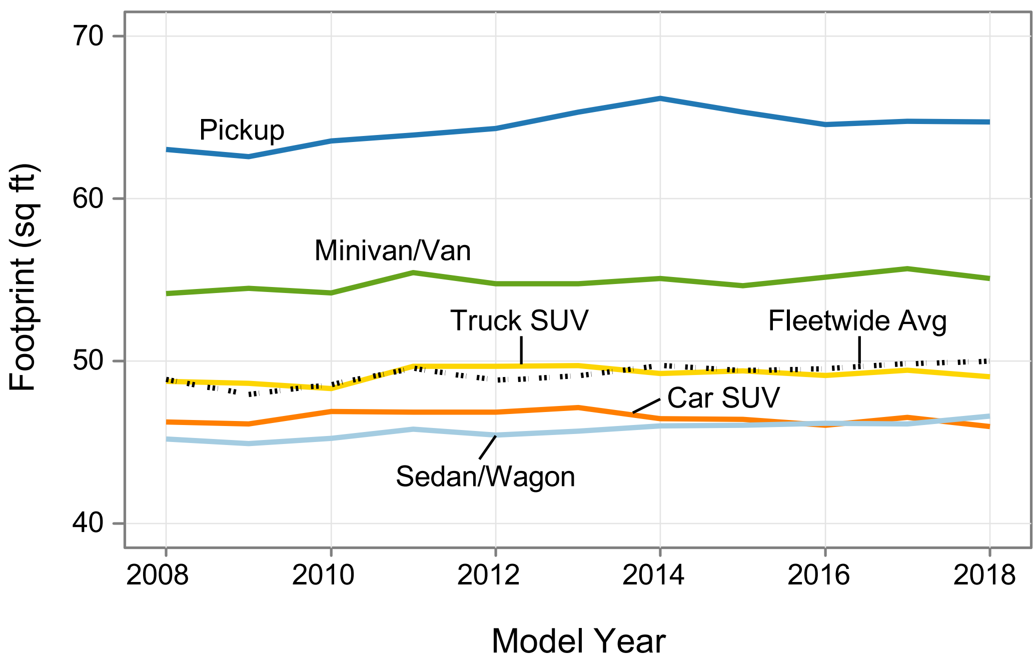
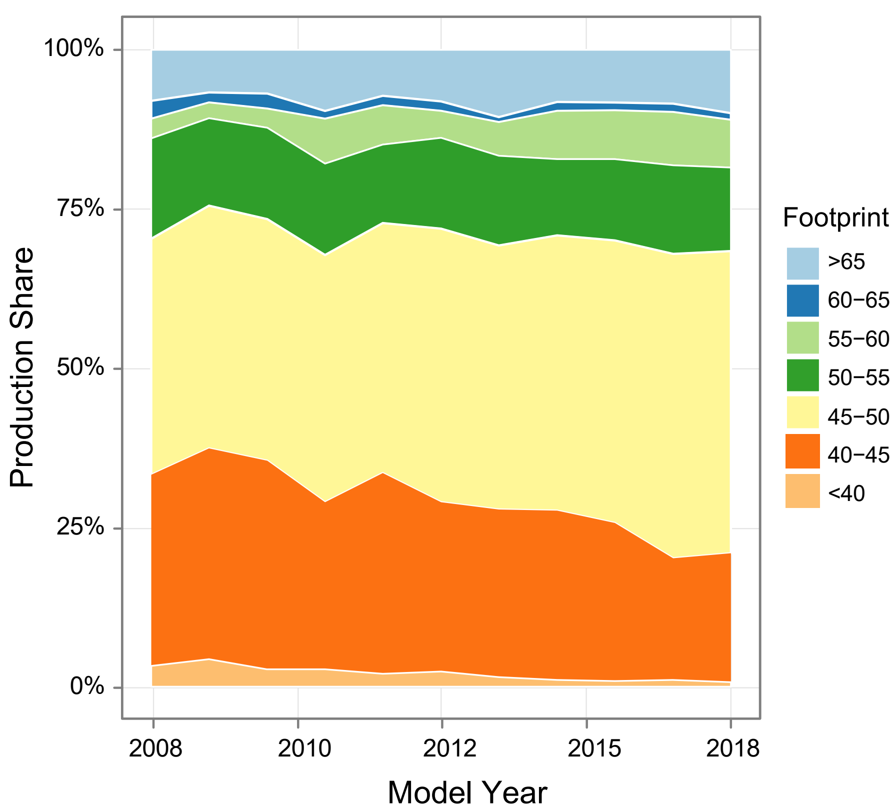


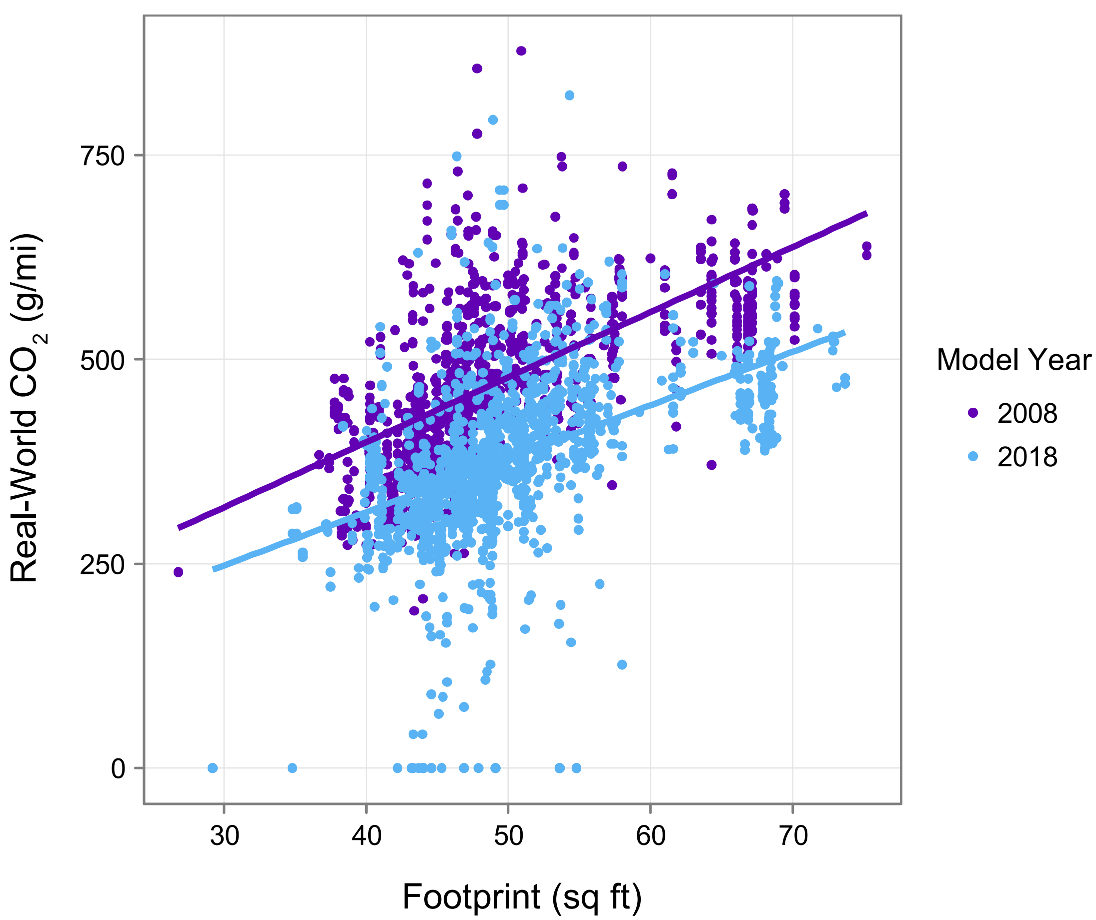
Figure 3.13. Footprint Distribution by Model Year



Vehicle Footprint and CO_2 Emissions

The relationship between vehicle footprint and CO_2 emissions is shown in Figure 3.14. Vehicles with a larger footprint are likely to weigh more and have more frontal area, which leads to increased aerodynamic resistance. Increased weight and aerodynamic resistance increases CO_2 emissions and decreases fuel economy. The general trend of increasing footprint and CO_2 emissions holds true for vehicles from model year 2008 and model year 2018, although vehicles produced in model year 2018 produce roughly 25% less CO_2 emissions than model year 2008 vehicles of a comparable footprint. Electric vehicles are shown in Figure 3.14 with zero tailpipe CO_2 emissions, regardless of footprint. As more electric vehicles enter the market, the relationship between footprint and tailpipe CO_2 emissions will become much flatter, or less sensitive to footprint.

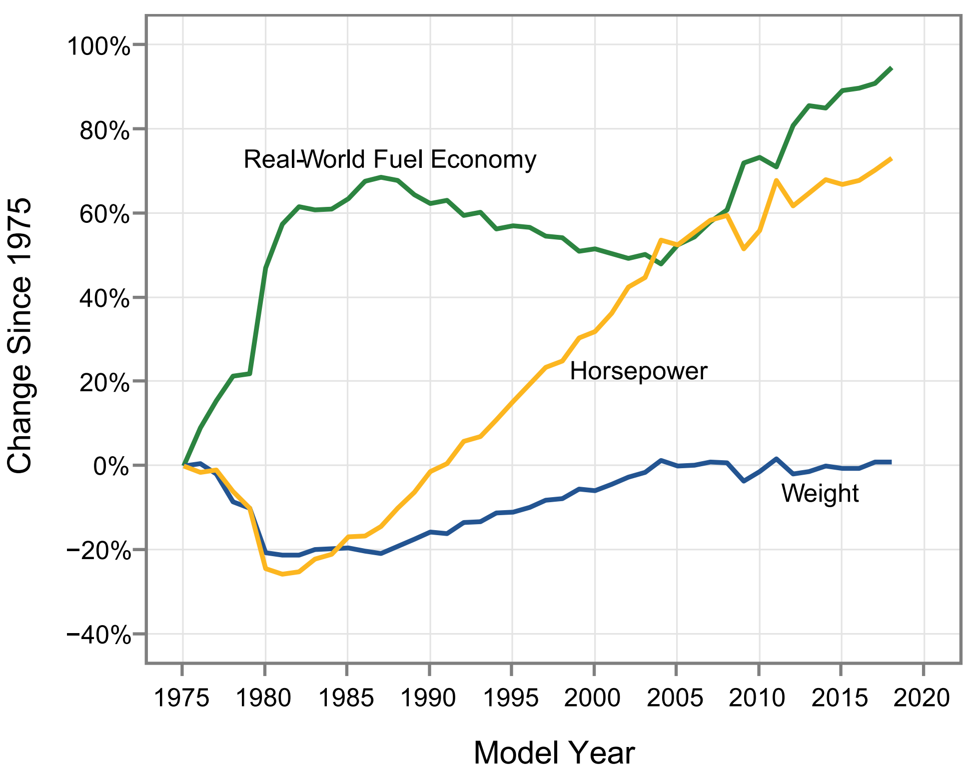
Figure 3.14. Relationship of Footprint and CO_2 Emissions



E. Summary

The past 40+ years of data show striking changes in the attributes of vehicles produced for sale in the United States. The marketplace has moved from more than 80% cars to a much more varied mix of vehicles, with recent growth in SUV sales (car SUVs and truck SUVs) resulting in SUVs capturing more than 40% of the market. The weight of an average new vehicle fell dramatically in the late 1970s, then slowly climbed for about 20 years before flattening off. The mix of vehicles in the sedans/wagons vehicle type have an average weight that is still 13% below 1975 values, but trucks are now almost 30% heavier than in model year 1975. Vehicle power and acceleration have increased across all vehicle types, with average horsepower more than doubling the lows reached in the early 1980s. Vehicle footprint has increased about 2% since this report began tracking the data in model year 2008. Figure 3.15 shows a summary of the relative changes in fuel economy, weight, horsepower, and fuel economy since 1975.

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



Over time, automotive technology innovation has been applied to vehicle design with differing emphasis between vehicle weight, power, CO_2 emissions and fuel economy. In the two decades before model year 2004, technology innovation was generally used to increase vehicle power, and weight increased due to changing vehicle design, increased vehicle size, and increased content. During this period, average new vehicle fuel economy steadily decreased and CO_2 emissions correspondingly increased. However, since model year 2004, technology has been used to increase fuel economy (up 29%) and power (up 11%), while maintaining vehicle weight and reducing CO_2 emissions (down 23%). The improvement in CO_2 emissions and fuel economy since 2004 is due to many factors, including gasoline prices, consumer preference, and increasing stringency of NHTSA light-duty car and truck CAFE standards.

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

Table 3.1. Vehicle Attributes by Model Year

Model Year	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Weight (lbs)	Horsepower (HP)	0 to 60 (s)	Footprint (ft^2)	Car Production Share	Truck Production Share
1975	681	13.1	4,060	137	-	-	80.7%	19.3%
1980	466	19.2	3,228	104	15.6	-	83.5%	16.5%
1985	417	21.3	3,271	114	14.1	-	75.2%	24.8%
1990	420	21.2	3,426	135	11.5	-	70.4%	29.6%
1995	434	20.5	3,613	158	10.1	-	63.5%	36.5%
2000	450	19.8	3,821	181	9.8	-	58.8%	41.2%
2001	453	19.6	3,879	187	9.5	-	58.6%	41.4%
2002	457	19.5	3,951	195	9.4	-	55.2%	44.8%
2003	454	19.6	3,999	199	9.3	-	53.9%	46.1%
2004	461	19.3	4,111	211	9.1	-	52.0%	48.0%
2005	447	19.9	4,059	209	9.0	-	55.6%	44.4%
2006	442	20.1	4,067	213	8.9	-	57.9%	42.1%
2007	431	20.6	4,093	217	8.9	-	58.9%	41.1%
2008	424	21.0	4,085	219	8.9	48.9	59.3%	40.7%
2009	397	22.4	3,914	208	8.8	47.9	67.0%	33.0%
2010	394	22.6	4,001	214	8.8	48.5	62.8%	37.2%
2011	399	22.3	4,126	230	8.5	49.5	57.8%	42.2%
2012	377	23.6	3,979	222	8.5	48.8	64.4%	35.6%
2013	368	24.2	4,003	226	8.4	49.1	64.1%	35.9%
2014	369	24.1	4,060	230	8.3	49.7	59.3%	40.7%
2015	361	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	233	8.2	49.8	52.5%	47.5%
2018 (prelim)	*348*	*25.4*	*4,094*	*237*	*8.0*	*50.0*	*51.7%*	*48.3%*

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
2001	53.9%	386	23.0	4.8%	472	18.8	17.3%	541	16.4	7.9%	493	18.0	16.1%	557	16.0
2002	51.5%	385	23.1	3.7%	460	19.3	22.3%	545	16.3	7.7%	475	18.7	14.8%	564	15.8
2003	50.2%	382	23.3	3.6%	446	19.9	22.6%	541	16.4	7.8%	468	19.0	15.7%	553	16.1
2004	48.0%	384	23.1	4.1%	445	20.0	25.9%	539	16.5	6.1%	464	19.2	15.9%	565	15.7
2005	50.5%	379	23.5	5.1%	440	20.2	20.6%	531	16.7	9.3%	460	19.3	14.5%	561	15.8
2006	52.9%	382	23.3	5.0%	434	20.5	19.9%	518	17.2	7.7%	455	19.5	14.5%	551	16.1
2007	52.9%	369	24.1	6.0%	431	20.6	21.7%	503	17.7	5.5%	456	19.5	13.8%	550	16.2
2008	52.7%	366	24.3	6.6%	419	21.2	22.1%	489	18.2	5.7%	448	19.8	12.9%	539	16.5
2009	60.5%	351	25.3	6.5%	403	22.0	18.4%	461	19.3	4.0%	443	20.1	10.6%	526	16.9
2010	54.5%	340	26.2	8.2%	386	23.0	20.7%	452	19.7	5.0%	442	20.1	11.5%	527	16.9
2011	47.8%	344	25.8	10.0%	378	23.5	25.5%	449	19.8	4.3%	424	20.9	12.3%	516	17.2
2012	55.0%	322	27.6	9.4%	381	23.3	20.6%	445	20.0	4.9%	418	21.3	10.1%	516	17.2
2013	54.1%	313	28.4	10.0%	365	24.3	21.8%	427	20.8	3.8%	422	21.1	10.4%	509	17.5
2014	49.2%	313	28.4	10.1%	364	24.4	23.9%	412	21.6	4.3%	418	21.3	12.4%	493	18.0
2015	47.2%	306	29.0	10.2%	353	25.1	28.1%	406	21.9	3.9%	408	21.8	10.7%	474	18.8
2016	43.8%	303	29.2	11.5%	338	26.2	29.1%	400	22.2	3.9%	410	21.7	11.7%	471	18.9
2017	41.0%	293	30.2	11.5%	339	26.2	31.8%	398	22.4	3.6%	399	22.2	12.1%	470	18.9
2018 (prelim)	*42.0%*	*284*	*30.8*	*9.7%*	*331*	*26.8*	*31.7%*	*387*	*23.0*	*3.3%*	*386*	*22.9*	*13.3%*	*462*	*19.3*

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

Table 3.3. Model Year 2017 Vehicle Attributes by Manufacturer

Manufacturer	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Weight (lbs)	HP	0 to 60 (s)	Footprint (ft^2)
BMW	341	25.9	4,107	257	7.0	47.9
FCA	420	21.2	4,510	280	7.5	52.8
Ford	388	22.9	4,360	262	7.9	52.5
GM	388	22.9	4,520	265	8.0	53.5
Honda	302	29.4	3,595	203	8.1	47.1
Hyundai	311	28.6	3,458	176	8.9	46.5
Kia	327	27.2	3,592	186	8.8	47.2
Mazda	306	29.0	3,569	178	8.9	46.0
Mercedes	385	23.1	4,536	288	7.0	50.0
Nissan- Mitsubishi	327	27.1	3,770	201	8.9	47.6
Subaru	312	28.5	3,724	181	9.3	45.0
Toyota	351	25.3	4,059	216	8.5	49.0
VW	335	26.5	3,894	225	7.9	46.3
Other	319	26.6	4,747	336	6.4	51.0
All Manufacturers	**357**	**24.9**	**4,093**	**233**	**8.2**	**49.8**

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

Table 3.4. Model Year 2017 Estimated Real-World Fuel Economy and CO_2 by Manufacturer and Vehicle Type

	Sedan/Wagon			Car SUV			Truck SUV			Minivan/Van			Pickup		
Manufacturer	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)	Prod Share	Real-World CO_2 (g/mi)	Real-World FE (mpg)
BMW	62.7%	314	28.0	5.5%	362	24.6	31.8%	391	22.8	-	-	-	-	-	-
FCA	10.4%	373	23.7	9.0%	354	25.1	45.6%	423	21.0	16.9%	400	22.2	18.1%	493	18.1
Ford	31.1%	319	27.8	14.8%	352	25.2	32.5%	427	20.8	1.8%	413	21.5	19.8%	457	19.5
GM	30.6%	292	30.2	13.1%	341	26.0	31.4%	439	20.3	0.0%	699	12.7	24.9%	467	19.1
Honda	58.2%	270	32.8	8.4%	301	29.5	28.7%	351	25.3	1.7%	383	23.2	3.0%	408	21.8
Hyundai	63.1%	277	32.1	30.6%	357	24.9	6.2%	430	20.7	-	-	-	-	-	-
Kia	55.0%	280	31.7	17.4%	354	25.1	21.6%	399	22.3	6.0%	423	21.0	-	-	-
Mazda	57.2%	283	31.5	13.9%	321	27.6	29.0%	345	25.8	-	-	-	-	-	-
Mercedes	50.7%	342	25.9	7.0%	340	26.1	40.8%	445	20.0	1.5%	396	22.5	-	-	-
Nissan-Mitsubishi	56.1%	293	30.2	10.2%	307	28.9	24.9%	368	24.1	2.0%	354	25.1	6.9%	480	18.5
Subaru	26.8%	311	28.6	-	-	-	73.2%	312	28.5	-	-	-	-	-	-
Toyota	41.6%	278	31.9	9.9%	342	25.9	27.2%	385	23.1	5.7%	399	22.3	15.6%	476	18.7
VW	72.0%	308	28.8	3.5%	395	22.5	24.5%	406	21.9	-	-	-	-	-	-
Other	34.1%	230	34.3	9.9%	106	51.3	56.0%	411	21.8	-	-	-	-	-	-
All Manufacturers	**41.0%**	**293**	**30.2**	**11.5%**	**339**	**26.2**	**31.8%**	**398**	**22.4**	**3.6%**	**399**	**22.2**	**12.1%**	**470**	**18.9**

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 2016–2018 (ft^2)

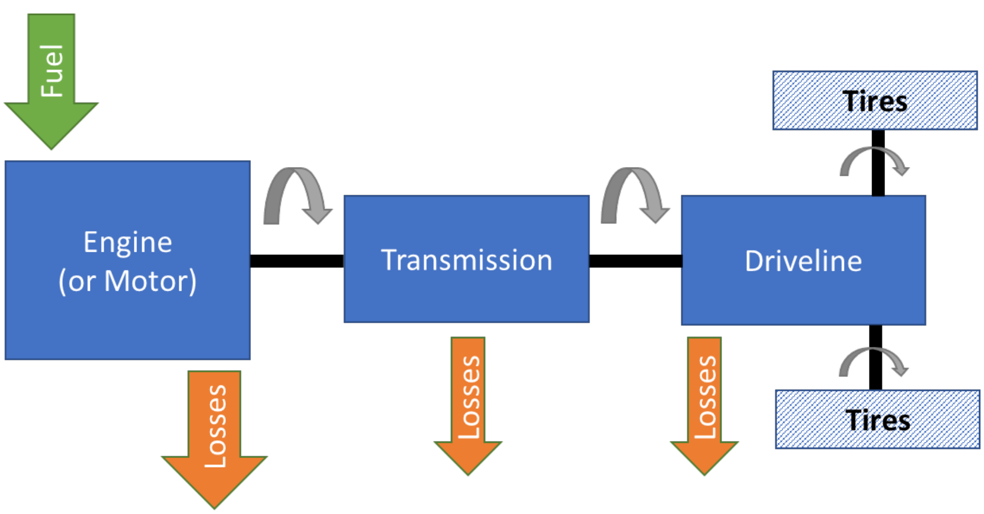
Manufacturer	Final MY 2016			Final MY 2017			*Preliminary MY 2018*		
	Car	**Truck**	**All**	**Car**	**Truck**	**All**	***Car***	***Truck***	***All***
BMW	47.1	50.6	48.0	46.7	50.6	47.9	*47.0*	*50.8*	*48.0*
FCA	47.5	53.2	51.4	47.4	54.1	52.8	*48.9*	*52.4*	*51.6*
Ford	46.7	59.0	53.3	46.9	57.3	52.5	*46.8*	*60.1*	*55.2*
GM	46.6	59.1	53.2	46.6	58.9	53.5	*46.3*	*58.3*	*53.3*
Honda	45.3	49.6	47.0	45.9	49.7	47.1	*46.3*	*50.5*	*47.8*
Hyundai	46.3	49.2	46.3	46.3	49.2	46.5	*46.8*	*47.5*	*46.9*
Kia	45.9	51.3	47.1	46.1	50.0	47.2	*46.1*	*50.2*	*47.2*
Mazda	45.4	47.1	46.0	45.5	47.2	46.0	*45.5*	*48.1*	*46.3*
Mercedes	47.5	51.7	48.9	48.5	52.0	50.0	*48.3*	*51.3*	*49.5*
Nissan-Mitsubishi	45.8	49.5	46.9	45.8	51.3	47.6	*45.8*	*52.0*	*48.0*
Subaru	44.7	44.8	44.7	45.1	45.0	45.0	*45.1*	*45.0*	*45.0*
Toyota	45.5	52.5	48.5	45.6	52.6	49.0	*45.7*	*51.1*	*48.2*
VW	45.1	48.9	45.9	45.0	50.2	46.3	*45.6*	*50.0*	*47.4*
Other	51.0	51.3	51.2	50.8	51.1	51.0	*49.7*	*50.4*	*50.0*
All Manufacturers	**46.1**	**53.7**	**49.5**	**46.2**	**53.8**	**49.8**	***46.5***	***53.8***	***50.0***

4. Vehicle Technology

Vehicle CO_2 emissions, fuel economy, weight, power, acceleration, and body type have all changed significantly over time, as shown in Section 3 of this report. Many of these attributes have improved in recent years, driven by an increasingly wide array of technological advancements developed by the automotive industry. Automotive engineers and designers are constantly creating and evaluating new technology and deciding how, or if, it should be applied to their vehicles.

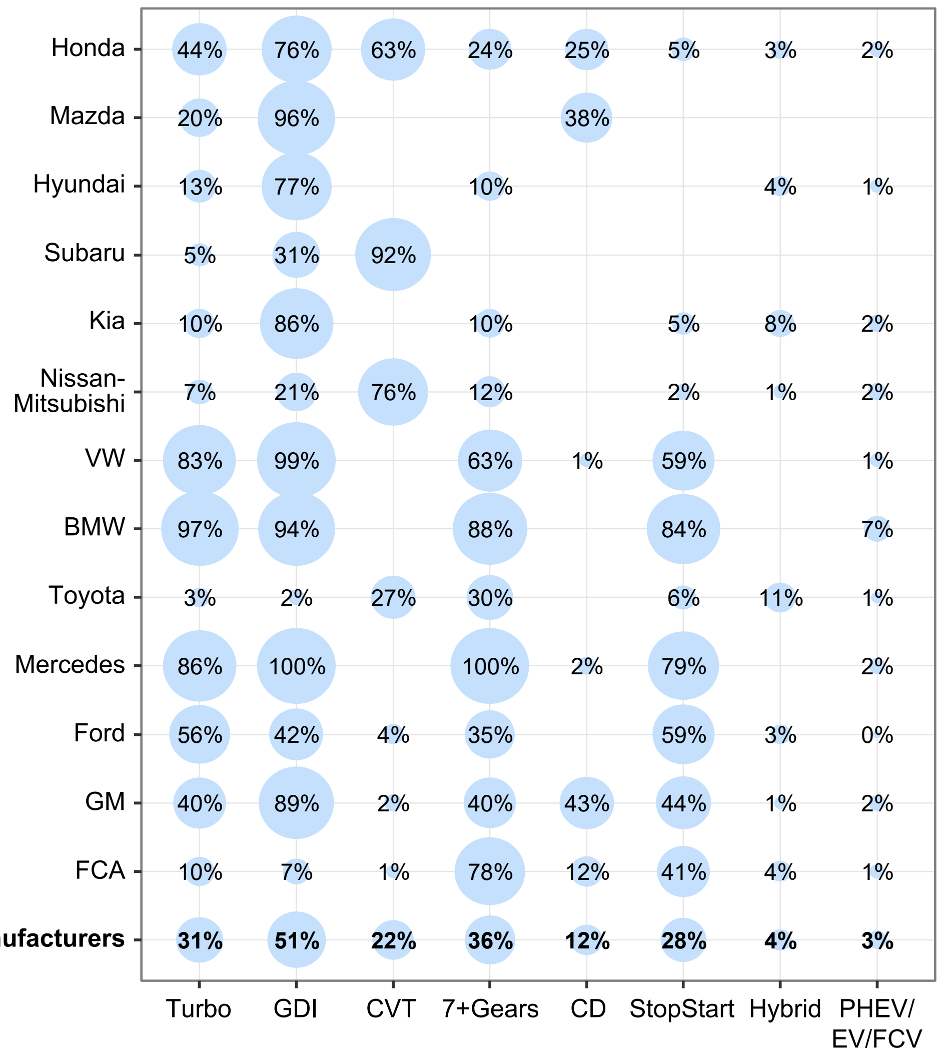
This section of the report focuses on three separate technological areas of a vehicle: the engine, transmission, and driveline. The engine (or motor) of an automobile is at the heart of any vehicle design and allows the vehicle to convert energy stored in fuel (or a battery) into rotational energy. The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

Figure 4.1. Vehicle Energy Flow



Manufacturers are adopting many new technologies to improve efficiency. Figure 4.2 illustrates projected manufacturer-specific technology adoption, with larger circles representing higher adoption rates, for model year 2018. The figure shows preliminary model year 2018 technology projections to provide insight on a quickly changing industry, even though there is some uncertainty in the preliminary data.

Figure 4.2. Manufacturer Use of Emerging Technologies for Model Year 2018



Engine technologies such as turbocharged engines (Turbo) and gasoline direct injection (GDI) allow for more efficient engine design and operation. Cylinder deactivation (CD) allows for only using part of the engine when less power is needed, and stop/start can turn off the engine entirely when the vehicle is stopped to save fuel. Hybrid vehicles use a larger battery to recapture braking energy and provide power when necessary, allowing for a smaller, more efficiently-operated engine. Transmissions that have seven or more speeds, or continuously variable transmissions (CVT) allow the engine to operate more frequently closer to its peak efficiency, providing more efficient average engine operation and a reduction in fuel usage.

The technologies in Figure 4.2 are all being adopted by manufacturers to reduce CO_2 emissions and increase fuel economy. In some cases, the adoption is rapid. For example, GDI was used in fewer than 3% of vehicles as recently as model year 2008 but is projected to be in about 50% of vehicles in model year 2018. Electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) are a small but growing percentage of new vehicles.

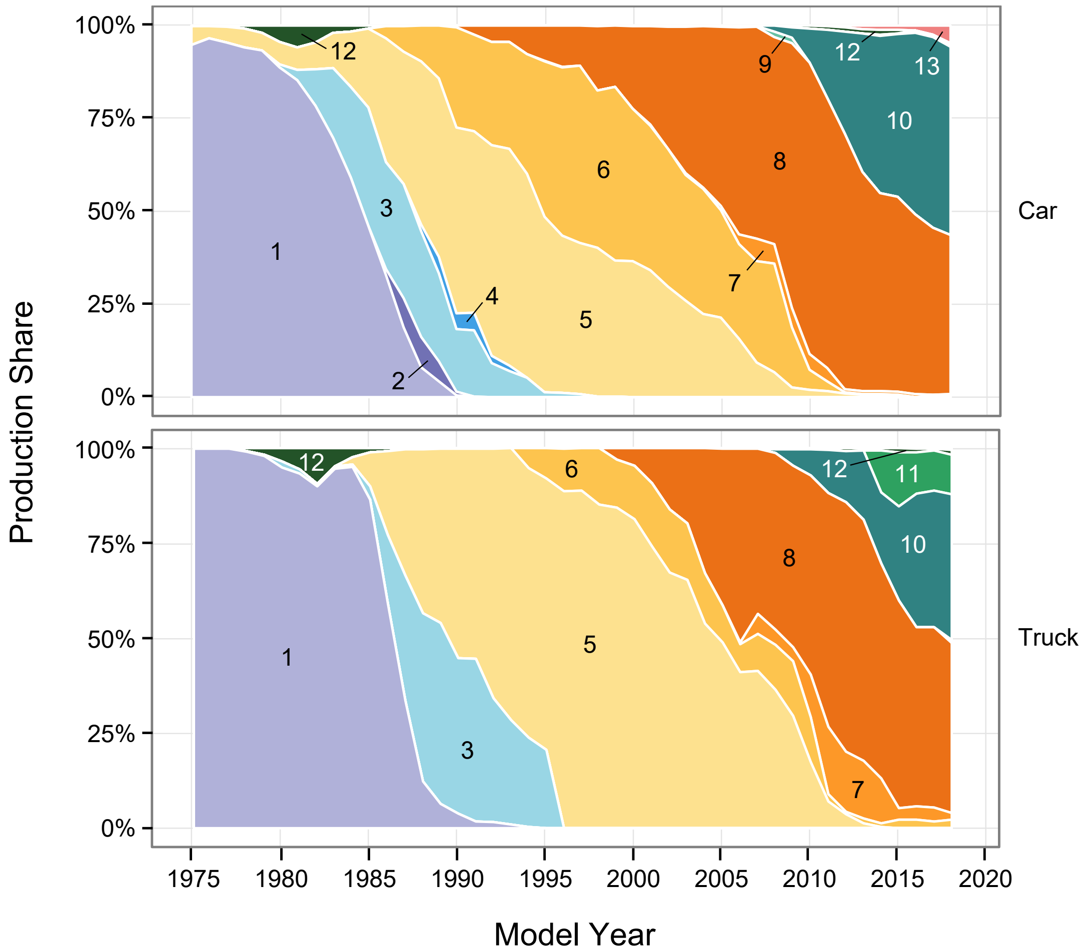
Each of the thirteen manufacturers shown in Figure 4.2 have included at least three of these technologies in their new vehicles. However, it is also clear that manufacturers' strategies to develop and adopt new technologies are unique and can vary significantly. Each manufacturer is choosing technologies that best meet the design requirements of their vehicles, and in many cases, that technology is changing quickly. The rest of this section will explore how engine, transmission, and driveline technology in general has changed since 1975, the impact of those technology changes, and the rate at which technology is adopted by the industry.

A. Engines

Vehicle engine technology has continually evolved in the 40+ years since EPA began collecting data. Over that time, engines using gasoline as a fuel have dominated the market, and the technology on those engines has changed dramatically. More recently, new engine designs such as PHEVs, EVs, and even FCVs have begun to enter the market, potentially offering dramatic reductions in tailpipe CO_2 emissions and further increases in fuel economy.

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

Figure 4.3. Production Share by Engine Technology



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

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

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

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

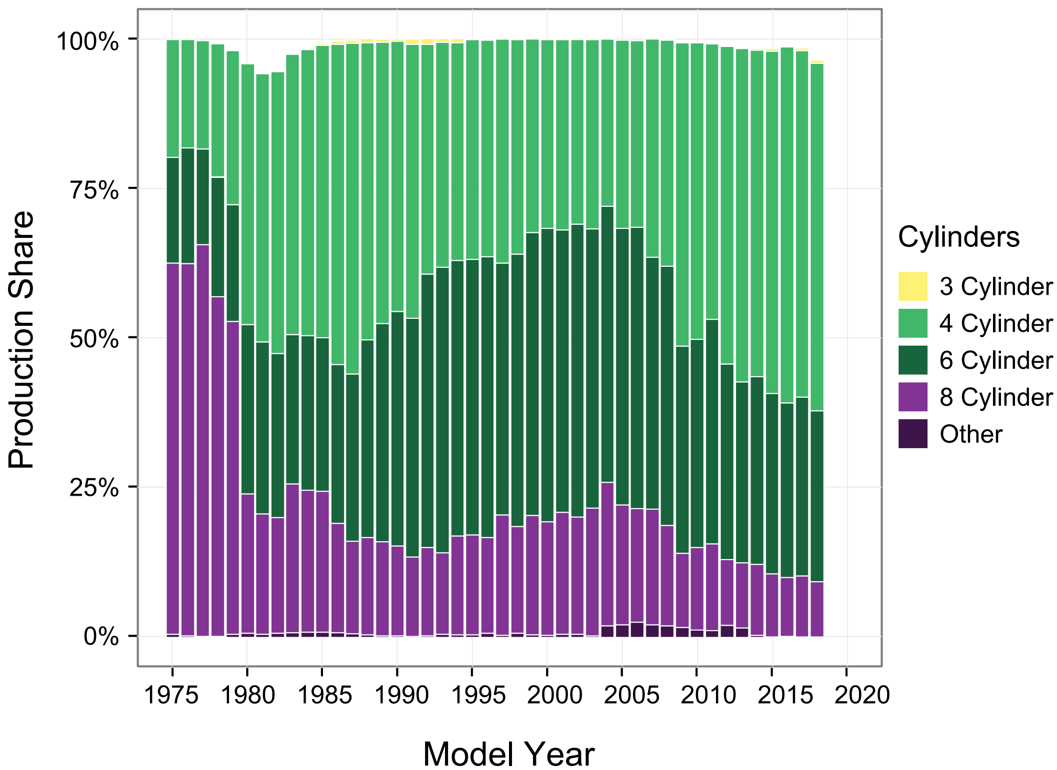
Gasoline Engines

Since EPA began tracking vehicle data in 1975, nearly 600 million vehicles have been produced for sale in the United States. Over 99 percent of those vehicles used gasoline engines as the only source of power (this includes hybrids). Gasoline engine technology has continually evolved and expanded over this time, resulting in a rich data source for examining the long-term technology trends in gasoline vehicles. Figure 4.3 shows an overview of this evolution, and the following discussion focuses on metrics that are applicable to gasoline engines. For the purposes of this report, hybrid vehicles are included with gasoline engines, as are “flex fuel” vehicles that are capable of operating on gasoline or a blend of 85% ethanol and 15% gasoline (E85).

Engine Size and Displacement

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

Figure 4.4. Gasoline Engine Production Share by Number of Cylinders



In the mid and late 1970s, the 8-cylinder engine was dominant, accounting for well over half of all new vehicle production. In model year 1980 there was a significant change in the market, as 8-cylinder engine production share dropped to about a quarter of the market and 4-cylinder production share increased to 45% of the market. Between model year 1980 and model year 1992, 4-cylinder engines were the most popular engines, although they slowly lost ground to 6-cylinder engines, and in model year 1992 6-cylinder engines became the most popular engine option. In model year 2009, 4-cylinder engines increased 13 percentage points in a single year to again become the most popular engine option, capturing a little over half of all production. Production share of 4-cylinder engines has generally increased since, and is at the highest point on record, accounting for 60% of production in model year 2017. Production share of 8-cylinder engines has continued to decrease, to less than 10%. Projected data for model year 2018 suggests that these trends will continue.

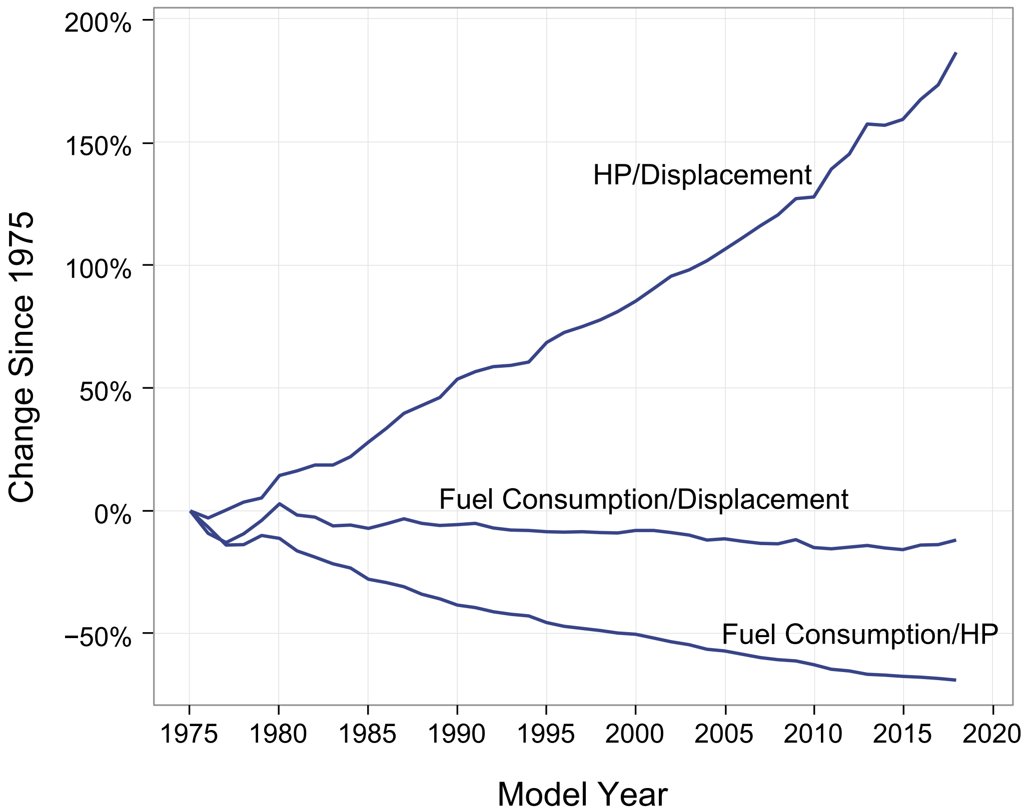
Overall engine size, as measured by the total volume of all the engine's cylinders, is directly related to the number of cylinders. As vehicles have moved towards engines with a lower number of cylinders, the total engine size, or displacement, is also at an all-time low. The average new vehicle in model year 1975 had a displacement of nearly 300 cubic inches, compared to an average of 138 cubic inches today. Gasoline engine displacement per cylinder has been relatively stable over the time of this report (around 35 cubic inches per cylinder since 1980), so the reduction in overall new vehicle engine displacement is almost entirely due to the shift towards engines with fewer cylinders.

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

Specific power has increased more than 175% since model year 1975, and has done so at a remarkably steady rate, as shown in Figure 4.5. The specific power of new vehicle gasoline engines has increased by about 0.02 horsepower per cubic inch every year for 40+ years. Considering the numerous and significant changes to engines over this time span, changes in consumer preferences, and the external pressures on vehicle purchases, the long-standing linearity of this trend is noteworthy. The roughly linear increase in specific power does not appear to be slowing. Turbocharged engines, direct injection, higher compression ratios, and many other engine technologies are likely to continue increasing engine specific power.

Figure 4.5 also shows two other important engine metrics, the amount of fuel consumed compared to the overall size of the engine (Fuel Consumption/Displacement), and the amount of fuel consumed relative to the amount of power produced by an engine (Fuel Consumption/HP). The amount of fuel consumed by a gasoline engine, relative to the total displacement, has fallen about 15% since model year 1975, and fuel consumption relative to engine horsepower has fallen more than 65% 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, continual, and have resulted in impressive improvements to internal combustion engines.

Figure 4.5. Percent Change for Specific Gasoline Engine Metrics



Fuel Delivery Systems and Valvetrains

All gasoline engines require a fuel delivery system that controls the flow of fuel delivered into the engine. The process for controlling fuel flow has change significantly over time, allowing for much more control over the combustion process and thus more efficient engines. In the 1970s and early 1980s, nearly all gasoline engines used carburetors to meter fuel delivered to the engine. Carburetors were replaced over time with fuel injection systems; first throttle body injection (TBI) systems, then port fuel injection (PFI) systems, and more recently gasoline direct injection (GDI), as shown in Figure 4.3. TBI and PFI systems use fuel injectors to electronically deliver fuel and mix it with air outside of the engine cylinder; the resulting air and fuel mixture is then delivered to the engine cylinders for combustion. Engines that utilize GDI spray fuel directly into the air in the engine cylinder for better control of the combustion process. Engines using GDI were first introduced into the market with very limited production in model year 2007. Ten years later, GDI engines were installed in 50% of model year 2017 gasoline vehicles and are projected to continue increasing.

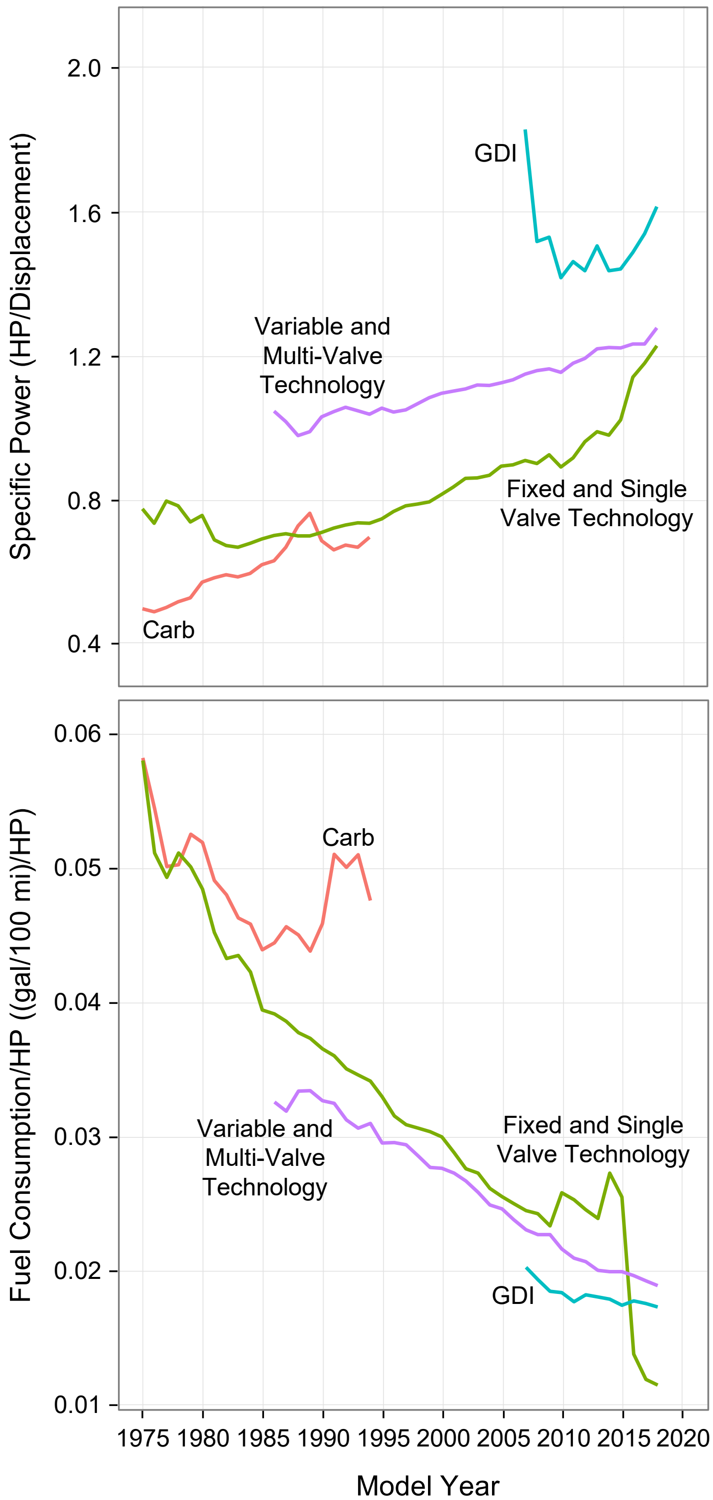
Another key aspect of engine design is the valvetrain. Each engine cylinder must have a set of valves that allow for air (or an air/fuel mixture) to flow into the engine cylinder prior to combustion and for exhaust gases to exit the cylinder after combustion. The number of valves per cylinder and the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

This report began tracking multi-valve engines (i.e., engines with more than two valves per cylinder) for cars in model year 1986 and for trucks in model year 1994. Since that time nearly the entire fleet has converted to multi-valve design. While some three- and five-valve engines have been produced, the vast 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 also adopted this technology. Figure 4.3 shows the evolution of engine technology, including fuel delivery method and the introduction of VVT and multi-valve engines.

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

Figure 4.6 shows the changes in specific power and fuel consumption for each of these engine packages over time. There is a very clear increase in specific power of each engine package as engines moved from carbureted engines to engines with two valves, fixed timing and port fuel injection, then to engines with multi-valve VVT and port fuel injection, and finally to GDI engines. Some of the increase for GDI engines may also be due to the fact that GDI engines are often paired with turbochargers to further increase power. Figure 4.6 also shows the reduction in fuel consumption per horsepower for each of the four engine packages.

Figure 4.6. Engine Metrics for Different Gasoline Technology Packages



Turbocharging

Turbochargers increase the power that an engine can produce by forcing more air, and thus fuel, into the engine. An engine with a turbocharger can produce more power than an identically sized engine that is naturally aspirated or does not have a turbocharger. The pressure of the exhaust gases provides the power to operate a turbocharger. Superchargers operate the same way as turbochargers but are directly connected to the engine for power. Alternate turbocharging and supercharging methods, such as electric superchargers, are also beginning to emerge.

Turbocharged engines have been increasing rapidly in the marketplace, as shown in Figure 4.7, and almost 30% of all engines are expected to be turbocharged gasoline engines in model year 2018. Many of these engines are applying turbochargers to create "turbo downsized" engine packages that can combine the improved fuel economy of smaller engines during normal operation but can provide the power of a larger engine by engaging the turbocharger when necessary. As evidence of this turbo downsizing, about 80% of turbocharged engines are 4-cylinder engines, with most other turbochargers being used in 6-cylinder engines. This is shown in Figure 4.8.

Most of the current turbocharged engines also use GDI and VVT. This allows for more efficient engine operation, helps increase the resistance to premature combustion (engine knock), and reduces turbo lag (the amount of time it takes for a turbocharger to engage). In model year 2017, more than 90% of new vehicles with gasoline turbocharged engines also used GDI.

Figure 4.9 examines the distribution of engine displacement and power of turbocharged engines over time. In model year 2010, turbochargers were used mostly in cars, and were available on engines both above and below the average engine displacement. The biggest increase in turbocharger use over the last few years has been in cars with engine displacement well below the average displacement. The distribution of horsepower for turbocharged engines is much closer to the average horsepower, even though the displacement is smaller, reflecting the higher power per displacement of turbocharged engines. This trend towards adding turbochargers to smaller, less powerful engines is consistent with the turbo downsizing trend.

Figure 4.7. Gasoline Turbo Engine Production Share by Vehicle Type

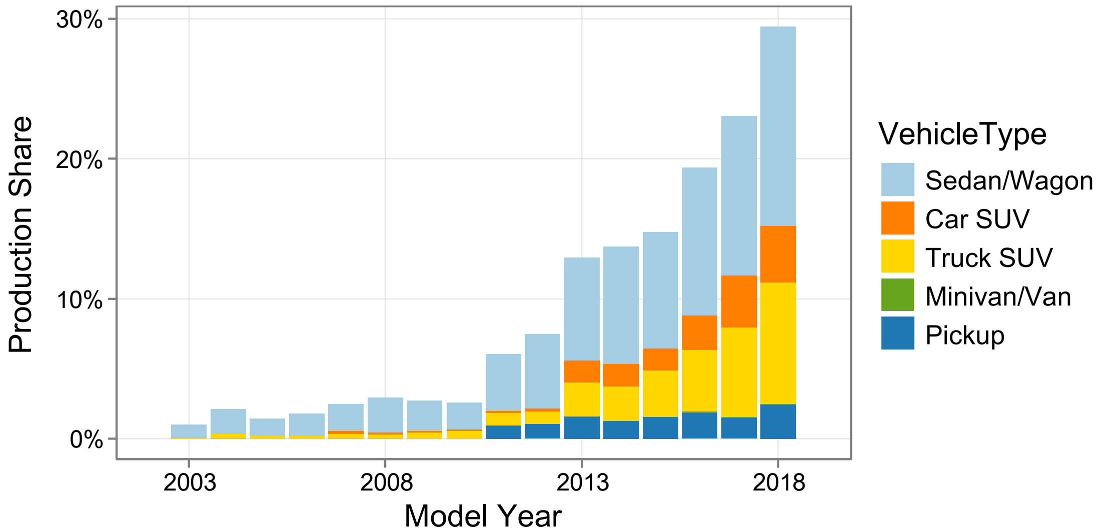


Figure 4.8. Gasoline Turbo Engine Production Share by Number of Cylinders

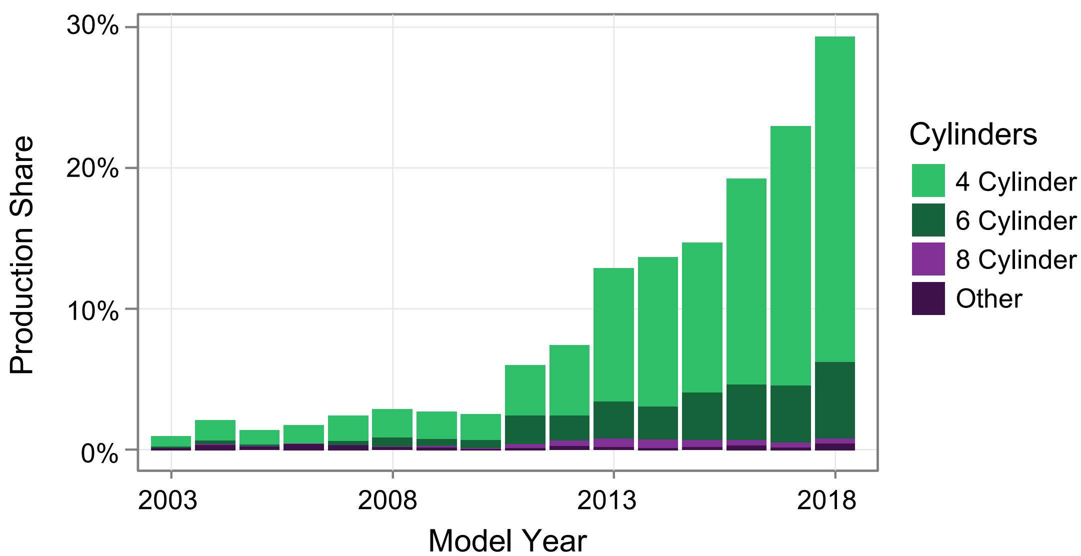
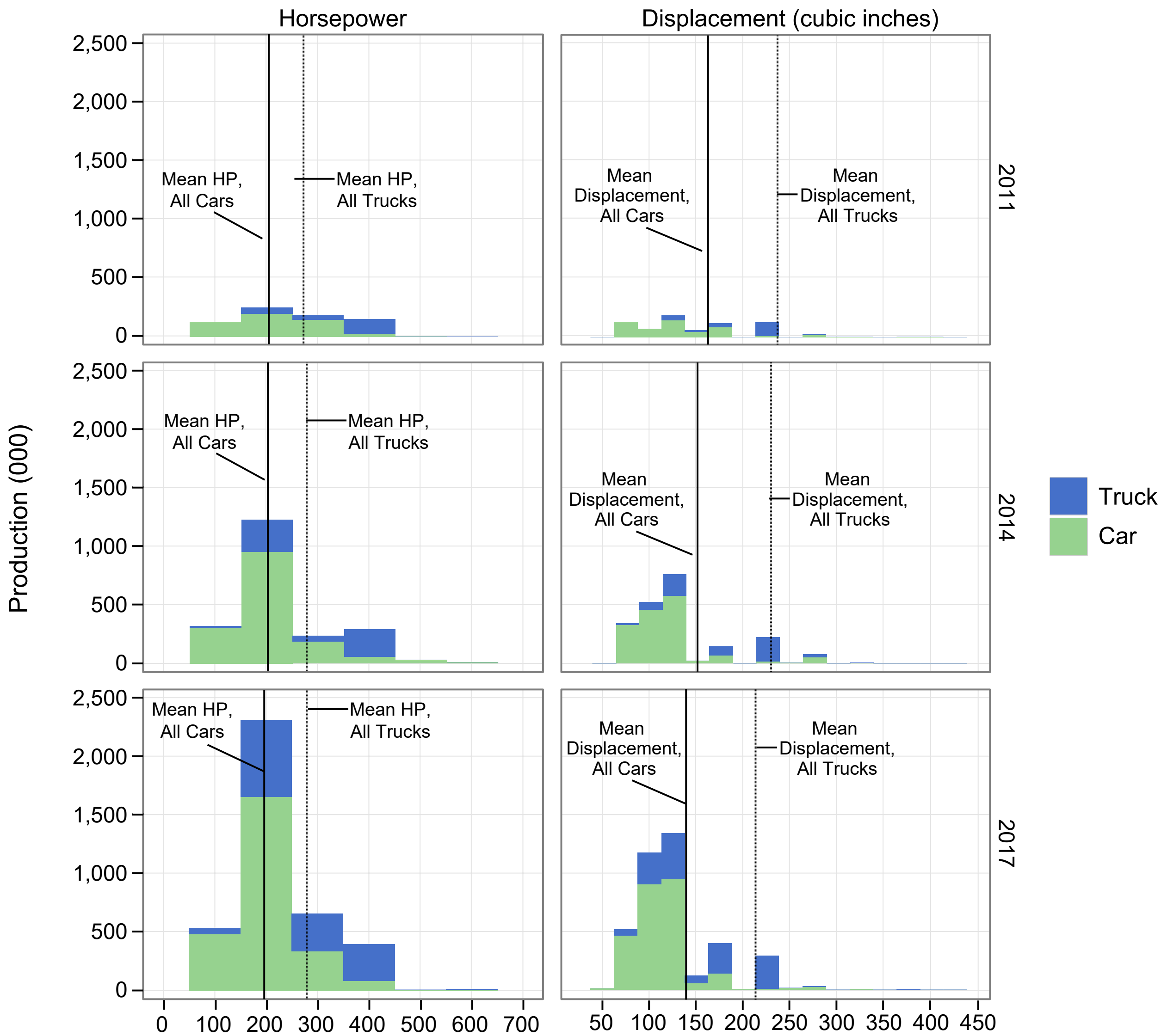


Figure 4.9. Distribution of Gasoline Turbo Vehicles by Displacement and Horsepower, Model Year 2011, 2014, and 2017



Cylinder Deactivation

Cylinder deactivation is an engine management approach that turns off the flow of fuel to one or more engine cylinders when driving conditions do not require full engine power. This effectively allows a large engine to act as a smaller engine when the additional cylinders are not needed, increasing engine efficiency and fuel economy. The use of cylinder deactivation in gasoline vehicles has been steadily climbing, and in model year 2017 gasoline engines with cylinder deactivation were 12% of all vehicles. This trend is expected to continue, especially as new improvements to cylinder deactivation technology, such as dynamic cylinder deactivation, reach the market.

Stop/Start

Engine stop/start technology allows the engine to be automatically turned off at idle, and very quickly restarted when the driver releases the brake pedal to move forward. By turning the engine off, a vehicle can eliminate the fuel use and CO_2 emissions that would have occurred if the engine was left running. This report began tracking stop/start technology in model year 2012 at less than one percent, and already the use of stop/start has increased to 18% of all vehicles, with an increase to almost 30% projected for model year 2018.

Hybrids

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

Hybrids were first introduced in the U.S. marketplace in model year 2000 with the Honda Insight. As more models and options were introduced, hybrid production generally increased to 3.8% of all vehicles in model year 2010. Since then, production of hybrids has remained in the range of 2–3% as shown in Figure 4.10. As shown in Figure 4.11, most hybrid vehicles have utilized 4-cylinder engines.

Figure 4.10. Gasoline Hybrid Engine Production Share by Vehicle Type

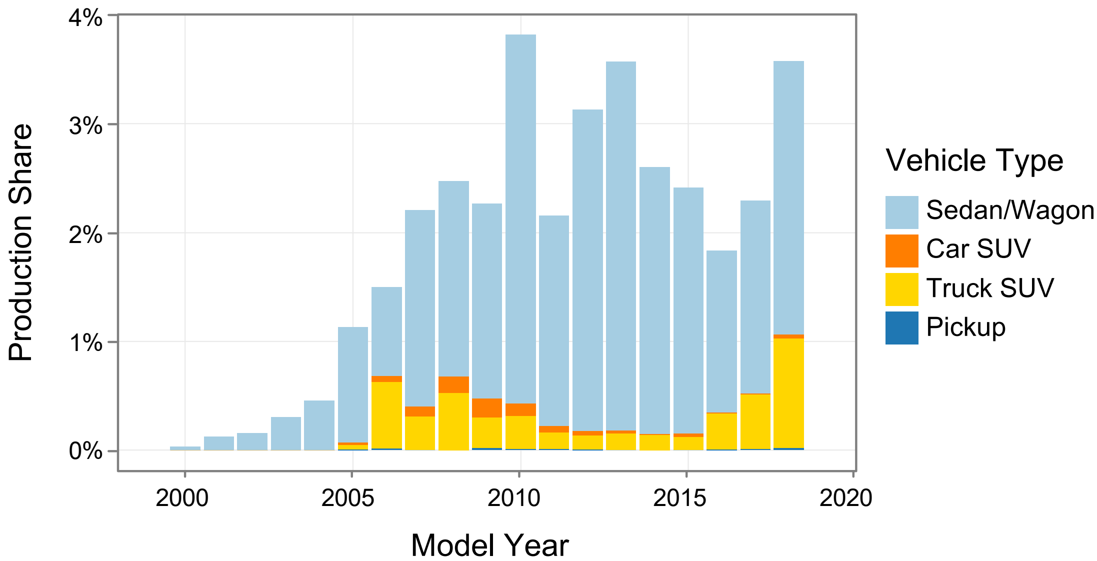
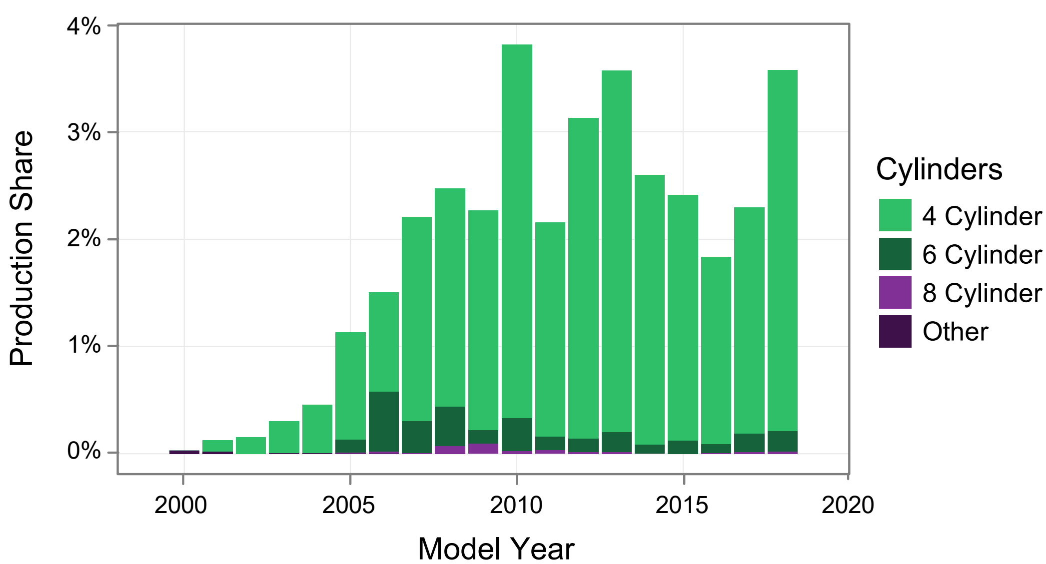


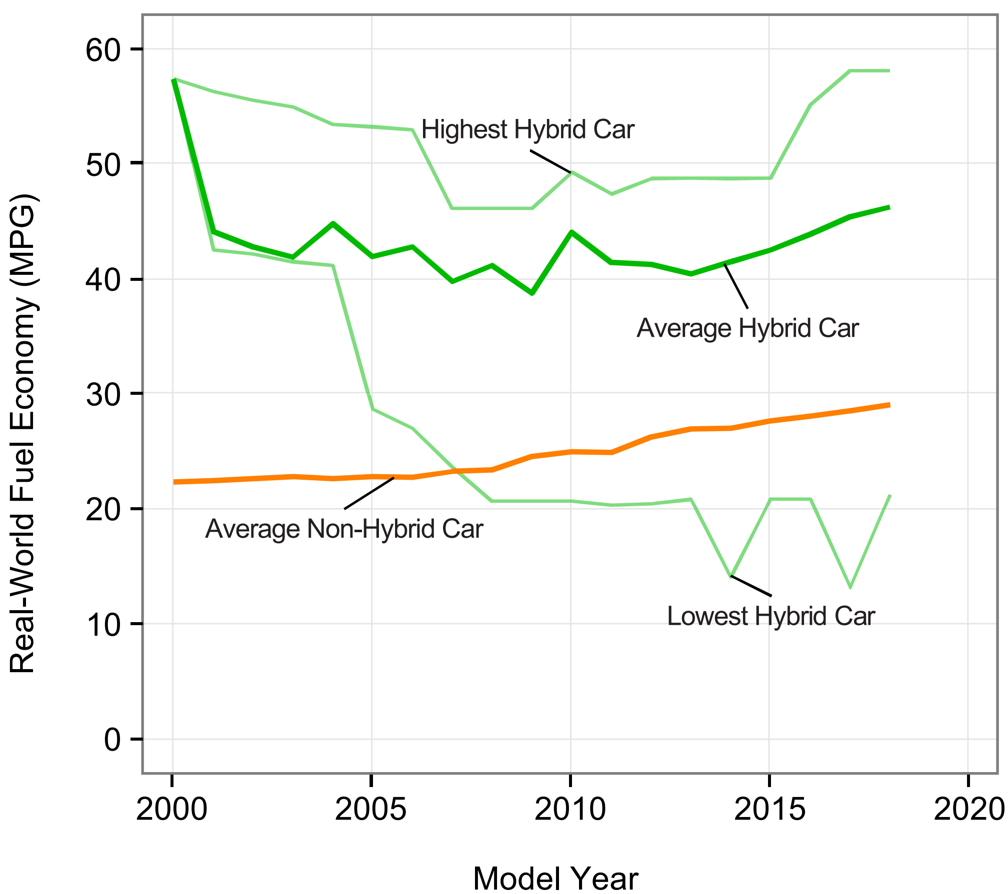
Figure 4.11. Gasoline Hybrid Engine Production Share by Number of Cylinders



The production-weighted distribution of fuel economy for all hybrid cars by year is shown in Figure 4.12. Hybrid cars, on average, had fuel economy more than 50% higher than the average non-hybrid car in model year 2017. As a production weighted average, hybrid cars (including sedan/wagons and car SUVs) achieved 45 mpg for model year 2017, while the average non-hybrid car achieved about 29 mpg.

Figure 4.12 is presented only for cars since the production of hybrid trucks has been limited. While the average fuel economy of hybrid cars remains higher than the average fuel economy of non-hybrid cars, the difference has narrowed considerably. Average hybrid car fuel economy has been relatively stable since model year 2001, while the fuel economy of the average non-hybrid car has increased more than 26%.

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



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

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

EVs typically result in lower CO_2 emissions over their lifetime compared to gasoline vehicles. This is due largely to two factors: EVs do not emit tailpipe emissions, and they are much more efficient in terms of onboard energy usage because an electric motor is much more efficient than a gasoline engine. Thus, even though there are emissions associated with the generation of electricity, the EV overall uses less energy than its gasoline-powered counterpart. Further, electricity-related CO_2 emissions vary depending on the electricity's fuel source. The mix of fuel sources used to generate electricity varies across the country, so the amount of CO_2 associated with electricity production similarly varies across the U.S. To enable a comparison between EVs and gasoline vehicles, EVs are rated in terms of miles per gallon-equivalent (mpge), which is the number of miles that an EV travels on an amount of electrical energy equivalent to the energy in a gallon of gasoline.

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

The production of EVs and PHEVs has increased rapidly in recent years. Prior to model year 2011, EVs were available, but generally only in small numbers for lease in California.[10] In model year 2011 the first PHEV, the Chevrolet Volt, was introduced along with the Nissan Leaf EV. Many additional models have been introduced since, and in model year 2017 combined EV/PHEV sales reached 1.4% of overall production, as shown in Figure 4.13. Combined EV/PHEV production is projected to reach almost 3% in model year 2018. The inclusion of model year 2017 EV and PHEV sales reduces the overall new vehicle average

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

CO_2 emissions by 4 g/mi, and this impact will continue to grow if EV and PHEV production increases. In model year 2017 there were three hydrogen FCVs available for sale, but they are only available in the state of California and in very small numbers. However there continues to be interest in FCVs as a future technology.

Figure 4.13. Production Share of EVs, PHEVs, and FCVs, Model Year 1995-2017[11]

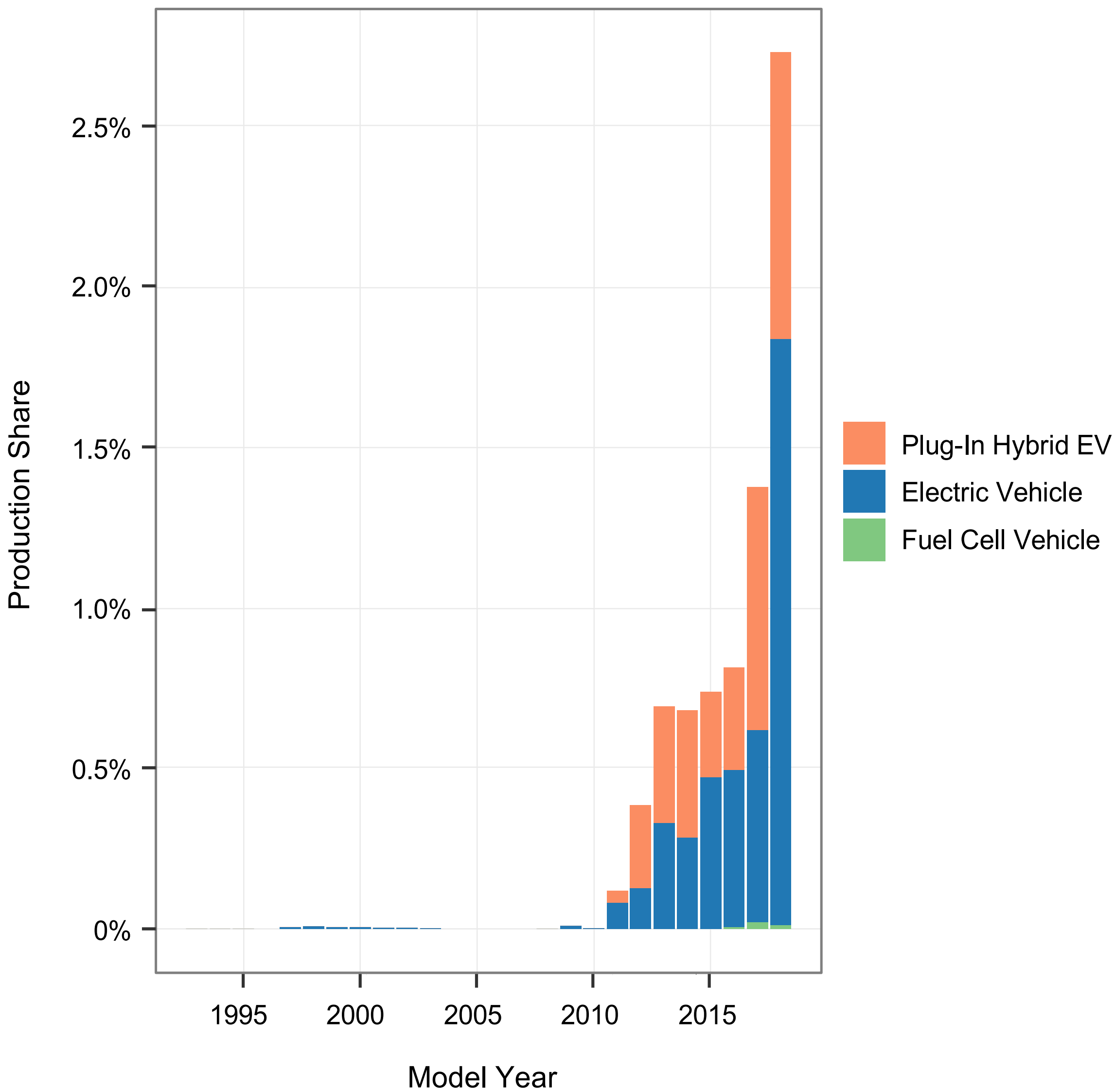


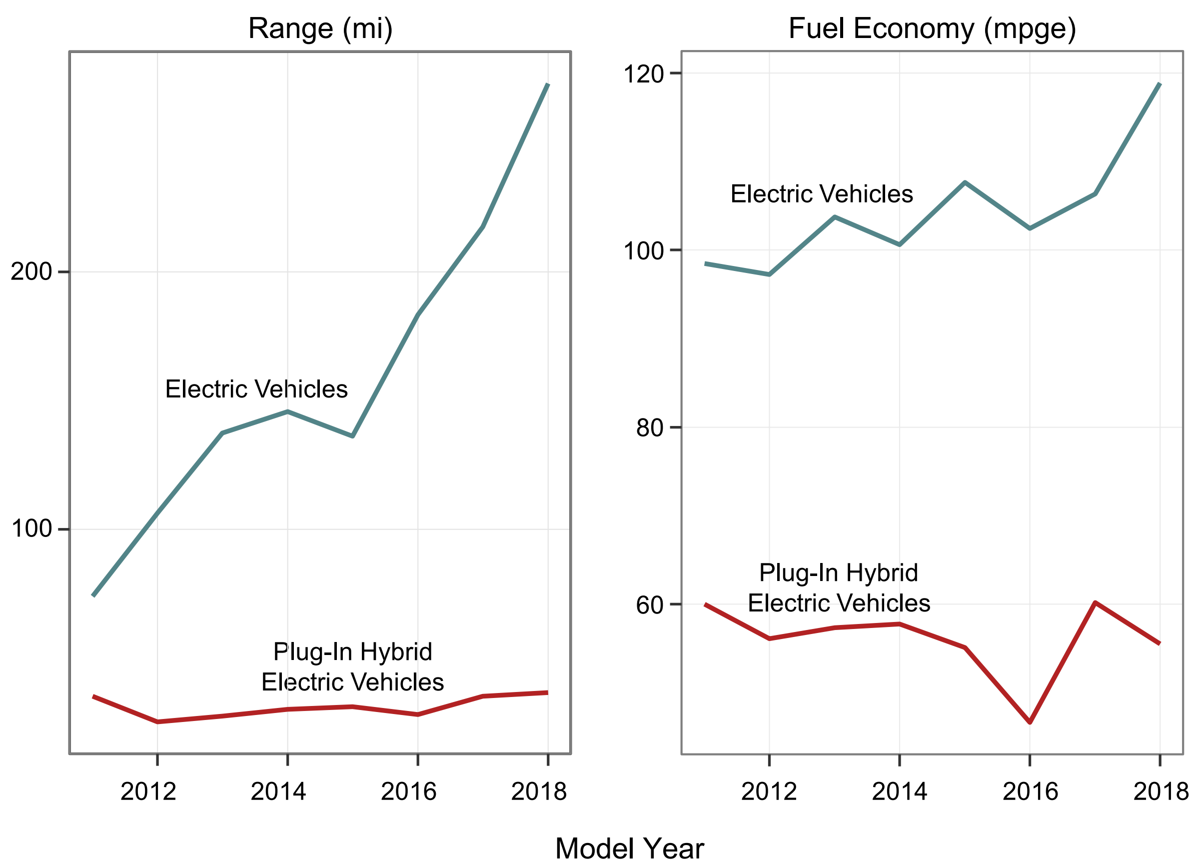
Figure 4.14 shows the range and fuel economy trends for EVs and PHEVs. The average range of new EVs has climbed substantially. In model year 2018 the average new EV is

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

projected to have a 273-mile range, or more than three and a half times the range of an average EV in 2011. This difference is largely attributable to higher production of new EVs with much longer ranges. The range values shown for PHEVs are the charge-depleting range, where the vehicle is operating on energy in the battery from an external source. This is generally the electric range of the PHEV, although the design of the specific vehicles may also use the gasoline engine in small amounts during charge depleting operation. The average charge depleting range for PHEVs has remained unchanged since model year 2011.

Along with improving range, the fuel economy of electric vehicles has also improved as measured in miles per gallon of gasoline equivalent (mpge). The fuel economy of electric vehicles has increased about 20% since model year 2011. The combined fuel economy of PHEVs has been more variable and does not appear to have a clear trend. For more information about EV and PHEV metrics, see Appendix E of this report.

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



Diesel Engines

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

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

Figure 4.15 shows the production share of diesel engines by vehicle type. Diesel engines have historically been more prevalent in the sedan/wagon vehicle type, however there has been very limited diesel sedan/wagon production in recent years. Light-duty diesel pickup trucks have recently re-entered the market, although only in small volumes. This report does not include the largest pickup trucks and work or vocational trucks, which have a higher penetration of diesel engines. As shown in Figure 4.16, current production of diesel engines for light-duty vehicles is limited to smaller four and six-cylinder engines.

Diesel engines, as with gasoline engines, have improved over time. Figure 4.17 shows the same metrics and trends that are explored in Figure 4.5 for gasoline engines. The specific power (HP/displacement) for diesel engines has increased about 200% since model year 1975. Fuel consumption per displacement dropped slightly in the 1980s but has increased back to about the same level as in model year 1975. Finally, fuel consumption per horsepower for diesel engines has declined about 75% since model year 1975.

The Department of Justice and EPA have reached settlements with Volkswagen and Fiat Chrysler Automobiles based on the sale of certain diesel vehicles equipped with devices to defeat the vehicles' emission control systems. This report includes the original fuel economy and GHG certification values of these vehicles, as EPA believes this is a reasonable representation of how these vehicles were expected to perform. The affected vehicles are certain model year 2009 to 2016 diesel vehicles from Volkswagen and 2014 to 2016 diesel vehicles from Fiat Chrysler Automobiles, and account for less than 1% of production in all affected years. For more information about these investigations, please see https://www.epa.gov/vw or https://www.epa.gov/fca.

Figure 4.15. Diesel Engine Production Share by Vehicle Type

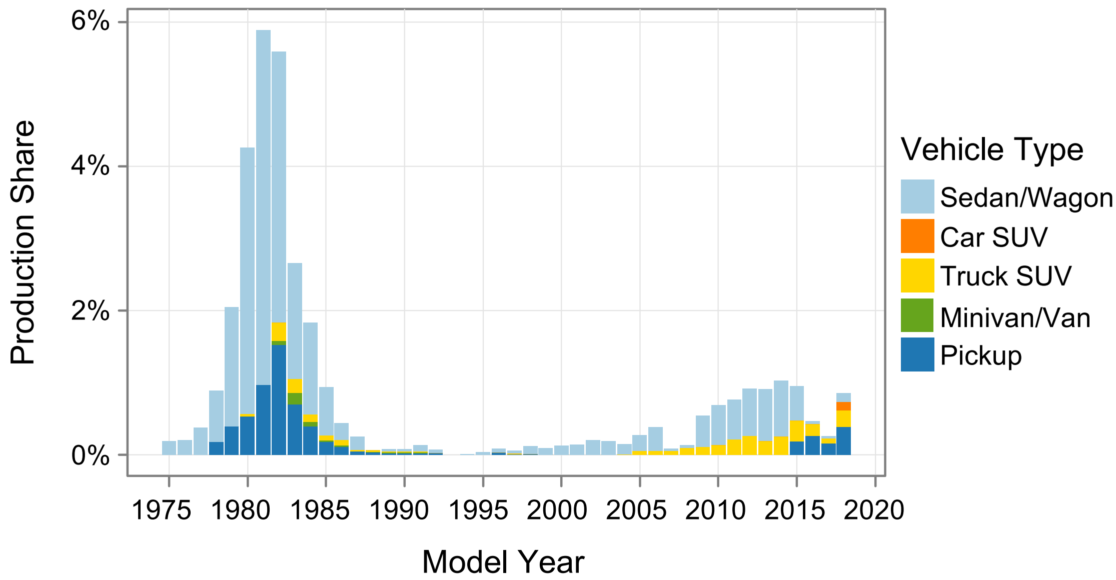


Figure 4.16. Diesel Engine Production Share by Number of Cylinders

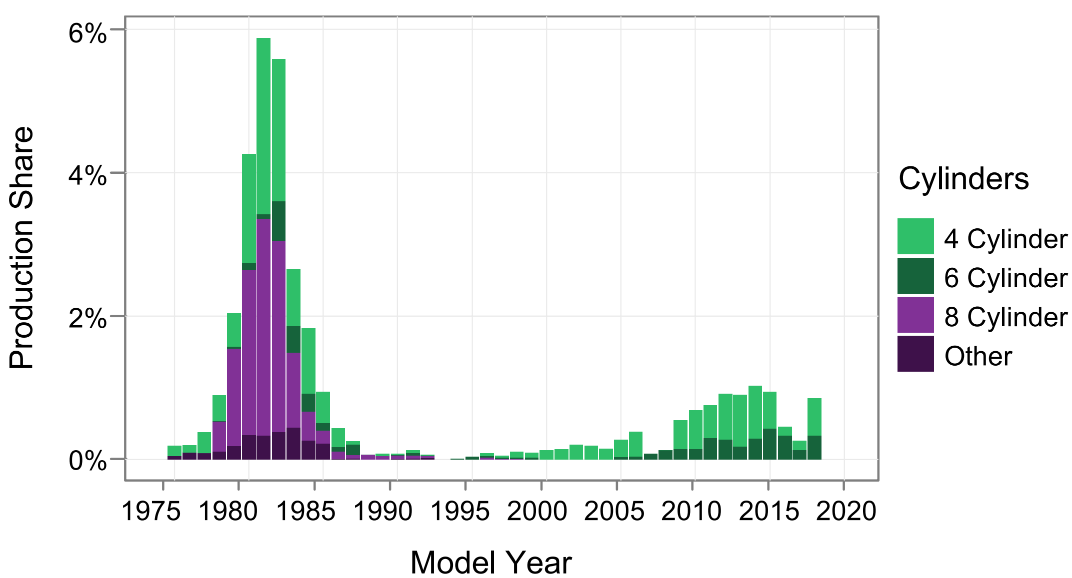
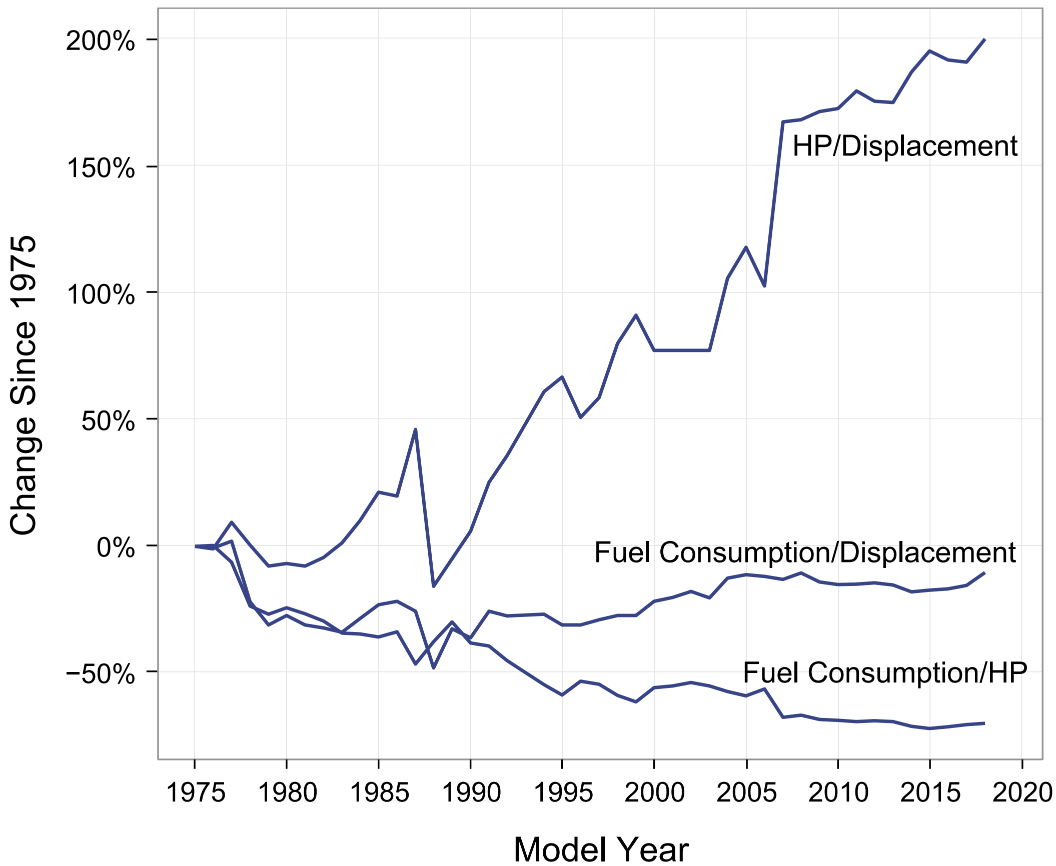


Figure 4.17. Percent Change for Specific Diesel Engine Metrics



Other Engine Technologies

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

B. Transmission and Drive Types

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

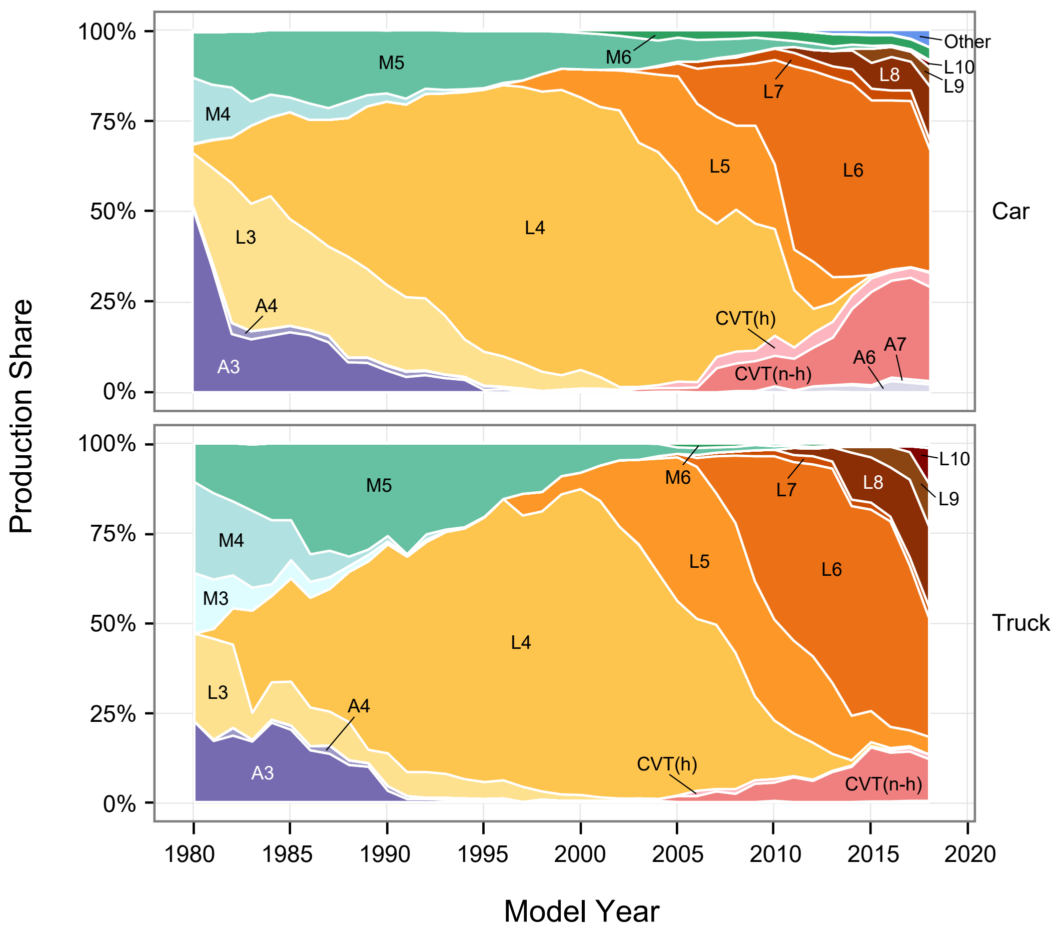
Transmissions

Transmission designs have been rapidly evolving to increase the number of gears available and allow for both better engine operation and improved efficiency. The number of gears in new vehicles continues to increase, as does the use of continuously variable transmissions (CVTs). Figure 4.18 shows the evolution of transmission production share for cars and trucks since model year 1980.[12] For this analysis, transmissions are separated into manual transmissions, CVTs, and automatic transmissions. Automatic transmissions are further separated into those with and without lockup mechanisms, which can lock up the torque converter in an automatic transmission under certain driving conditions and improve efficiency. CVTs have also been split into hybrid and non-hybrid versions to reflect the fact that hybrid CVTs are generally very different mechanically from traditional CVTs.

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

[12] EPA has incomplete transmission data prior to MY 1980.

Figure 4.18. Transmission Production Share



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

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

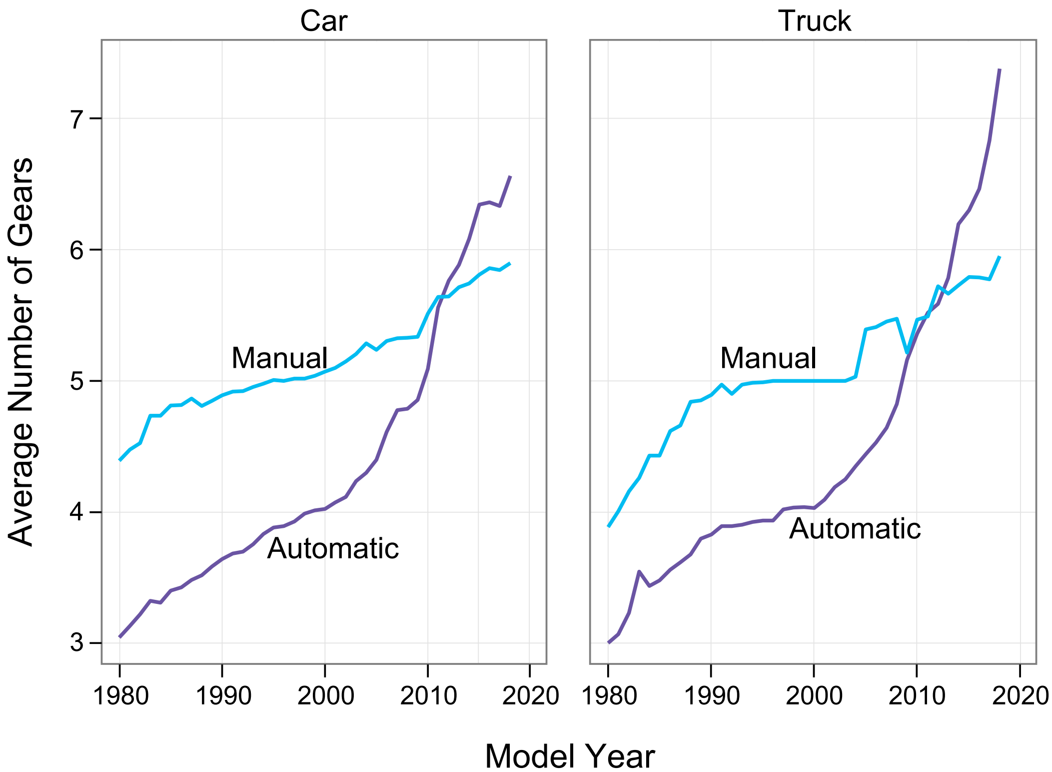
In the early 1980s, three-speed automatic transmissions, both with and without lockup torque converters (shown as L3 and A3) were the most popular transmissions, but by model year 1985, the four-speed automatic transmission with lockup (L4) became the most popular transmission, a position it would hold for 25 years. Over 80% of all new vehicles produced in model year 1999 were equipped with an L4 transmission. After model year 1999, the production share of L4 transmissions slowly decreased as L5 and L6 transmissions were introduced into the market. Production of L5 and L6 transmissions combined passed the production of L4 transmissions in model year 2007. Interestingly, five-speed transmissions were never the leading transmission technology in terms of production share.

Six-speed transmissions became the most popular transmission choice in model year 2010 and reached 60% of new vehicle production in model year 2013. However, six-speed transmissions may already have peaked, as transmissions with more than six-speeds and CVTs have been expanding quickly. CVTs were installed in almost 25% of all new vehicles in model year 2017 (including hybrids). This is a significant increase considering that, as recently as model year 2006, CVTs were installed in less than 2% of vehicles produced. Transmissions with seven or more speeds were installed in almost 25% of vehicles in model year 2017 and are quickly increasing.

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

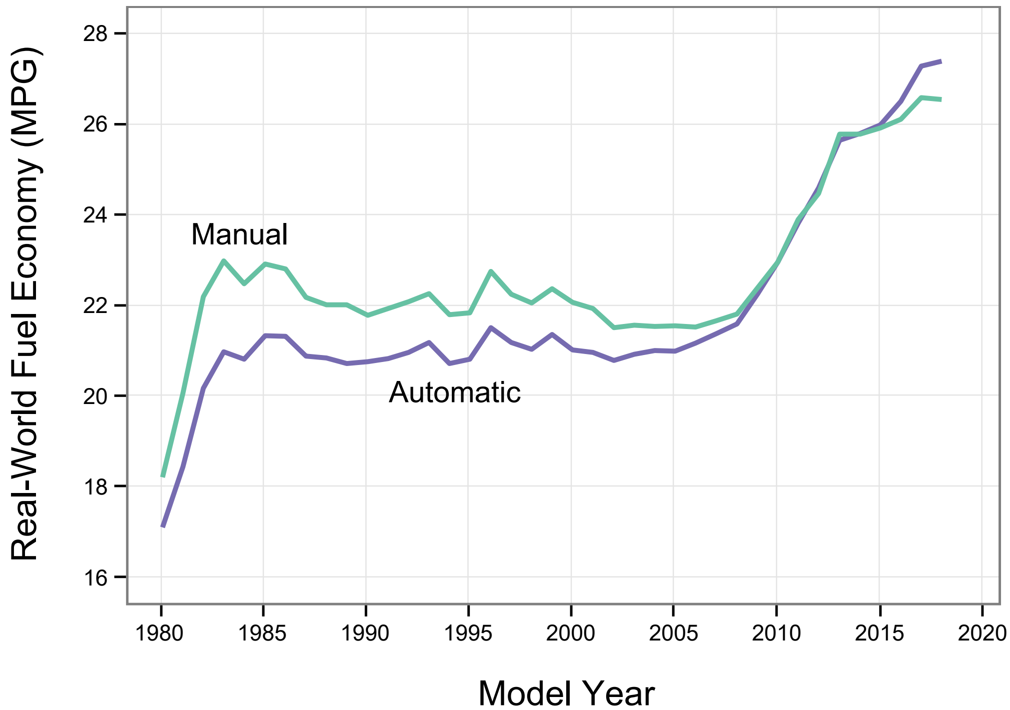
Since 1980, there has also been a large shift away from manual transmissions. Manual transmission production peaked in model year 1980 at nearly 35% of production and has since fallen to 2.1% in model year 2017. Today, manual transmissions are used primarily in small vehicles, some sports cars, and a few pickups.

Figure 4.19. Average Number of Transmission Gears for New Vehicles



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

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

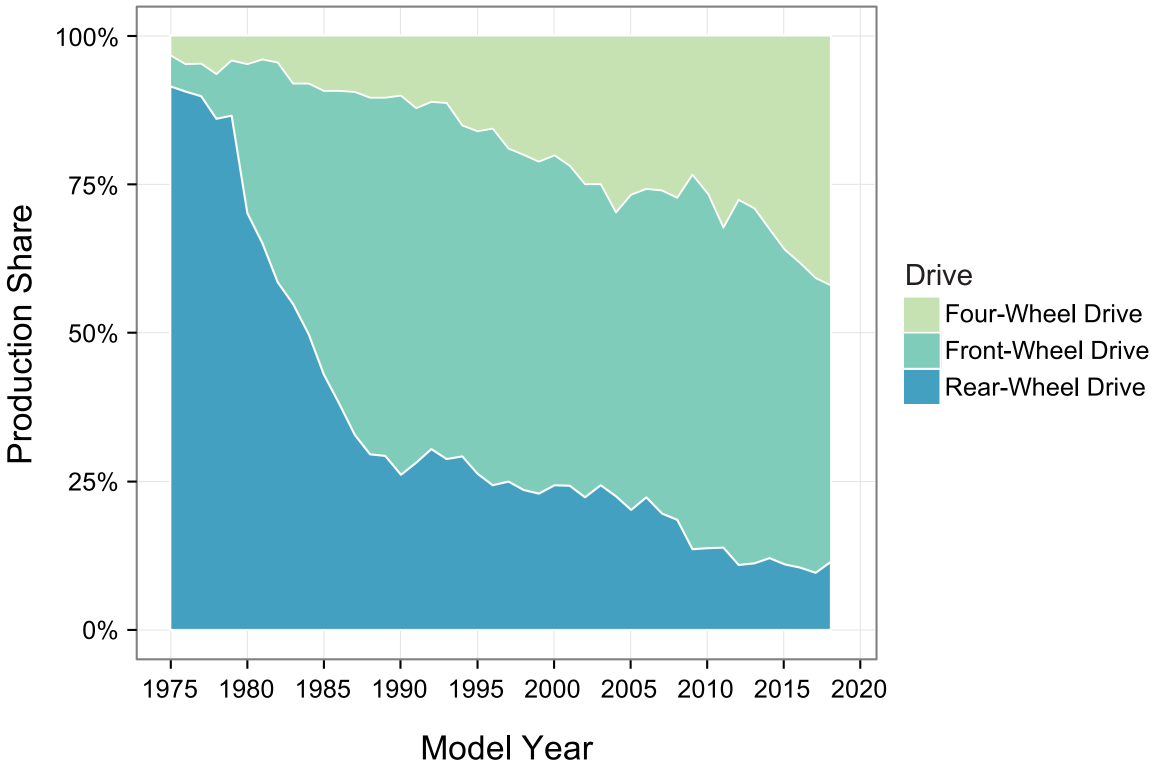


Drive Types

There has been a long and steady trend in new vehicle drive type away from rear-wheel drive vehicles towards front-wheel drive and four-wheel drive vehicles, as shown in Figure 4.21. In model year 1975, over 91% of new vehicles were produced with rear-wheel drive. Since then, production of rear-wheel drive vehicles has steadily declined to less than 10% in model year 2017. Current production of rear-wheel drive vehicles is mostly limited to pickup trucks and some performance vehicles.

As production of rear-wheel drive vehicles declined, production of front-wheel drive vehicles increased. Front-wheel drive vehicle production was only 5% of new vehicle production in model year 1975 but began increasing until about 64% of all new vehicles in model year 1990 were front-wheel drive designs. Front-wheel drive has remained the most popular vehicle design, but the production share of front-wheel drive vehicles has been falling as production of four-wheel drive vehicles has been steadily growing. Four-wheel drive (including all-wheel drive) systems have increased from 3.3% in model year 1975 to 41% in model year 2017. If this trend continues, four-wheel drive may be the most popular drive system within a few years.

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



C. Technology Adoption

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

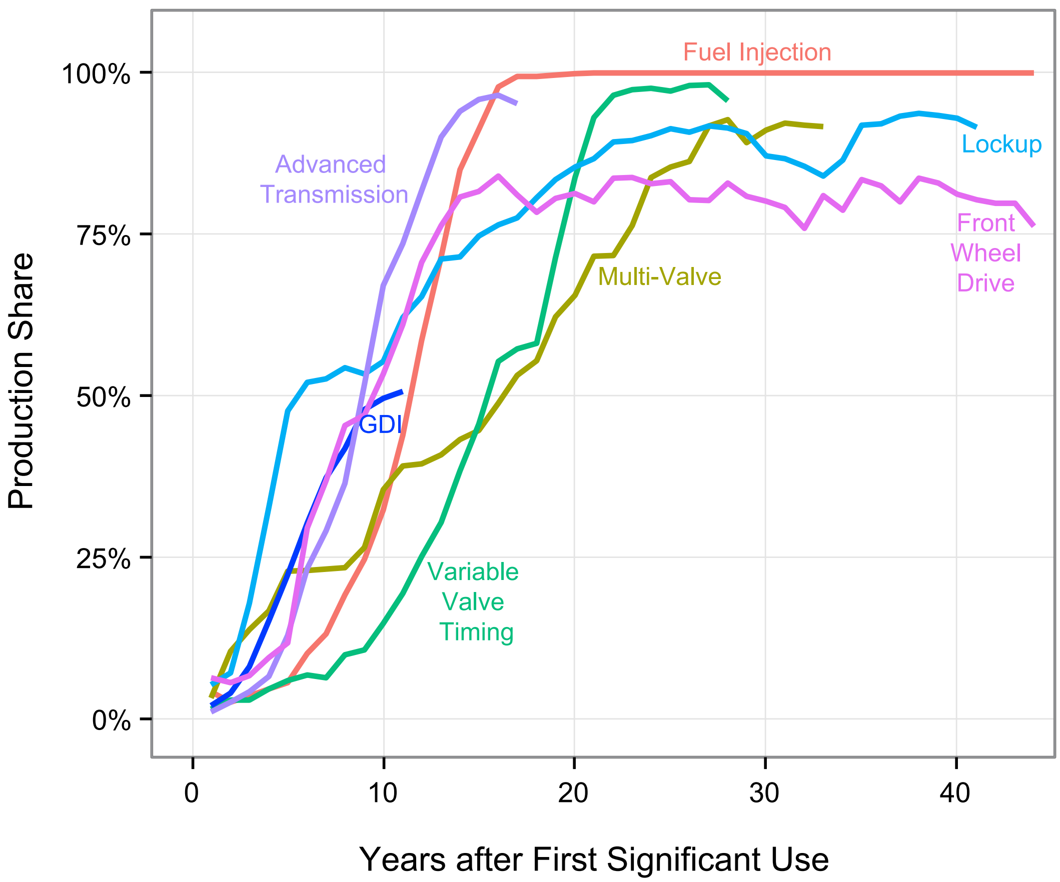
Industry-Wide Technology Adoption Since 1975

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

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

The analysis for Figure 4.22 focuses on technologies that have achieved widespread use by multiple manufacturers and does not look at narrowly-adopted technologies which never achieved widespread use. One limitation to the data in this report is that EPA does not begin tracking technology production share data until after the technologies had achieved some limited market share. For example, EPA did not begin to track multi-valve engine data until model year 1986 for cars and model year 1994 for trucks, and in both cases multi-valve engines had captured about 5% market share by that time. Likewise, turbochargers were not tracked in Trends until model year 1996 for cars and model year 2003 for trucks, and while turbochargers had less than a 1% market share in both cases at that time, it is likely that turbochargers had exceeded 1% market share in the late 1980s. Cylinder deactivation was utilized by at least one major manufacturer in the 1980s.

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



Technology Adoption by Manufacturers

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

Figure 4.23 begins to disaggregate the industry-wide trends to examine how individual manufacturers have adopted new technologies.[13] For each technology, Figure 4.23 shows the amount of time it took specific manufacturers to move from initial introduction to 80% penetration for each technology, as well as the same data for the overall industry. After 80% penetration, the technology is assumed to be largely incorporated into the manufacturer's fleet, and changes between 80% and 100% are not highlighted.

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

The data for variable valve timing (VVT), for example, show that several manufacturers adopted the technology much faster than the overall industry rate might suggest. As shown in Figure 4.22, it took a little over 20 years for VVT to reach 80% penetration across the industry. However, Figure 4.23 shows that several individual manufacturers implemented at least 80% VVT in significantly less time than the overall industry. Therefore, 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.

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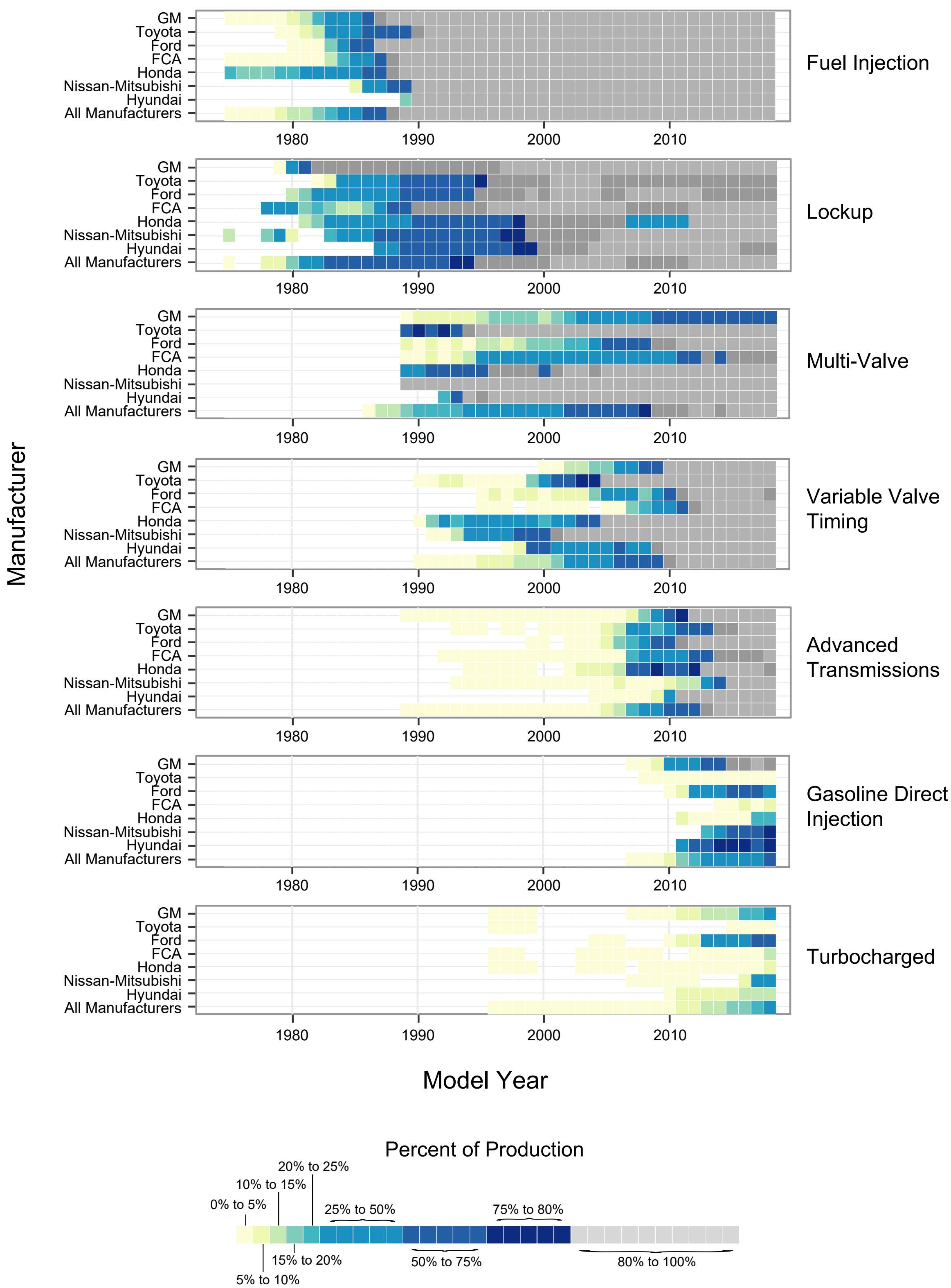
[13] This figure is based on available data. Some technologies may have been introduced into the market before this report began tracking them. Generally, these omissions are limited, with the exception of multi-valve engine data for Honda. Honda had already achieved 70% penetration of multi-valve engines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

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



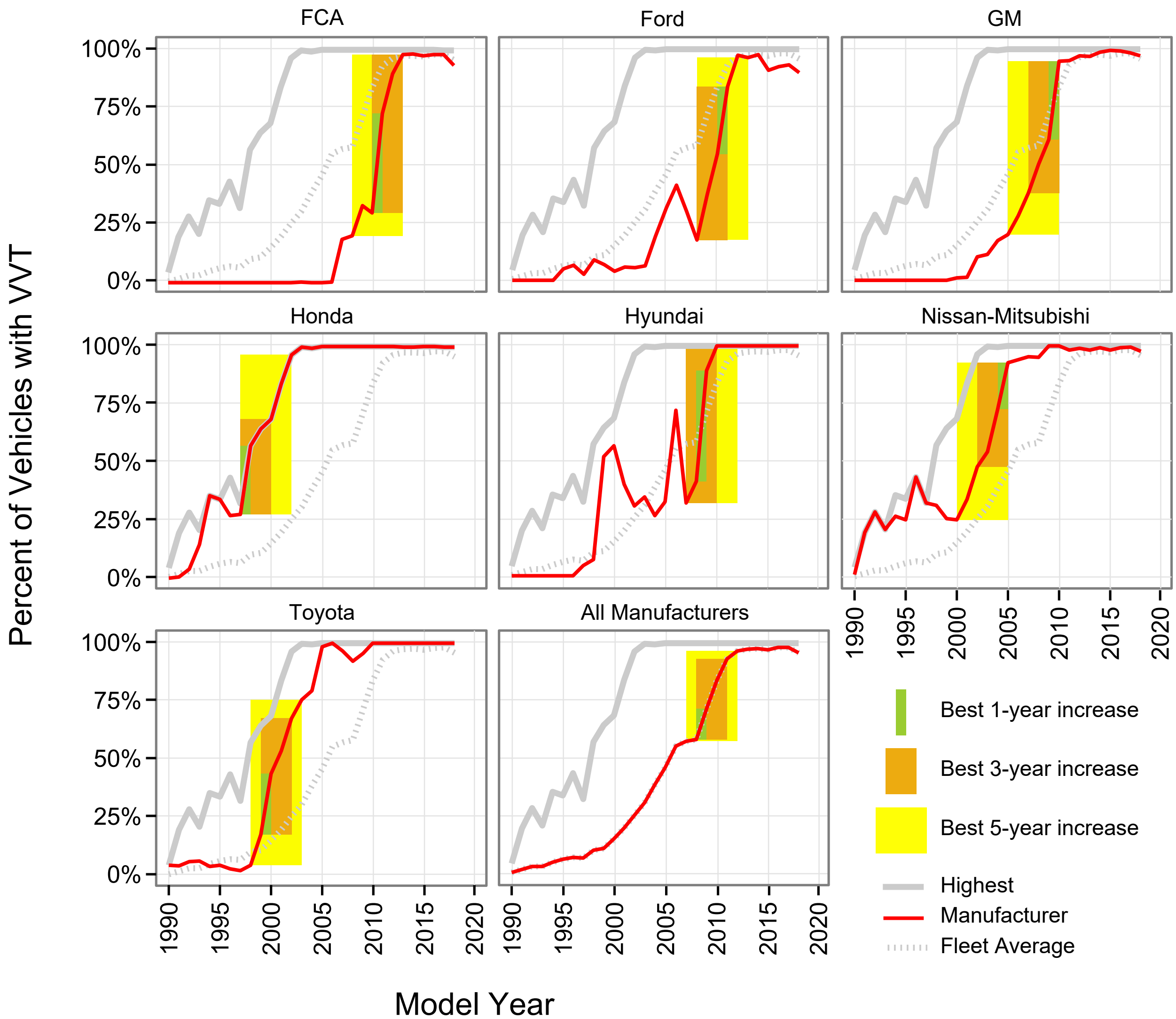
The discrepancy between manufacturer adoption rates, and the timeframe when they chose to adopt them, is clear in Figure 4.23 for VVT. For more detail, Figure 4.24 shows the percent penetration of VVT over time for each manufacturer (solid red line) versus the average for all manufacturers (dotted grey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

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

Figure 4.23 and Figure 4.24 examine manufacturer specific technology adoption in different ways, but both figures clearly support the conclusion that some manufacturers have been able to adopt technology much faster than industry-wide data suggest, and that there is significant variation in how individual manufacturers have adopted technology.

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

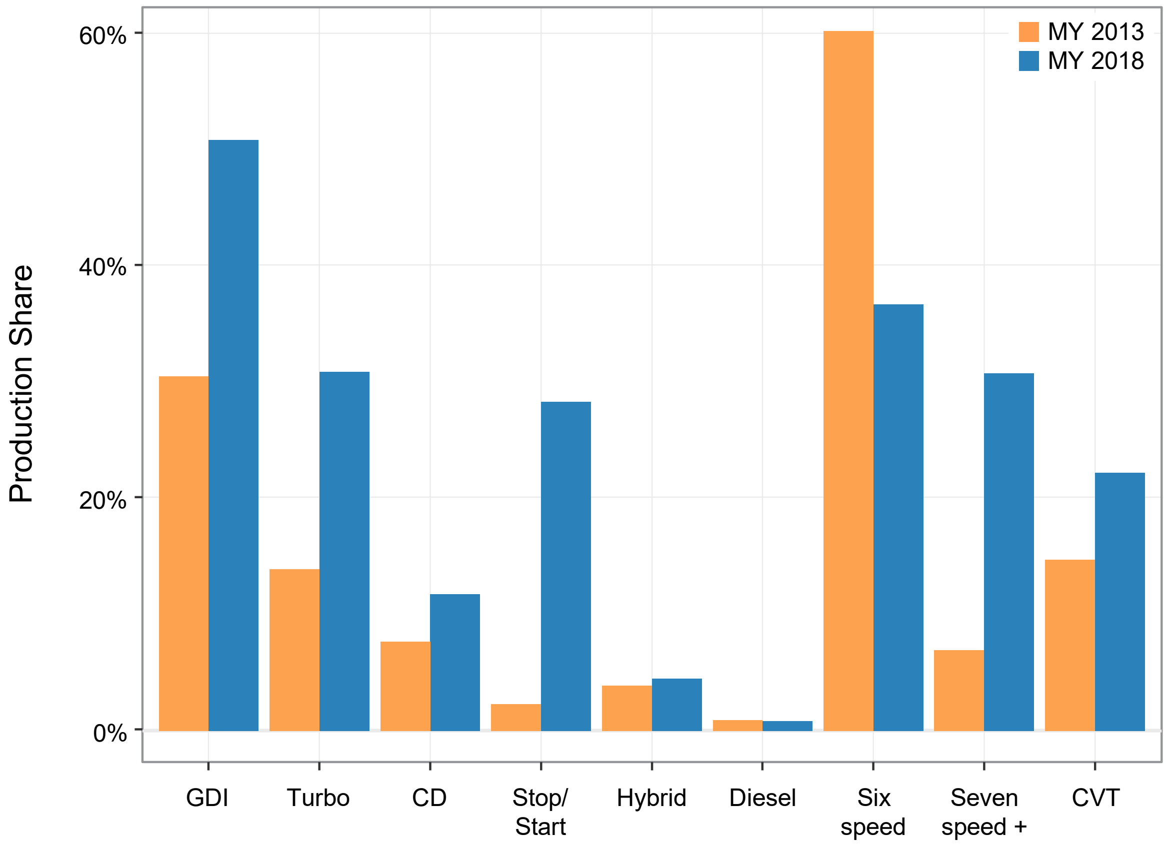
Figure 4.24. VVT Adoption Details by Manufacturer



Technology Adoption in the Last Five Years

Over the last five years, engines and transmissions have continued to evolve and adopt new technologies. Figure 4.25 shows the penetration of several key technologies in model year 2012 and the projected penetration for each technology in model year 2017 vehicles. Over that five-year span, GDI is projected to increase market share by about 27%, CVTs by more than 10%, and transmissions with seven- or more speeds by more than 18% across the entire industry. These are large changes taking place across the industry over a relatively short time. As discussed in the previous section, individual manufacturers are making technology changes at even faster rates.

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



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

Table 4.1. Production Share by Engine Technologies

	Powertrain				Fuel Delivery Method													
Model Year	Gasoline	Gasoline Hybrid	Diesel	Other	Carb	GDI	Port	TBI	Elec-tric	FCV	Avg. No. of Cylinders	CID	HP	Multi-Valve	VVT	CD	Turbo	Stop/ Start
1975	99.8%	-	0.2%	-	95.7%	-	4.1%	0.0%	-	-	6.8	293	137	-	-	-	-	-
1980	95.7%	-	4.3%	-	89.7%	-	5.2%	0.8%	-	-	5.6	198	104	-	-	-	-	-
1985	99.1%	-	0.9%	-	56.1%	-	18.2%	24.8%	-	-	5.5	189	114	-	-	-	-	-
1990	99.9%	-	0.1%	-	2.1%	-	70.8%	27.0%	-	-	5.4	185	135	23.1%	-	-	-	-
1995	100.0%	-	0.0%	-	-	-	91.6%	8.4%	-	-	5.6	196	158	35.6%	-	-	-	-
2000	99.8%	0.0%	0.1%	-	-	-	99.8%	0.0%	-	-	5.7	200	181	44.8%	15.0%	-	1.3%	-
2001	99.7%	0.1%	0.1%	-	-	-	99.9%	-	-	-	5.8	201	187	49.0%	19.6%	-	2.0%	-
2002	99.6%	0.2%	0.2%	-	-	-	99.8%	-	-	-	5.8	203	195	53.3%	25.3%	-	2.2%	-
2003	99.5%	0.3%	0.2%	-	-	-	99.8%	-	-	-	5.8	204	199	55.5%	30.6%	-	1.2%	-
2004	99.4%	0.5%	0.1%	-	-	-	99.9%	-	-	-	5.9	212	211	62.3%	38.5%	-	2.3%	-
2005	98.6%	1.1%	0.3%	-	-	-	99.7%	-	-	-	5.8	205	209	65.6%	45.8%	0.8%	1.7%	-
2006	98.1%	1.5%	0.4%	-	-	-	99.6%	-	-	-	5.7	204	213	71.7%	55.4%	3.6%	2.1%	-
2007	97.7%	2.2%	0.1%	-	-	-	99.8%	-	-	-	5.6	203	217	71.7%	57.3%	7.3%	2.5%	-
2008	97.4%	2.5%	0.1%	-	-	2.3%	97.6%	-	-	-	5.6	199	219	76.4%	58.2%	6.7%	3.0%	-
2009	97.2%	2.3%	0.5%	-	-	4.2%	95.2%	-	-	-	5.2	183	208	83.8%	71.5%	7.3%	3.3%	-
2010	95.5%	3.8%	0.7%	0.0%	-	8.3%	91.0%	-	-	0.0%	5.3	188	214	85.5%	83.8%	6.4%	3.3%	-
2011	97.0%	2.2%	0.8%	0.1%	-	15.4%	83.8%	-	0.1%	0.0%	5.4	192	230	86.4%	93.1%	9.5%	6.8%	-
2012	95.5%	3.1%	0.9%	0.4%	-	22.5%	76.5%	-	0.1%	0.0%	5.1	181	222	91.8%	96.6%	8.1%	8.4%	0.6%
2013	94.8%	3.6%	0.9%	0.7%	-	30.5%	68.3%	-	0.3%	-	5.1	176	226	92.8%	97.4%	7.7%	13.9%	2.3%
2014	95.7%	2.6%	1.0%	0.7%	-	37.4%	61.3%	-	0.3%	0.0%	5.1	180	230	89.2%	97.6%	10.6%	14.8%	5.1%
2015	95.9%	2.4%	0.9%	0.7%	-	41.9%	56.7%	-	0.5%	0.0%	5.0	177	229	91.2%	97.2%	10.5%	15.7%	7.1%
2016	96.9%	1.8%	0.5%	0.8%	-	48.0%	51.0%	-	0.5%	0.0%	5.0	174	230	92.3%	98.0%	10.4%	19.9%	9.6%
2017	96.1%	2.3%	0.3%	1.4%	-	49.7%	49.4%	-	0.6%	0.0%	5.0	174	233	91.9%	98.1%	11.9%	23.4%	17.8%
2018 (prelim)	*92.8%*	*3.6%*	*0.9%*	*2.7%*	-	*50.7%*	*46.6%*	-	*1.8%*	*0.0%*	*5.0*	*169*	*237*	*91.7%*	*95.7%*	*11.8%*	*30.8%*	*28.3%*

Table 4.2. Production Share by Transmission Technologies

Model Year	Manual	Automatic with Lockup	Automatic without Lockup	CVT (Hybrid)	CVT (Non-Hybrid)	Other	4 Gears or Fewer	5 Gears	6 Gears	7 Gears	8 Gears	9+ Gears	CVT (Hybrid)	CVT (Non-Hybrid)	Average No. of Gears
1975	23.0%	0.2%	76.8%	-	-	-	99.0%	1.0%	-	-	-	-	-	-	-
1980	34.6%	18.1%	46.8%	-	-	0.5%	87.9%	12.1%	-	-	-	-	-	-	3.5
1985	26.5%	54.5%	19.1%	-	-	-	80.7%	19.3%	-	-	-	-	-	-	3.8
1990	22.2%	71.2%	6.5%	-	0.0%	0.0%	79.9%	20.0%	0.1%	-	-	-	-	0.0%	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%	-	-	-	-	0.0%	4.1
2001	9.0%	90.3%	0.6%	0.1%	0.0%	-	80.7%	18.5%	0.7%	-	-	-	0.1%	0.0%	4.2
2002	8.2%	91.4%	0.3%	0.1%	0.1%	-	77.1%	21.6%	1.1%	-	-	-	0.1%	0.1%	4.2
2003	8.0%	90.8%	0.1%	0.3%	0.8%	-	69.2%	28.1%	1.7%	-	-	-	0.3%	0.8%	4.3
2004	6.8%	91.8%	0.3%	0.4%	0.7%	-	63.9%	31.8%	3.0%	0.2%	-	-	0.4%	0.7%	4.4
2005	6.2%	91.5%	0.1%	1.0%	1.3%	-	56.0%	37.3%	4.1%	0.2%	-	-	1.0%	1.3%	4.5
2006	6.5%	90.6%	0.0%	1.5%	1.4%	-	47.7%	39.2%	8.8%	1.4%	-	-	1.5%	1.4%	4.6
2007	5.6%	87.1%	0.0%	2.1%	5.1%	-	40.5%	36.1%	14.4%	1.5%	0.2%	-	2.1%	5.1%	4.8
2008	5.2%	86.8%	0.2%	2.4%	5.5%	-	38.8%	31.9%	19.4%	1.8%	0.2%	-	2.4%	5.5%	4.8
2009	4.8%	85.6%	0.2%	2.1%	7.3%	-	31.2%	32.2%	24.5%	2.5%	0.1%	-	2.1%	7.3%	5.0
2010	3.8%	84.1%	1.2%	3.8%	7.2%	-	24.6%	23.5%	38.1%	2.7%	0.2%	-	3.8%	7.2%	5.2
2011	3.2%	86.5%	0.3%	2.0%	8.0%	-	14.2%	18.7%	52.3%	3.1%	1.7%	-	2.0%	8.0%	5.5
2012	3.6%	83.4%	1.1%	2.7%	9.2%	-	8.1%	18.2%	56.3%	2.8%	2.6%	-	2.7%	9.2%	5.5
2013	3.5%	80.4%	1.4%	2.9%	11.8%	-	5.4%	12.8%	60.1%	2.8%	4.1%	-	2.9%	11.8%	5.6
2014	2.8%	76.7%	1.6%	2.3%	16.6%	-	2.2%	7.8%	58.4%	3.3%	8.4%	1.1%	2.3%	16.6%	5.9
2015	2.6%	72.3%	1.4%	2.2%	21.5%	-	1.5%	4.5%	54.2%	3.1%	9.5%	3.5%	2.2%	21.5%	5.9
2016	2.2%	72.4%	2.6%	1.7%	21.1%	-	1.1%	3.0%	54.9%	2.9%	11.3%	4.1%	1.7%	21.1%	6.0
2017	2.1%	71.5%	2.6%	1.9%	21.9%	-	1.0%	2.4%	49.0%	3.3%	14.6%	5.1%	1.9%	21.9%	6.1
2018 (prelim)	*2.5%*	*71.8%*	*3.5%*	*2.6%*	*19.6%*	-	*2.1%*	*2.6%*	*36.7%*	*3.5%*	*18.7%*	*8.5%*	*2.6%*	*19.6%*	*6.4*

Table 4.3. Production Share by Drive Technology

Model Year	Car			Truck			All		
	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Four Wheel Drive
1975	6.5%	93.5%	-	-	82.8%	17.2%	5.3%	91.4%	3.3%
1980	29.7%	69.4%	0.9%	1.4%	73.6%	25.0%	25.0%	70.1%	4.9%
1985	61.1%	36.8%	2.1%	7.3%	61.4%	31.3%	47.8%	42.9%	9.3%
1990	84.0%	15.0%	1.0%	15.8%	52.4%	31.8%	63.8%	26.1%	10.1%
1995	80.1%	18.8%	1.1%	18.4%	39.3%	42.3%	57.6%	26.3%	16.2%
2000	80.4%	17.7%	2.0%	20.0%	33.8%	46.3%	55.5%	24.3%	20.2%
2001	80.3%	16.7%	3.0%	16.3%	34.8%	48.8%	53.8%	24.2%	22.0%
2002	82.9%	13.5%	3.6%	15.4%	33.1%	51.6%	52.7%	22.3%	25.0%
2003	80.9%	15.9%	3.2%	15.4%	34.1%	50.4%	50.7%	24.3%	25.0%
2004	80.2%	14.5%	5.3%	12.5%	31.0%	56.5%	47.7%	22.4%	29.8%
2005	79.2%	14.2%	6.6%	20.1%	27.7%	52.2%	53.0%	20.2%	26.8%
2006	75.9%	18.0%	6.0%	18.9%	28.0%	53.1%	51.9%	22.3%	25.8%
2007	81.0%	13.4%	5.6%	16.1%	28.4%	55.5%	54.3%	19.6%	26.1%
2008	78.8%	14.1%	7.1%	18.4%	24.8%	56.8%	54.2%	18.5%	27.3%
2009	83.5%	10.2%	6.3%	21.0%	20.5%	58.5%	62.9%	13.6%	23.5%
2010	82.5%	11.2%	6.3%	20.9%	18.0%	61.0%	59.6%	13.7%	26.7%
2011	80.1%	11.3%	8.6%	17.7%	17.3%	65.0%	53.8%	13.8%	32.4%
2012	83.8%	8.8%	7.5%	20.9%	14.8%	64.3%	61.4%	10.9%	27.7%
2013	83.0%	9.3%	7.7%	18.1%	14.5%	67.5%	59.7%	11.1%	29.1%
2014	81.3%	10.6%	8.2%	17.5%	14.2%	68.3%	55.3%	12.1%	32.6%
2015	80.4%	9.7%	9.9%	16.0%	12.6%	71.4%	52.9%	10.9%	36.1%
2016	79.8%	9.1%	11.0%	15.8%	12.2%	72.0%	51.2%	10.5%	38.3%
2017	79.8%	8.3%	11.9%	16.1%	11.0%	72.8%	49.6%	9.6%	40.8%
2018 (prelim)	*76.3%*	*10.9%*	*12.8%*	*14.5%*	*12.1%*	*73.5%*	*46.4%*	*11.5%*	*42.1%*

5. Manufacturer GHG Compliance

On May 7, 2010, the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) established the first phase of a National Program to reduce greenhouse gas (GHG) emissions and improve fuel economy for 2012 to 2016 model year light-duty vehicles. On October 15, 2012, EPA and NHTSA established the second phase of the joint National Program for model years 2017–2025. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles. This section of the report is designed to provide as much information as possible about how the manufacturers are performing under EPA's GHG program.

The GHG program is a credit-based averaging, banking, and trading (ABT) program that evaluates every manufacturer's annual performance against increasingly stringent standards based on the vehicles each manufacturer sells. Credits represent emission reductions manufacturers achieve by reducing vehicle emissions beyond the standards. The provisions of the ABT program allow manufacturers to achieve the standards based on fleet average CO_2 emissions (i.e., the standards do not apply to individual vehicles), to bank credits or deficits for future years, and to trade credits between manufacturers. Manufacturers demonstrate compliance with the overall program by maintaining a positive or neutral credit balance.

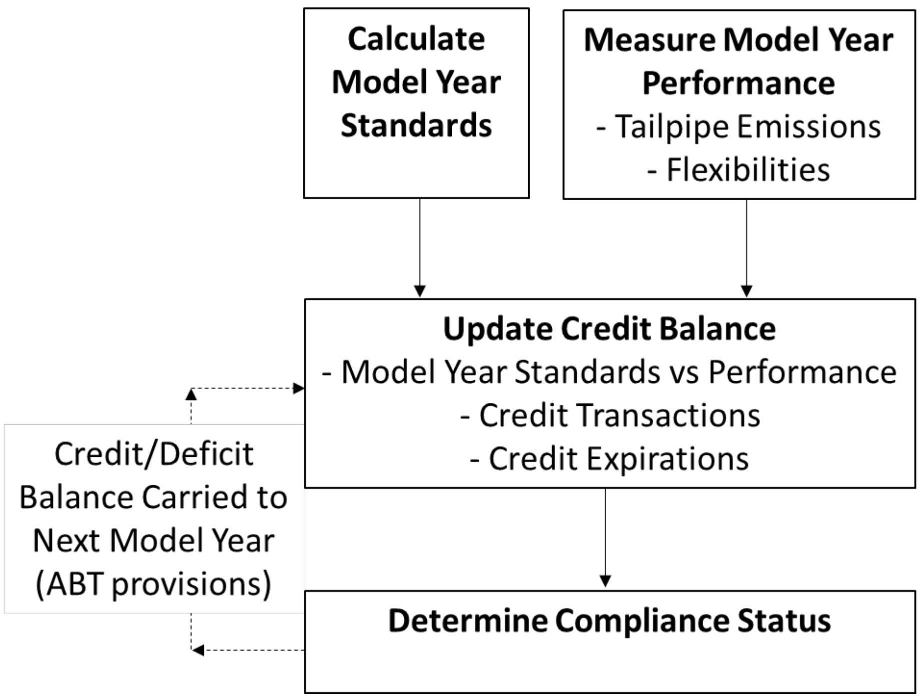
Averaging, banking and trading have been an important part of many mobile source programs under the Clean Air Act. These provisions help manufacturers in planning and implementing the orderly phase-in of emissions reduction technology in their production, consistent with their unique redesign schedules. EPA believes the net effect of the ABT provisions is that they allow additional flexibility, encourage earlier introduction of emission reduction technologies than might otherwise occur, and do so without reducing the overall effectiveness of the program.

The GHG Program and the Compliance Process

At the end of a model year, each manufacturer must determine its compliance status with the GHG program, and report compliance data to EPA, as summarized in Figure 5.1. First, each manufacturer must determine its individual car and truck standards, based on the footprint and production volumes of the vehicles it produced in that model year. Footprint – the area enclosed by where the four tires touch the ground – is a measure of vehicle size.

Second, manufacturers must determine their model year performance separately for cars and trucks. For each car/truck fleet, the performance is calculated based on measured CO_2 tailpipe emissions and the impact of flexibilities that manufacturers may qualify for and use. These flexibilities include optional credits for improved air-conditioning systems, emission reducing technologies that are not accounted for on standard EPA tests, alternative fuel vehicles, and alternate standards for small volume manufacturers.

Figure 5.1. GHG Program Compliance Process



After determining their standards and performance, manufacturers must determine an updated credit balance. Each manufacturer must compare their car and truck fleets' performance to their respective car and truck fleet standards to determine a credit surplus or shortfall. The model year credit surplus or shortfall for each fleet, any prior credit balance, and the impact of any credit transactions or expiring credits combine to determine the manufacturer's updated credit balance.

Finally, manufacturers must determine their compliance status. If a manufacturer ends the model year with a positive credit balance, they are in compliance with the GHG program, and their credit balance will be carried forward to the next model year. If a manufacturer ends the model year with a negative credit balance that they are unable to offset, they are considered to have a credit deficit. A deficit does not immediately result in non-compliance with EPA's GHG program. Manufacturers must, however, offset any deficit within three years after the model year in which it was generated to avoid non-compliance. For example, a manufacturer with a deficit remaining from model year 2014 after the 2017 model year would be considered out of compliance with the 2014 model year standards. Manufacturers may not carry forward any credits unless all deficits have been offset.

GHG Compliance and Credit Data

This section includes final compliance data for model years 2009 to 2017. However, credit transactions can occur between manufacturers at any time, and manufacturers may submit requests for credits retroactively. The data in this report reflect all credits and transactions reported to EPA prior to October 31st, 2018. Any additional credit requests or transactions will be reflected in next year's report. This report includes the most up to date data for all model years, and therefore supersedes all previous reports.

The GHG program uses two different metrics to measure CO_2 emissions, per vehicle emission rates measured in grams per mile (g/mi), and total vehicle lifetime emissions reductions measured in megagrams (Mg). Manufacturer standards, tailpipe CO_2 emissions, and most annual credits and flexibilities described in this report are discussed as per vehicle emission rates in g/mi.

However, the total credit balance of manufacturers is calculated in Mg to account for the number of vehicles produced and the expected lifetime use of those vehicles, in addition to manufacturer performance compared to their standards (see inset "How to Calculate Vehicle Lifetime Emission Reductions from a Per-Mile Emission Rate"). Any discussion of manufacturer total credit balances, credit transactions, and compliance will be in terms of megagrams or teragrams (Tg) of credits.

How to Calculate Vehicle Lifetime Emission Reductions from a Per-Mile Emission Rate

In the GHG Program, vehicle lifetime emission reductions are measured in megagrams (Mg) of CO_2, which is 1,000 kilograms, and also known as a metric ton. Emission reductions in Mg are determined from gram per mile (g/mi) emission rates, production volume, and expected lifetime miles. To calculate total Mg of credits the following equation is used:

$$\text{Credits [Mg]} = (CO_2 \times \text{VMT} \times \text{Production}) / 1{,}000{,}000$$

"CO_2" represents a credit in g/mi. "VMT" represents the total lifetime miles, which is specified in the regulations as 195,264 miles for cars and 225,865 for trucks. "Production" represents the production volume to which the CO_2 credit applies. To calculate g/mi from Mg:

$$CO_2\text{ [g/mi]} = (\text{Credits[Mg]} \times 1{,}000{,}000) / (\text{VMT} \times \text{Production})$$

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 2017 model year, the weighted VMT is 209,789 miles. For convenience, this report will report credits in Tg (1,000,000 Mg) where appropriate.

Unlike the previous sections, 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.

In addition, four small volume manufacturers have been excluded from this section of the report. Aston Martin, Ferrari, Lotus, and McLaren have applied for alternative standards available to small manufacturers, and decisions on these applications remain pending. A future edition of this report will include data from these companies once EPA makes a final determination on their requests. As a result, the total fleetwide production volume reported in this section will be slightly lower than values reported elsewhere in this report.

To download the data presented in this section, and any additional data EPA may make available, please see the report website: https://www.epa.gov/automotive-trends.

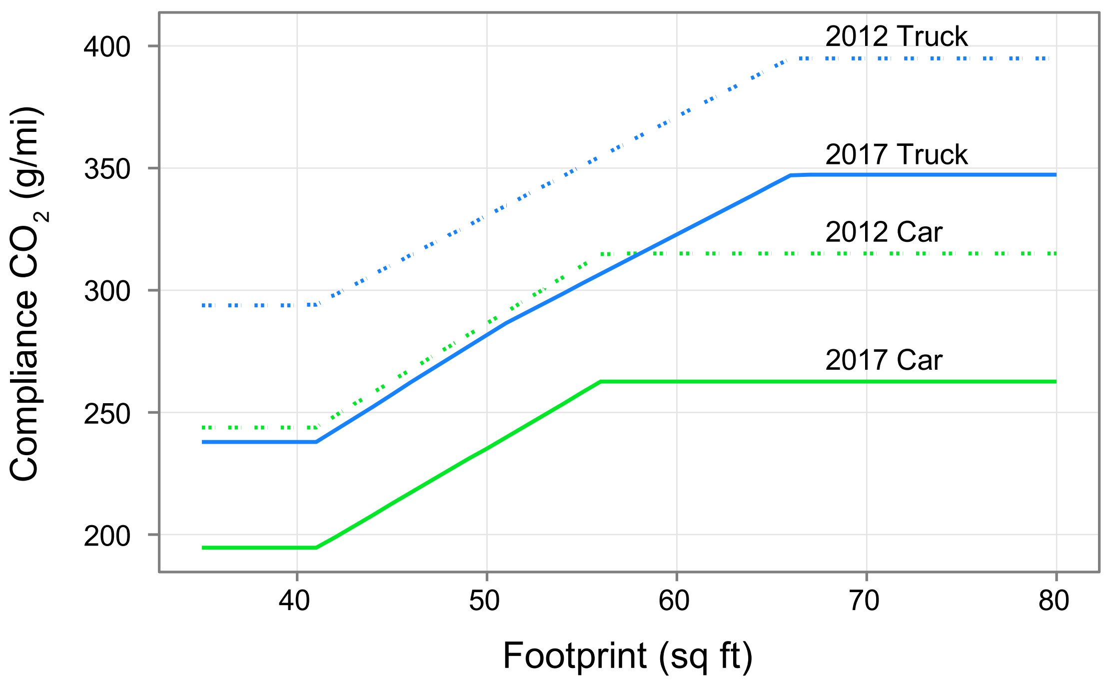
A. Footprint-Based CO_2 Standards

At the end of each model year, manufacturers are required to calculate unique CO_2 standards for each fleet (cars and trucks) as specified in the regulations. As described previously, these standards are specific to each manufacturer's car and truck fleet based on the number of vehicles produced and the vehicle footprints within each fleet. Manufacturers must calculate new standards each year as the footprint targets become more stringent, and as their footprint distribution and production change. See Section 3 for a discussion of the trends in footprint across the industry and the definitions of "car" and "truck" under the regulations.

The regulations define footprint "curves" that provide a CO_2 emissions target for every vehicle footprint, as shown in Figure 5.2. For example, a car with a footprint of 46 square feet in model year 2017 (the average car footprint) has a compliance CO_2 target of 217 g/mi. This is a target, and not a standard, as there are no footprint-based CO_2 emissions requirements for individual vehicles. 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 program. Using one production-weighted average to define a single fleet standard allows for some individual vehicles to be above that standard, relying on other vehicles below the fleet standard to achieve compliance.

The footprint curves for the 2012 and 2017 model years are shown in Figure 5.2. The targets have gradually decreased (become more stringent) from 2012 to the current 2017 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. Trends in the overall average footprint value and vehicle type mix, as discussed in Section 3, are thus important because of the direct impact on the annual GHG standards.

Figure 5.2. 2012–2017 Model Year CO_2 Footprint Target Curves



In model year 2017, the average car and truck footprints were about the same as the previous year, at 46 and 54 square feet, respectively. The industry did continue to move more towards trucks, as trucks increased their market share by almost three percentage points. The more stringent model year 2017 targets resulted in a reduction of the car standard by 12 g/mi and of the truck standard by 1 g/mi. While there is no combined car and truck standard for regulatory purposes, this report will often calculate one to provide an overall view of the industry and to allow comparison across manufacturers. Overall, the effective combined car and truck standard decreased by 5 g/mi from 2016 to 2017.

Jaguar Land Rover and Volvo opted to continue to meet the 2016 model year standards in 2017 under special provisions for intermediate volume manufacturers (less than 50,000 vehicles produced per year). These provisions allow qualifying manufacturers to use an alternative compliance schedule that allows them to meet the 2016 model year standards in the 2017 and 2018 model years, then delay meeting the 2018-2020 standards by one model year, then finally aligning with the primary standards and other manufacturers in the 2021 model year. Thus, the standards shown in Table 5.1 for these two manufacturers reflect the less stringent 2016 model year footprint target curves rather than the 2017 curves.

Table 5.1. Manufacturer Footprint and Standards for Model Year 2017

	Footprint (ft^2)			Standards (g/mi)		
Manufacturer	**Car**	**Truck**	**All**	**Car**	**Truck**	**All**
BMW	46.7	50.6	47.9	221	284	243
BYD Motors	47.9	-	47.9	226	-	226
FCA	47.4	54.1	52.8	225	297	285
Ford	46.9	57.3	52.5	222	308	272
GM	46.6	58.9	53.5	221	315	277
Honda	45.9	49.7	47.1	217	279	240
Hyundai	46.3	49.2	46.5	219	278	223
Jaguar Land Rover	49.0	51.0	50.6	244	287	278
Kia	46.1	50.0	47.2	218	281	237
Mazda	45.5	47.2	46.0	216	268	233
Mercedes	48.5	52.0	50.0	229	290	257
Nissan-Mitsubishi	45.8	51.3	47.6	217	286	243
Subaru	45.1	45.0	45.0	213	258	247
Tesla	53.8	-	53.8	252	-	252
Toyota	45.6	52.6	49.0	216	290	255
VW	45.0	50.2	46.3	213	282	232
Volvo	48.4	51.2	50.0	241	288	270
All Manufacturers	**46.2**	**53.8**	**49.8**	**219**	**295**	**258**

B. Model Year Performance

After determining their standards for a given model year, manufacturers must determine the CO_2 emissions performance for their car and truck fleets. In this report, we use the concept of a fleet's "performance" as a useful way to explain how manufacturers' fleets are performing in comparison to the standards (it is not explicitly part of the regulations). Model year performance is defined as the average production-weighted tailpipe CO_2 emissions of that fleet, adjusted by the net impact of all applicable flexibilities.

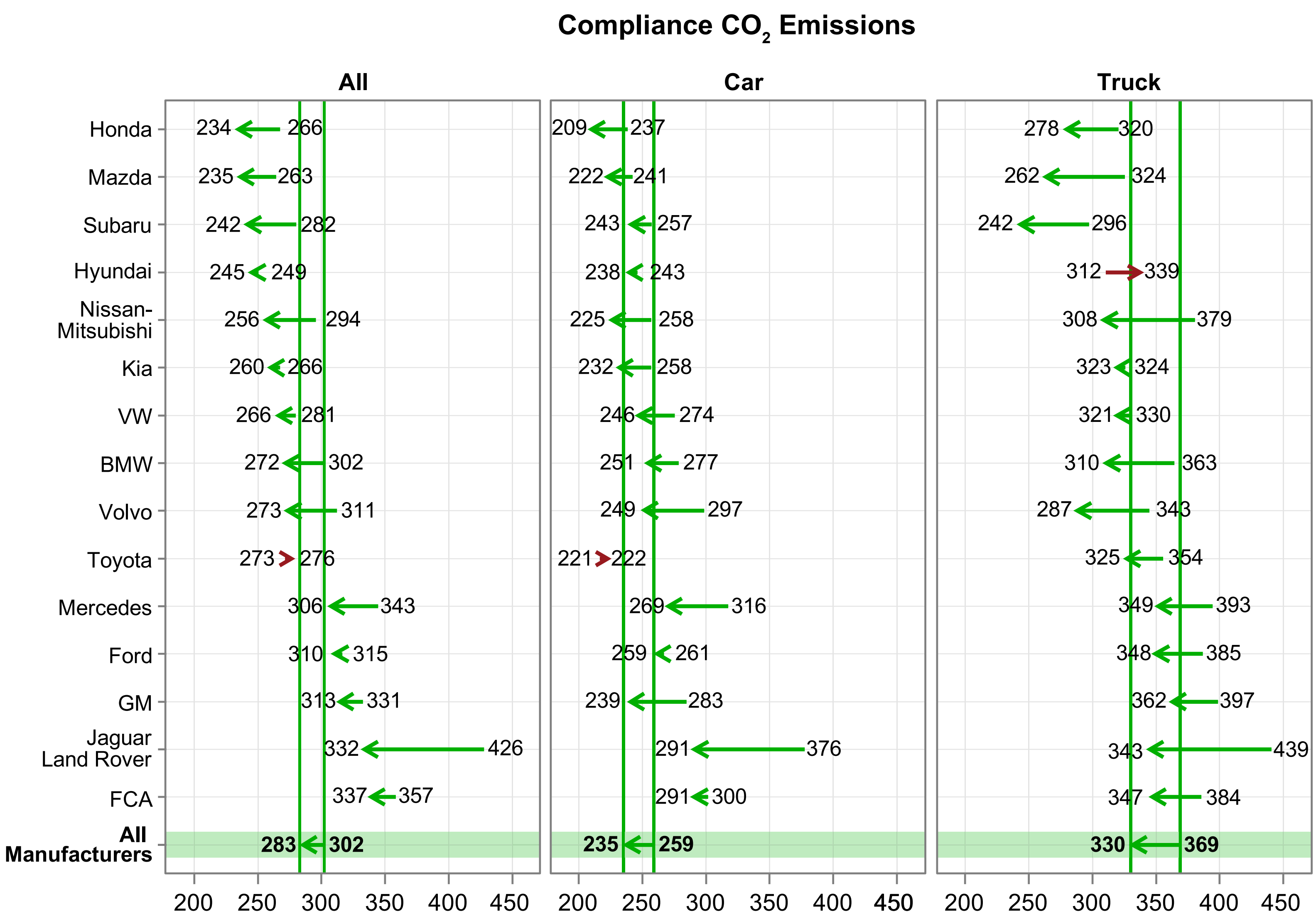
Tailpipe CO_2 Emissions

The starting point for determining compliance for each manufacturer is their "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 credits or incentives. 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.

Figure 5.3 shows the 2-cycle tailpipe emissions reported by each manufacturer for the 2012 and 2017 model years, for all vehicles and for car and truck fleets. Companies that produce solely electric vehicles (Tesla and BYD) are excluded from the figure because they produce zero tailpipe emissions on the 2-cycle test procedures.

Every manufacturer except Toyota has reduced tailpipe GHG emissions since the program took effect in model year 2012. Compared to the first year of the program, Jaguar Land Rover leads manufacturers in both the overall reduction in 2-cycle CO_2 emissions (94 g/mi) and the percentage reduction (22%). Seven manufacturers have reduced tailpipe CO_2 emissions by 10–15%, while the remainder produced single digit percentage reductions since the first year of the program. Overall, tailpipe CO_2 emissions of the entire fleet have been reduced by 19 g/mi, or about 6%, since the 2012 model year. These tailpipe values should not be directly compared to the manufacturer's standards presented in Table 5.1, as the standards were created taking into consideration the optional credit opportunities available to manufacturers, and final fleet performance values will take these credits into account.

Figure 5.3. Changes in "2-Cycle" Tailpipe CO_2 Emissions, Model Year 2012 to 2017 (g/mi)



Credits for Producing Alternative Fuel Vehicles

EPA's GHG program provides several incentives for dedicated and dual fuel alternative fuel vehicles. Dedicated alternative fuel vehicles run exclusively on an alternative fuel (e.g., compressed natural gas (CNG), electricity). Dual fuel vehicles can run both on an alternative fuel and on a conventional fuel; the most common is the gasoline-ethanol flexible fuel vehicle (FFV), which can run on E85 (85% ethanol and 15% gasoline), or on conventional gasoline. Dual fuel vehicles also include those that use CNG and gasoline, or electricity and gasoline. This section separately describes three categories of alternative fuel vehicles: advanced technology vehicles using electricity or hydrogen fuel cells, CNG vehicle, and FFVs.

Advanced Technology Vehicles

Advanced technology vehicle incentives apply to electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs). For the 2012–2016 model years, these incentives allowed EVs and FCVs to use zero g/mi to characterize their emissions, and PHEVs 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 2017–2021 model years, manufacturers may continue to use zero g/mi for these vehicles, without any limits. This incentive is reflected in the 2-cycle emissions values shown previously.

For model years 2017–2021, there are also temporary incentive "multipliers" for EVs, PHEVs, FCVs, and CNG vehicles. Multipliers allow manufacturers to count these vehicles as more than one vehicle in their fleet average emissions calculations. For example, the 2.0 multiplier for 2017 model year EVs allows a manufacturer to count every EV produced as two EVs, thus doubling the impact of their EV production. 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 Natural Gas Vehicles, and Dual-Fuel Natural Gas Vehicles
2017	2.0	1.6
2018	2.0	1.6
2019	2.0	1.6
2020	1.75	1.45
2021	1.5	1.3

Figure 5.4. Model Year 2017 Production of EVs, PHEVs, and FCVs

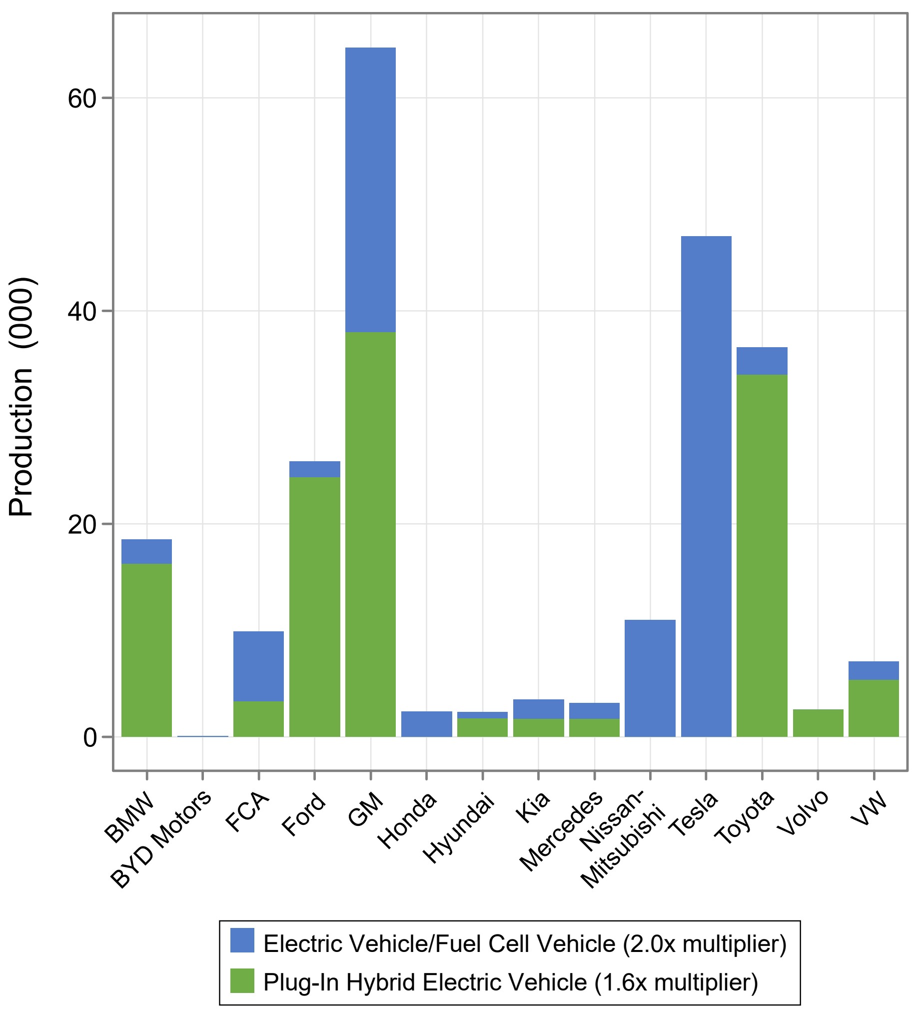


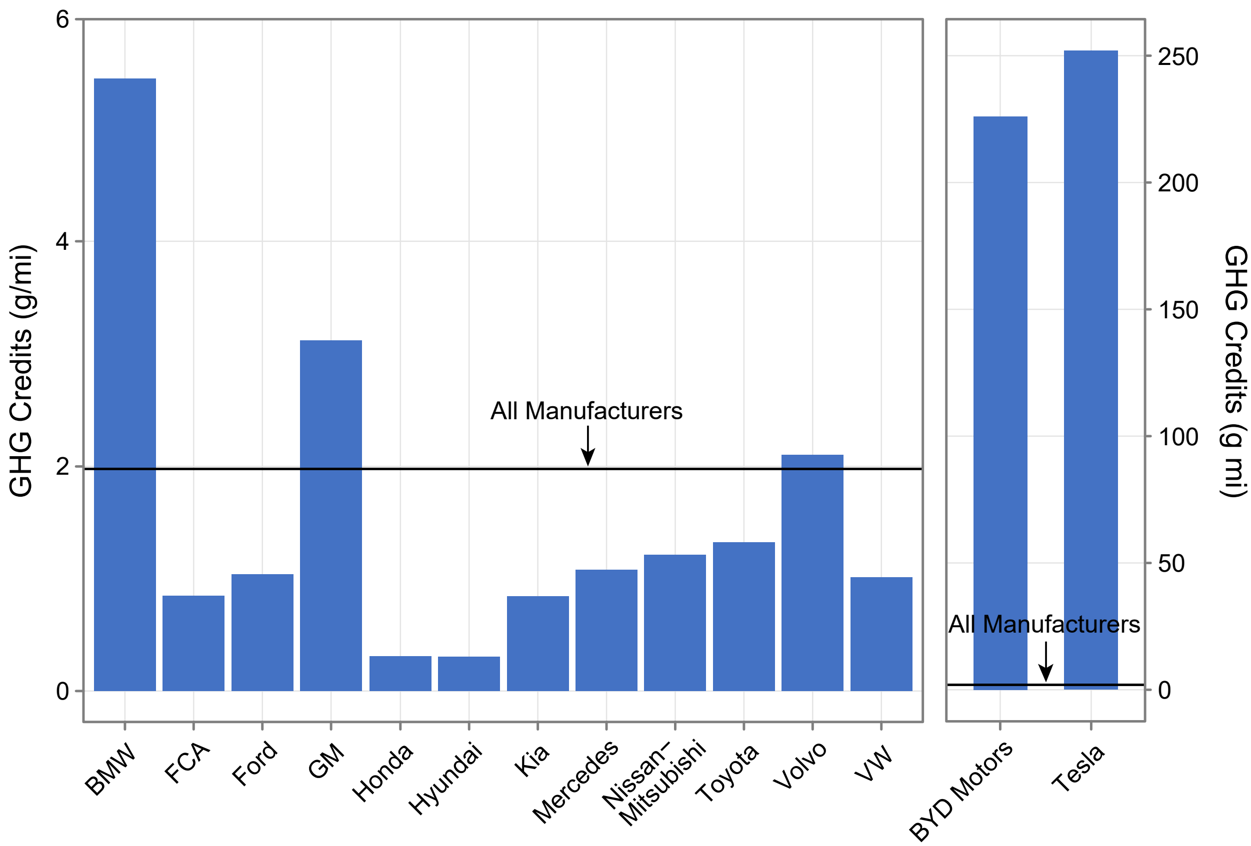
Figure 5.4 shows the 2012–2017 production volume of vehicles qualifying for the zero g/mi incentive. More than 230,000 EVs, PHEVs, and FCVs were produced in the 2017 model year; 55% of which were PHEVs with a multiplier of 1.6, and the remaining 45% were EVs and FCVs with a multiplier of 2.0. Since the 2012 model year, production of advanced technology vehicles has increased almost fivefold, with virtually every manufacturer offering something in this category of vehicles. Most are EVs and PHEVs; only a very small fraction are FCVs. Figure 4.13 in the previous section shows the overall trends in EVs, PHEVs, and FCVs.

EPA and NHTSA received a joint petition from the Alliance of Automobile Manufacturers and the Association of Global Automakers on June 20, 2016 regarding aspects of the CAFE and GHG programs. Item 8 of the petition, titled "Correct the Multiplier for BEVs, PHEVs, FCVs, and CNGs," notes that "the equation through which the number of earned credits is calculated is inaccurately stated in the regulations" and that credits would be inadvertently lost due to the error. Agreeing with the automaker petition, EPA proposed to modify the regulations to correctly calculate the multiplier-based credits in a notice of proposed rulemaking (NPRM) published on October 1, 2018.

EPA will not prejudge the outcome of an ongoing regulatory process, therefore this report is unable to include official multiplier-based credits for manufacturers until the rulemaking process is completed. However, for the purposes of this report, and to represent the multiplier-based credits fairly and consistently across manufacturers, we include a preliminary determination of multiplier-based credits for each manufacturer with qualifying vehicles. These preliminary credits were determined using the methodology proposed in the October 2018 NPRM and should be viewed only as unofficial estimates. Official values will be included in a future edition of this report after regulations are finalized.

The multiplier-based credits are dependent on the type of advanced technology vehicle and the proportion of a manufacturer's fleet made up of qualifying vehicles. Figure 5.5 shows the estimated multiplier-based credits, in g/mi, for each manufacturer. About 5% of BMW's model year 2017 production was EVs and PHEVs, giving the company a benefit of 5.5 g/mi (i.e., effectively reducing their fleet performance by 5.5 g/mi). General Motors, through the success of the Chevrolet Volt and Chevrolet Bolt, which collectively made up almost 2.5% of GM's fleet, established a multiplier-based benefit of 3.1 g/mi. The companies that make solely EVs – BYD and Tesla – are shown separately in Figure 5.5 because of the disproportionate credit values for these companies.

Figure 5.5. Model Year 2017 Advanced Technology Credits by Manufacturer



Compressed Natural Gas Vehicles

There were no CNG vehicles subject to the GHG standards in the 2017 model year. The Honda Civic CNG was the only CNG vehicle produced for general purchase by consumers during the first phase of EPA's GHG program, and it was only available in the 2012–2014 model years. In the 2015 and 2016 model years, Quantum Technologies offered a dual fuel (CNG and gasoline) version of GM's Chevrolet Impala through an agreement with GM, but none were produced in the 2017 model year.

Gasoline-Ethanol Flexible Fuel Vehicles

For the 2012 to 2015 model years, FFVs could earn GHG 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. A 2014 guidance letter defined 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.

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

Most manufacturers focused their FFV production in the truck segment, with trucks making up almost 75% of all FFV production in the 2017 model year. Only Nissan-Mitsubishi increased FFV production relative to the previous model year, after producing no FFVs in the 2016 model year. All others reduced their production of FFVs, down 13% relative to model year 2016 and reaching a low since the start of the program in model year 2012. Total FFV production in model year 2017 was down by almost 60% relative to model year 2014, the peak year for FFV production. FFV production is shown in Figure 5.6. The credit impact of those FFV credits is shown in Figure 5.7.

Figure 5.6. Production of FFVs, Model Year 2012–2017

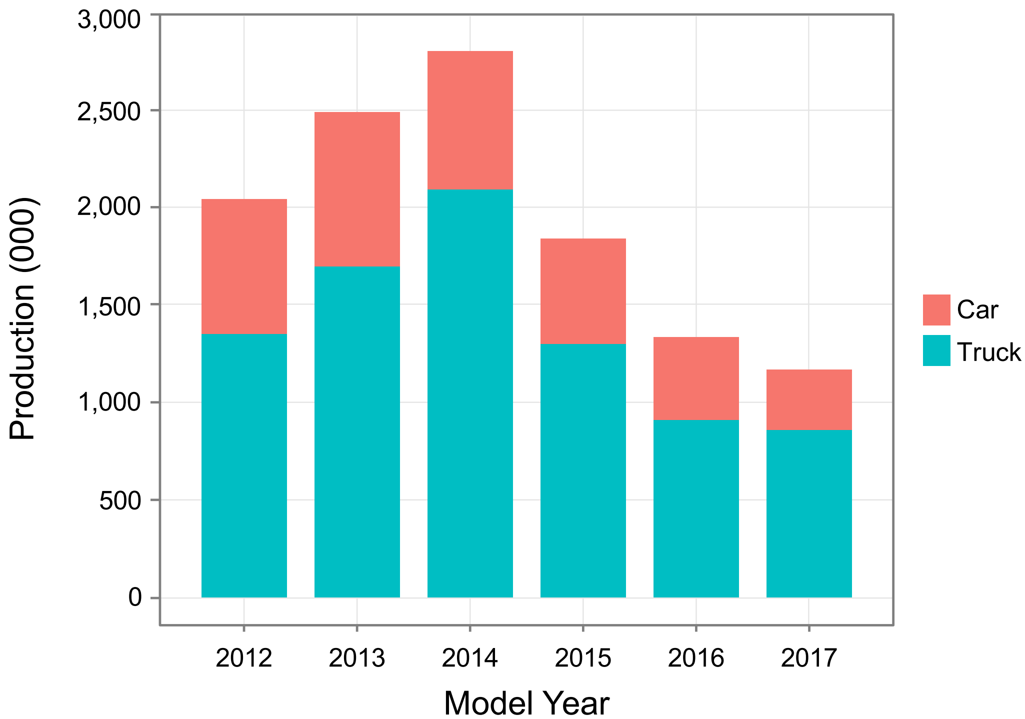
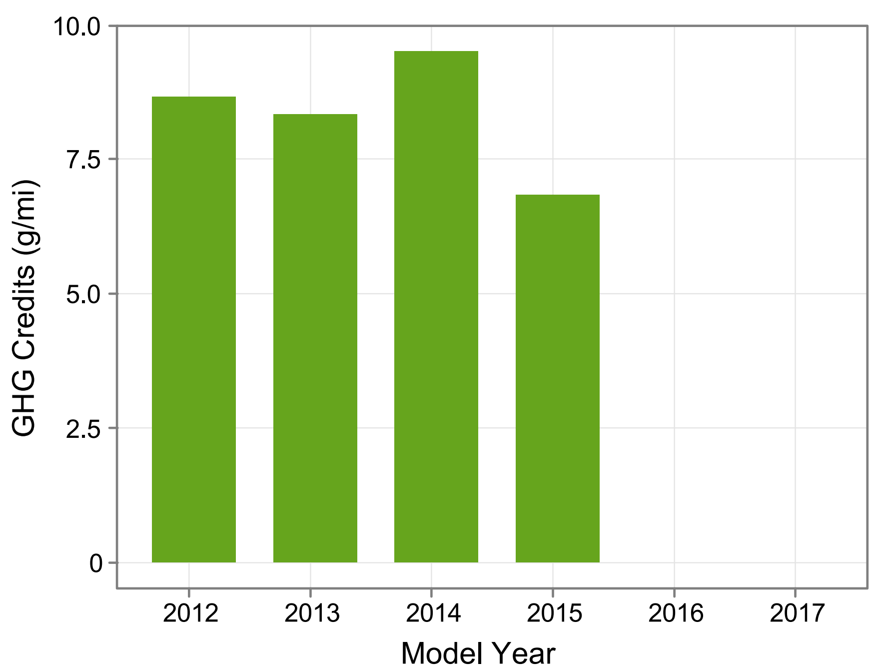


Figure 5.7. FFV Credits by Model Year



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 Credits

The high global warming potential (GWP)[14] of the current predominant automotive refrigerant, HFC-134a, means that leakage of a small amount of refrigerant will have a far greater impact on global warming than emissions of a similar volume 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 converted to a g/mi credit value based on the GWP of the refrigerant, then the g/mi value is used to determine the total tons of credits based on the production volume of the vehicles employing that A/C system.

In the 2012 model year, all leakage credits were based on improvements to the A/C system components (e.g., O-rings, seals, valves, and fittings). In the 2013 model year, GM and Honda introduced vehicles using HFO-1234yf, which has an extremely low global warming potential (GWP) of 4, as compared to a GWP of 1430 for HFC-134a. In the four model years since, use has expanded to ten manufacturers and almost 40% of the fleet. BMW and Jaguar Land Rover have now fully implemented HFO-1234yf across their fleets, and FCA's adoption is at 85% of their 2017 model year fleet. Ford, GM, and Honda have exceeded

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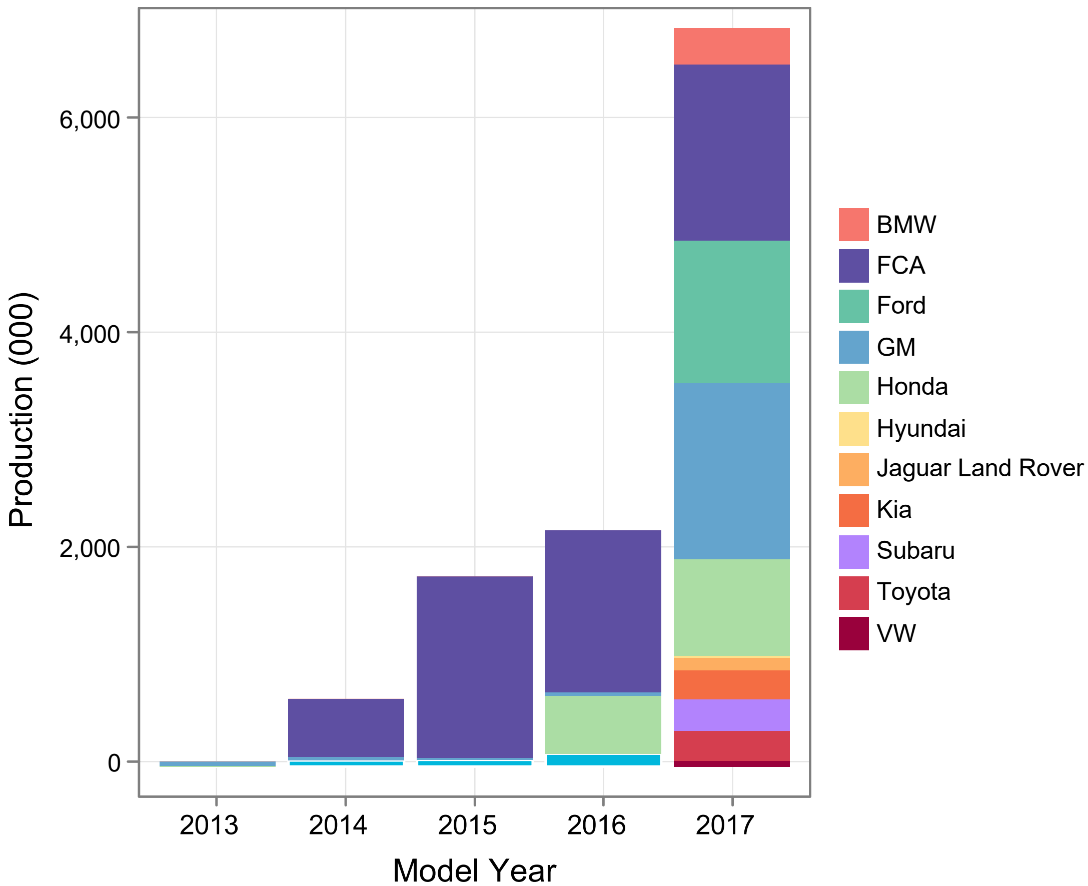
[14] The global warming potential (GWP) represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of CO_2. The GWP of CO_2 is 1.0.

50% adoption of HFO-1234yf across their fleets. As a result, the overall fleet generated about 12.5 Tg more CO_2 credits than it would have using solely HFC-134a, which is equivalent to a 3.5 g/mi reduction in CO_2 emissions for the entire 2017 model year fleet. The growth in usage of HFO-1234yf is illustrated in Figure 5.8.

Figure 5.8. HFO-1234yf Adoption by Manufacturer



Fourteen manufacturers reported A/C leakage credits in the 2017 model year. These manufacturers reported more than 32 Tg of A/C leakage credits in 2017, accounting for GHG reductions of 9 g/mi across the 2017 vehicle fleet.

Air Conditioning Efficiency Credits

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

Most of the additional load on the engine from A/C systems comes from the compressor, which pressurizes the refrigerant and pumps it around the system loop. A significant additional load may also come from electric or hydraulic fans, which move air across the condenser, and from the electric blower, which moves air across the evaporator and into the cabin. Manufacturers have several options for improving efficiency, including more efficient compressors, fans, and motors, and system controls that avoid over-chilling the air (and subsequently re-heating it to provide the desired air temperature). For vehicles equipped with automatic climate-control systems, real-time adjustment of several aspects of the overall system can result in improved efficiency.

The regulations provide manufacturers with a "menu" of A/C system technologies and associated credit values (in g/mi of CO_2), some of which are described above. These credits are capped at 5.7 g/mi for all vehicles in the 2012–2016 model years, and at 5.0 and 7.2 g/mi for cars and trucks, respectively, in the 2017 and later model years. The total tons of credits are then based on the total volume of vehicles in a model year using these technologies.

Fifteen manufacturers used the A/C credit provisions—leakage reductions, efficiency improvements, or both—as part of their compliance demonstration in the 2017 model year. These manufacturers reported a total of more than 16 Tg of A/C efficiency credits in the 2017 model year, accounting for about 4.5 g/mi across the 2017 fleet. Manufacturers were also allowed to generate A/C efficiency credits in the 2009–2011 model years (see the discussion of early credits in Section 5.C).

Air Conditioning Credit Summary

A summary of the A/C leakage and efficiency credits reported by the industry for all model years, including the early credit program years, is shown in Figure 5.9. Leakage credits have been more prevalent than efficiency credits, but both credit types are growing in use. Figure 5.10 shows the benefit of A/C credits, translated from teragrams to grams per mile, for each manufacturer's fleet for the 2017 model year.

Jaguar Land Rover had the highest reported credit on a per vehicle g/mi basis, at 23 g/mi. Thus, A/C credits are the equivalent of about a 7% reduction from tailpipe emissions for

Jaguar Land Rover. BMW was also at about 7%, and several manufacturers were between 3–6%. Mazda was the only manufacturer not using the optional A/C credit program.

Figure 5.9. Fleetwide A/C Credits by Credit Type

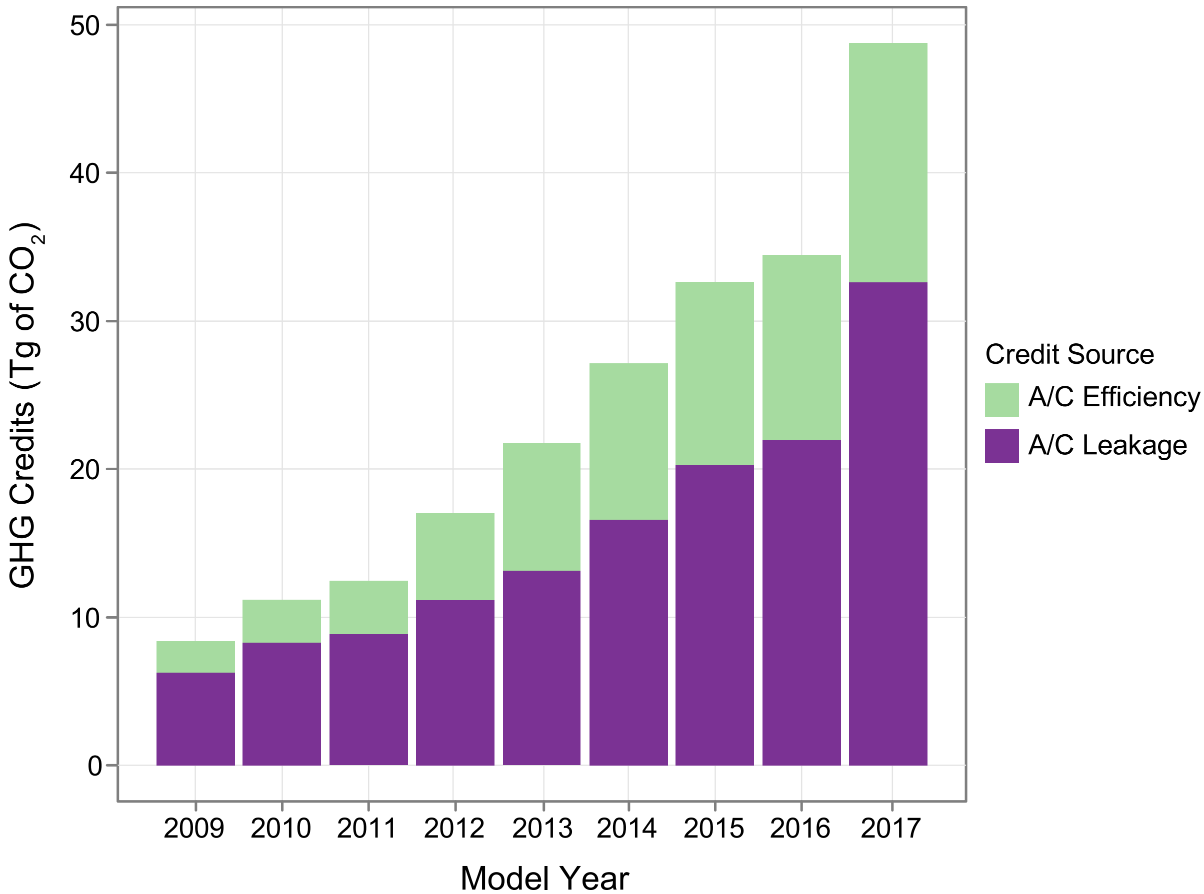
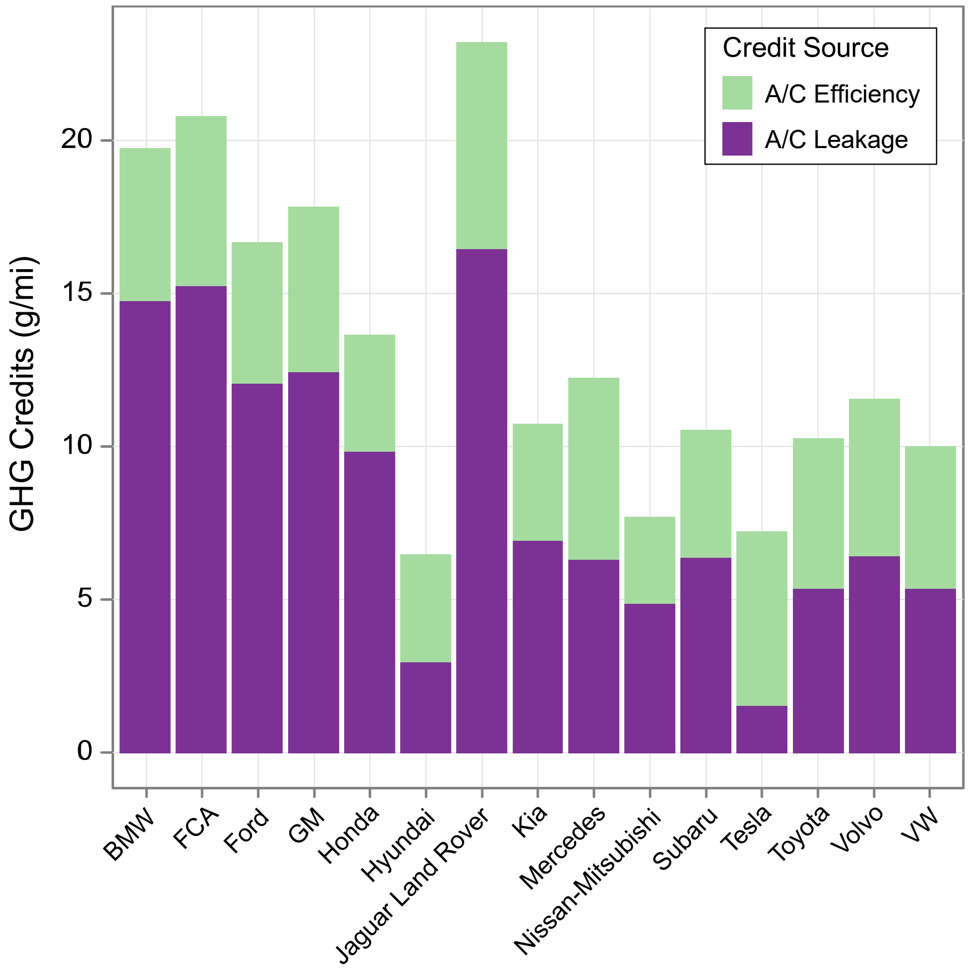


Figure 5.10. Total A/C Credits by Manufacturer for Model Year 2017



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" CO_2 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 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.[15] 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 amount of credit awarded varies for each technology and between cars and trucks. The impact of credits from this pathway on a manufacturer’s fleet is capped at 10 g/mi, meaning that any single vehicle might accumulate more than 10 g/mi, but the cumulative effect on a single manufacturer’s fleet may not exceed a credit of more than 10 g/mi. The regulations clearly define each technology and any requirements that apply for the technology to generate credits. Figure 5.11 shows the adoption of menu technologies, by manufacturer. These credits were widely used in model year 2017, with more than 90% of off-cycle credits generated via the menu pathway. Each of these technologies is discussed below.

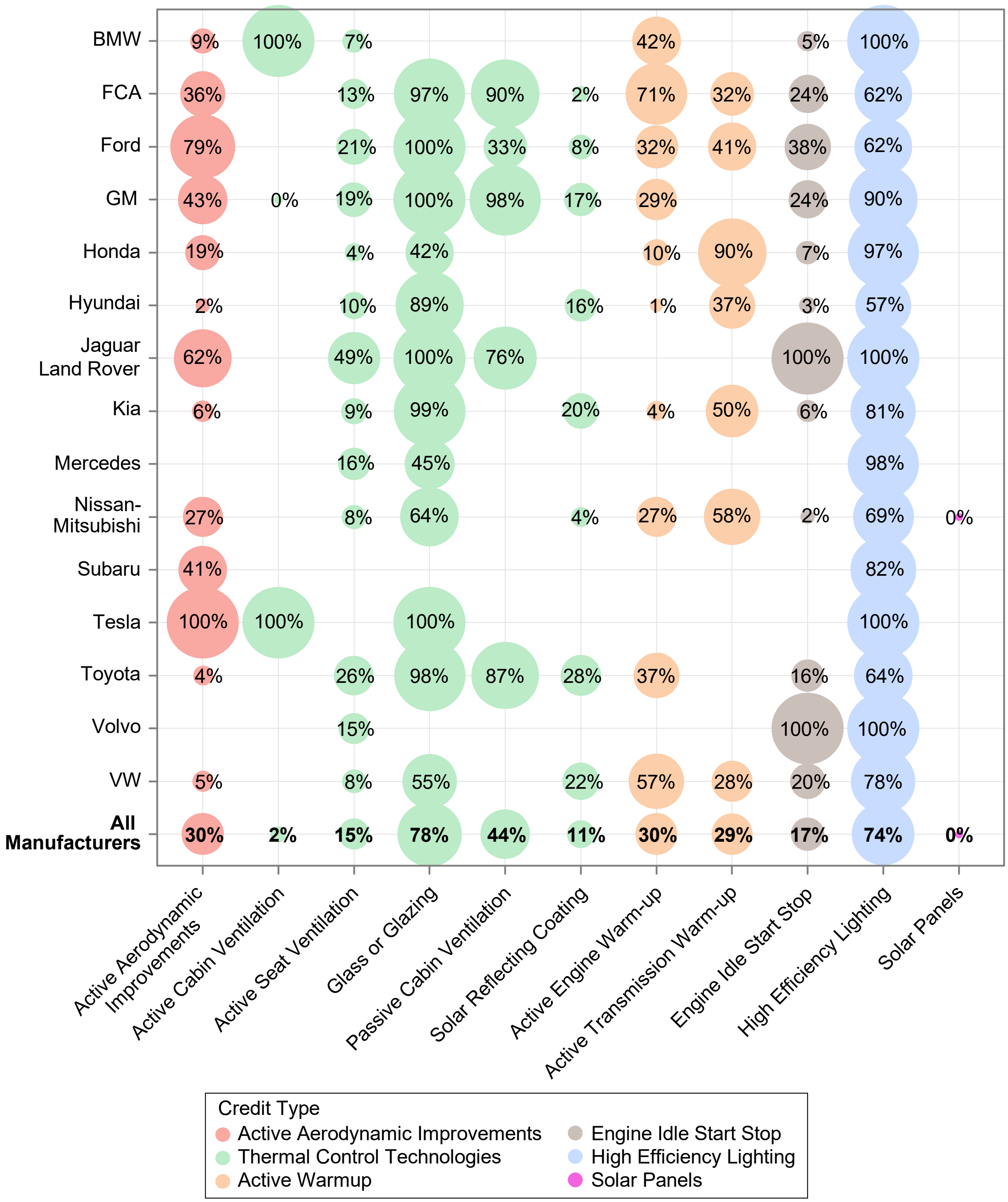
Active Aerodynamics

Active aerodynamics refers to technologies which are automatically activated to improve the aerodynamics of a vehicle under certain conditions. These include grill shutters and spoilers, which allow air to flow over and around the vehicle more efficiently, and suspension systems that improve air flow at higher speeds by reducing the height of the vehicle. Credits are variable and based on the measured improvement in the coefficient of drag, a test metric that reflects the efficiency of airflow around a vehicle.

Most manufacturers implemented at least some level of active aerodynamics on their model year 2017 vehicles. Ford had the highest implementation, at nearly 80% of all new vehicles, and realized the greatest CO_2 reduction of just over 1 g/mi. Overall, almost 30% of new vehicles qualified for these credits, reducing overall fleet CO_2 emissions by 0.3 g/mi.

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

Figure 5.11. Off-Cycle Menu Technology Adoption by Manufacturer



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 subsequently lower the load on the A/C system, the amount of fuel required to run the A/C system, and 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 seat ventilation was used by many manufacturers and the rate of implementation jumped from about five percent in model year 2016 to almost 15% in model year 2017. Jaguar Land Rover remained the leader in adopting active seat ventilation, with implementation on half of their vehicles (this is consistent with this technology being largely limited to luxury brands or models).

As was the case in the previous model year, there was significant penetration of glass or glazing technology across manufacturers, with a majority reporting this technology on more than 50% of their vehicles, and seven manufacturers approaching a 100% implementation rate. Three-quarters of the 2017 model year fleet was equipped with glass or glazing technologies, resulting in a fleetwide GHG reduction of 2.1 g/mi. Four manufacturers – FCA, GM, Jaguar Land Rover, and Toyota – achieved reductions of more than 3 g/mi from this technology group, largely from their use of glass and cabin ventilation technologies.

Due to the likelihood of synergistic effects among the various thermal technologies, the total per-vehicle credit allowed from this technology group is capped at 3.0 g/mi for cars and 4.3 g/mi for trucks. Because this category of credits is capped, the actual credits attributable to each technology in this category cannot be accurately summarized. For example, credits for a car with active cabin ventilation (2.1 g/mi), active seat ventilation (1.0 g/mi), and reflective paint (0.4 g/mi) would total to 3.5 g/mi, thus exceeding the cap by 0.5 g/mi. Credits for this car would have to be truncated at 3.0 g/mi, and there is no non-arbitrary methodology to assign that 3.0 g/mi to the array of technologies involved. Therefore, this report can only detail the credits derived from the overall category, but not from the individual technologies in the category.

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 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. FCA employed active engine warmup in more than 70% of its new vehicles and active transmission warmup in about one third, resulting in an aggregate CO_2 reduction for their fleet of about 3.4 g/mi. Honda led manufacturers in installing active transmission warmup technology, which appeared on 90% of its new vehicles, contributing to a benefit from warmup technologies for Honda of about 2.1 g/mi. Overall each of these technologies was installed in about 30% of all new vehicles, resulting in a CO_2 reduction of about 1.4 g/mi across the 2017 model year fleet.

Engine Idle Stop/Start

Engine idle stop/start systems allow the engine to turn off when the vehicle is at a stop (e.g., at a stoplight), 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. Almost 17% of new vehicles qualified for and claimed this credit, resulting in a fleetwide CO_2 reduction of about 0.6 g/mi. Jaguar Land Rover and Volvo claimed start/stop credits on 100% of their vehicles in model year 2017 providing these manufacturers with CO_2 reductions of near 4 g/mi. Other manufacturers have not come close to this adoption rate, with Ford being the closest at almost 40%.

High Efficiency Exterior Lights

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

Unlike some other off-cycle technologies, safety regulations require that all vehicles must be equipped with lights, and the popularity of high efficiency lights across manufacturers may reflect that lighting improvements are relatively straightforward to implement. All manufacturers reporting off-cycle credits indicated implementation on at least half of their fleet, with several manufacturers at or near 100% implementation. More than 70% of new vehicles used high efficiency lighting in some form in model year 2017, reducing fleetwide CO_2 emissions by about 0.25 g/mi.

Solar Panels

Vehicles that use batteries for propulsion, such as electric, plug-in hybrid electric, and hybrid vehicles may receive credits for solar panels that are used to charge the battery directly or to provide power directly to essential vehicle systems (e.g., heating and cooling systems). Credits are based on the rated power of the solar panels. Nissan-Mitsubishi was the only company to claim this credit in model year 2017, and only for a very small number of vehicles.

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.

Table 5.3. Model Year 2017 Off-Cycle Technology Credits from the Menu, by Manufacturer and Technology (g/mi)

Manufacturer	Active Aero-dynamics	Active Engine Warmup	Active Trans Warmup	Thermal Controls	Engine Start-Stop	High Efficiency Lighting	Solar Panel	Total Menu Credits
BMW	0.1	1.2	-	2.4	0.1	0.7	-	4.6
FCA	0.3	2.2	1.0	3.6	1.0	0.1	-	8.2
Ford	1.0	0.8	1.0	2.5	1.3	0.2	-	6.8
GM	0.5	0.6	-	3.4	0.6	0.4	-	5.5
Honda	0.1	0.2	1.9	0.6	0.2	0.3	-	3.3
Hyundai	0.0	0.0	0.7	0.8	0.0	0.1	-	1.6
Jaguar Land Rover	0.3	-	-	3.2	4.0	0.7	-	8.2
Kia	0.0	0.1	1.0	1.1	0.1	0.1	-	2.4
Mercedes	-	-	-	1.0	-	0.7	-	1.7
Nissan-Mitsubishi	0.1	0.5	1.2	0.8	0.0	0.2	0.0	2.9
Subaru	0.2	-	-	-	-	0.3	-	0.5
Tesla	1.5	-	-	3.0	-	0.8	-	5.2
Toyota	0.0	1.1	-	3.2	0.6	0.2	-	5.1
Volkswagen	0.0	1.0	0.6	0.7	0.7	0.4	-	3.4
Volvo	-	-	-	0.2	3.7	0.9	-	4.7
All Manufacturers	**0.3**	**0.8**	**0.7**	**2.1**	**0.6**	**0.3**	**0.0**	**4.7**

Off-Cycle 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.[16] The additional emission tests allow emission benefits to be demonstrated over some elements of real-world driving not captured by the GHG compliance tests, including high speeds, rapid accelerations, and cold temperatures. Credits determined according to this methodology do not undergo additional public review.

GM is the only manufacturer to have requested off-cycle credits based on 5-cycle testing. These credits are for an auxiliary electric pump used on certain GM gasoline-electric hybrid

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

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 equipped with this technology and has since applied the technology to several other vehicles in subsequent model years, including 2017. However, the production volume of these vehicles, and the impact of this credit, has been low.

Off-Cycle Credits Based on an Alternative Methodology

This third pathway for off-cycle technology credits allows manufacturers to seek EPA approval to use an alternative methodology for determining the off-cycle technology CO_2 credits.[17] 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. Eight manufacturers have petitioned for and been granted credits using this pathway, five of which reported credits in the 2017 model year for two technologies.[18]

In the fall of 2013, Mercedes requested off-cycle credits for the following off-cycle technologies in use or planned for implementation in the 2012-2016 model years: stop-start systems, high-efficiency lighting, infrared glass glazing, and active seat ventilation. EPA approved methodologies for Mercedes to determine these off-cycle credits in September 2014.

Subsequently, FCA, Ford, and GM requested off-cycle credits under this pathway, which EPA approved in September 2015. FCA and Ford submitted applications for off-cycle credits from high efficiency exterior lighting, solar reflective glass/glazing, solar reflective paint, and active seat ventilation. Ford's application also demonstrated off-cycle benefits from active aerodynamic improvements (grill shutters), active transmission warm-up, active engine warm-up technologies, and engine idle stop-start. GM's application described the real-world benefits of an A/C compressor made by Denso with variable crankcase suction

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

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

valve technology. EPA approved the credits for FCA, Ford, and GM in September of 2015.

EPA approved additional credits under this pathway in January of 2017 for BMW, Ford, GM, and Volkswagen, and later for Hyundai. In December 2016, EPA approved a methodology for determining credits from high-efficiency alternators that Ford had applied for in 2016. EPA subsequently approved high-efficiency alternator credits also for FCA, GM, and Toyota. High efficiency alternators use new technologies that reduce the overall load on the engine while continuing to meet the electrical demands of the vehicle systems, resulting in lower fuel consumption and lower CO_2 emissions.

Most of the approved credits have been for previous model years, and thus are not included in the detailed reporting for the 2017 model year in this section. Credit balances have been updated to include retroactive credits that have been reported to EPA, and any relevant tables that include data from previous model years will reflect the addition of these credits. Table 5.5 shows the impact of the credits submitted for the Denso SAS compressor and high-efficiency alternators. On a total fleetwide basis, the aggregated credit is less than 0.5 g/mi.

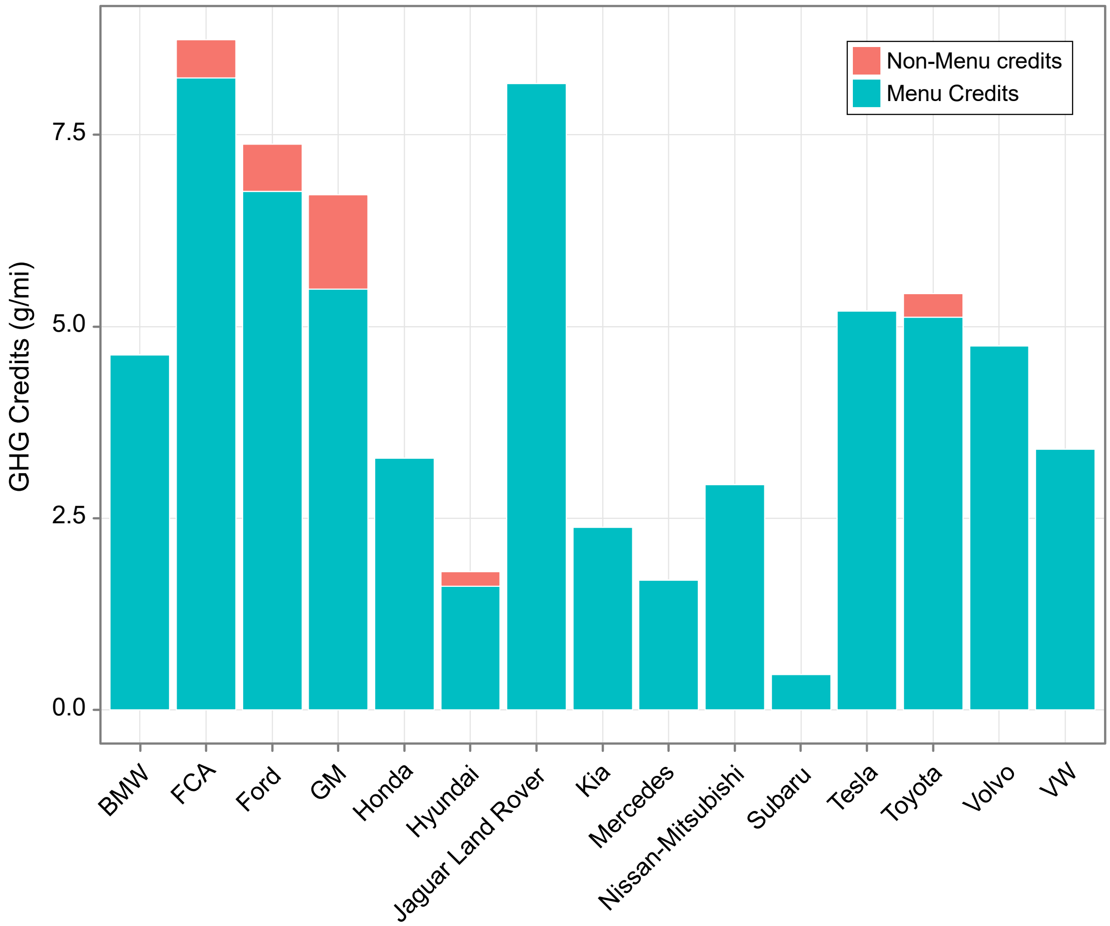
Table 5.4. Model Year 2017 Off-Cycle Technology Credits from an Alternative Methodology, by Manufacturer and Technology (g/mi)

Manufacturer	Denso SAS A/C Compressor	High-Efficiency Alternator	Total Alternative Methodology Credits
FCA	-	0.5	0.5
Ford	-	0.6	0.6
GM	0.7	0.5	1.2
Hyundai	0.2	-	0.2
Toyota	0.2	0.1	0.3
All Manufacturers	**0.2**	**0.2**	**0.4**

Off-Cycle Credit Summary

On average, the industry achieved almost 5 g/mi of off-cycle credits in model year 2017. About 90% of those credits were claimed using technologies, and credit definitions, on the off-cycle menu. The remaining credits were due almost entirely to manufacturer submitted alternative methodologies. Only a very small number of credits (GM) were created through the 5-cycle testing pathway. Figure 5.12 shows the average number of credits, in g/mi, that each manufacturer achieved in model year 2017. FCA led the way with the highest average off-cycle credits, followed closely Jaguar Land Rover, Ford, and GM. Most manufacturers achieved at least some off-cycle credits, although Mazda, and BYD did not report any off-cycle credits for model year 2017.

Figure 5.12. Total Off-Cycle Credits by Manufacturer for Model Year 2017



Alternative Standards for Methane and Nitrous Oxide

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

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

The second option for manufacturers is to include CH_4 and N_2O, on a CO_2-equivalent basis, when calculating their fleet average performance values, in lieu of demonstrating compliance with the regulatory caps. This method directly accounts for CH_4 and N_2O, increasing the performance value of a manufacturer's fleets, while the standards remain unchanged. Analyses of emissions data have shown that use of this option may add approximately 3 g/mi to a manufacturer's fleet average. Only Subaru chose to use this approach in the 2017 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 a deficit (in Megagrams) based on the less stringent standards and on the production volumes of the vehicles to which those standards apply. Eight manufacturers made use of the flexibility offered by this approach in the 2017 model year. In aggregate, the industry created a deficit of about 0.5 Tg due to this approach.

Alternative Standards for Small Volume Manufacturers

EPA established the Temporary Lead-time Allowance Alternative Standards (TLAAS) to assist manufacturers with limited product lines that may be especially challenged in the early years of EPA's GHG program. The TLAAS program was established to provide additional lead-time for manufacturers with narrow product offerings which may not be able to take full advantage of averaging or other program flexibilities due to the limited scope of the types of vehicles they sell. This program was only available during the 2012–2015 model years and is only shown in historic data.

Summary of Manufacturer Performance

Each of the flexibilities described here have been used by manufacturers as part of their compliance strategies under the GHG program. As described above, the availability of these flexibilities, 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 flexibilities by manufacturer for model year 2017, and for the industry as a whole over the course of the GHG Program.

Table 5.5. Manufacturer Performance in Model Year 2017, All (g/mi)

Manufacturer	2-Cycle Tailpipe	Credits: FFV	Credits: TLAAS	Credits: A/C	Credits: ATVs	Credits: Off-Cycle	CH_4 & N_2O Deficit	Performance Value
BMW	272	-	-	19.8	5.5	4.6	0.2	242
BYD Motors	0	-	-	-	226.2	-	-	-226
FCA	337	-	-	20.8	0.8	8.7	0.1	307
Ford	310	-	-	16.7	1.0	7.4	0.8	286
GM	313	-	-	17.9	3.1	6.7	0.1	285
Honda	234	-	-	13.7	0.3	3.3	-	217
Hyundai	245	-	-	6.5	0.3	1.8	-	237
Jaguar Land Rover	332	-	-	23.2	-	8.2	-	301
Kia	260	-	-	10.8	0.8	2.4	-	246
Mazda	235	-	-	-	-	-	0.3	235
Mercedes	306	-	-	12.3	1.1	1.7	-	291
Nissan-Mitsubishi	256	-	-	7.7	1.2	2.9	0.0	244
Subaru	242	-	-	10.6	-	0.5	-	231
Tesla	0	-	-	7.3	252.0	6.5	-	-266
Toyota	276	-	-	10.3	1.3	5.4	0.1	259
VW	266	-	-	10.0	1.0	3.4	0.0	252
Volvo	273	-	-	11.6	2.1	4.7	-	254
All Manufacturers	**283**	**-**	**-**	**13.7**	**2.0**	**5.1**	**0.2**	**263**

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

Model Year	2-Cycle Tailpipe	Credits: FFV	Credits: TLAAS	Credits: A/C	Credits: ATVs	Credits: Off-Cycle	CH_4 & N_2O Deficit	Performance Value
2012	302	8.1	0.6	6.1	-	0.9	0.2	287
2013	294	7.8	0.5	6.9	-	1.0	0.3	278
2014	294	8.9	0.2	8.4	-	2.8	0.2	274
2015	286	6.4	0.3	9.4	-	2.9	0.2	267
2016	285	-	-	10.1	-	3.1	0.1	271
2017	283	-	-	13.7	2.0	5.1	0.2	263

Table 5.7. Manufacturer Performance in Model Year 2017, Car (g/mi)

Manufacturer	2-Cycle Tailpipe	Credits					CH_4 & N_2O Deficit	Performance Value
		FFV	TLAAS	A/C	ATVs	Off-Cycle		
BMW	251	-	-	18.4	6.7	3.5	0.1	223
BYD Motors	0	-	-	-	226.2	-	-	-226
FCA	291	-	-	16.7	3.4	3.4	0.0	267
Ford	259	-	-	15.0	2.5	4.7	0.2	237
GM	239	-	-	12.9	7.8	5.3	0.0	213
Honda	209	-	-	10.5	0.5	2.0	-	196
Hyundai	238	-	-	6.4	0.3	1.5	-	230
Jaguar Land Rover	291	-	-	18.8	-	5.6	-	267
Kia	232	-	-	10.3	1.2	2.0	-	219
Mazda	222	-	-	-	-	-	0.2	222
Mercedes	269	-	-	11.0	1.9	1.1	-	255
Nissan-Mitsubishi	225	-	-	6.9	1.9	2.0	0.1	214
Subaru	243	-	-	6.9	-	0.5	-	236
Tesla	0	-	-	7.3	252.0	6.5	-	-266
Toyota	222	-	-	7.6	2.8	3.6	0.1	208
VW	246	-	-	9.0	1.1	2.4	0.0	234
Volvo	249	-	-	9.4	-	3.4	-	236
All Manufacturers	**235**	-	-	**10.1**	**3.9**	**3.0**	**0.0**	**218**

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

Model Year	2-Cycle Tailpipe	Credits					CH_4 & N_2O Deficit	Performance Value
		FFV	TLAAS	A/C	ATVs	Off-Cycle		
2012	259	4.0	0.2	5.4	-	0.5	0.1	249
2013	251	4.0	0.1	6.3	-	0.7	0.3	240
2014	250	4.6	0.1	7.5	-	1.8	0.3	236
2015	243	3.1	0.0	8.0	-	2.0	0.1	230
2016	240	-	-	8.6	-	1.9	0.1	230
2017	235	-	-	10.1	3.9	3.0	0.0	218

Table 5.9. Manufacturer Performance in Model Year 2017, Truck (g/mi)

Manufacturer	2-Cycle Tailpipe	Credits					CH_4 & N_2O Deficit	Performance Value
		FFV	TLAAS	A/C	ATVs	Off-Cycle		
BMW	310	-	-	22.3	3.2	6.8	0.3	278
FCA	347	-	-	21.7	0.3	9.8	0.1	315
Ford	348	-	-	18.0	-	9.4	1.2	322
GM	362	-	-	21.2	-	7.7	0.1	333
Honda	278	-	-	19.2	-	5.5	-	253
Hyundai	339	-	-	7.0	-	5.3	-	327
Jaguar Land Rover	343	-	-	24.4	-	8.8	-	310
Kia	323	-	-	11.8	-	3.2	-	308
Mazda	262	-	-	-	-	-	0.6	263
Mercedes	349	-	-	13.8	0.1	2.4	-	333
Nissan-Mitsubishi	308	-	-	9.1	-	4.5	-	294
Subaru	242	-	-	11.7	-	0.5	-	230
Toyota	325	-	-	12.7	-	7.1	0.1	305
VW	321	-	-	12.8	0.8	6.1	-	301
Volvo	287	-	-	12.8	3.4	5.6	-	265
All Manufacturers	**330**	-	-	**17.1**	**0.1**	**7.1**	**0.3**	**306**

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

Model Year	2-Cycle Tailpipe	Credits					CH_4 & N_2O Deficit	Performance Value
		FFV	TLAAS	A/C	ATVs	Off-Cycle		
2012	369	14.5	1.3	7.3	-	1.5	0.3	346
2013	360	13.8	1.1	7.9	-	1.6	0.3	337
2014	349	14.3	0.3	9.7	-	4.1	0.1	321
2015	336	10.2	0.6	11.0	-	4.1	0.2	311
2016	332	-	-	11.8	-	4.5	0.2	316
2017	330	-	-	17.1	0.1	7.1	0.3	306

C. End of Year Credit Balance

Each model year, manufacturers must determine their tailpipe CO_2 emissions, the flexibilities that they are eligible to use, and the performance values for their car and truck fleets. The car and truck performance values can be compared to the respective footprint-based CO_2 standards to determine "net compliance" in a model year for each fleet. This value provides a snapshot of how each manufacturer's fleet performed within the model year, but it is not an enforceable compliance value and does not give a complete picture of the manufacturer's status under the GHG program, due to the ABT-based design of the overall GHG program.

As discussed at the beginning of this section, the GHG program allows manufacturers to take advantage of averaging, banking, and trading options. The averaging provisions allow manufacturers to use a production-weighted standard for car and truck fleets, as opposed to standards for individual vehicles. It also allows manufacturers to use surplus credits from their car fleet to offset a shortfall within their truck fleet, or vice versa, within a model year. The banking provisions allow manufacturers to carry credits, or deficits, between model years, and the trading provisions allow manufacturers to trade credits between manufacturers.

The following discussion provides more detail on the credit program and how credit balances are determined. This includes accounting for credit expirations and forfeitures, credits earned under the early credit program, each manufacturer's annual standards and performance values, and credit transactions between companies. The discussion will focus on credits in terms of Megagrams (or Teragrams), which is how the credits are accounted for within the GHG program.

Expiration or Forfeiture of Credits

All credits earned within the GHG program have expiration dates. However, the only credits that have expired so far were credits earned under the early credit program (discussed below) from model year 2009. All credits earned from model years 2010 to 2016, which make up the vast majority of credits currently held by manufacturers, will expire at the end of model year 2021. Beginning in model year 2017, all credits have a 5-year lifetime (i.e., credits earned in model year 2017 will expire at the end of model year 2022).

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. 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.

Credits for Early Adoption of Technology

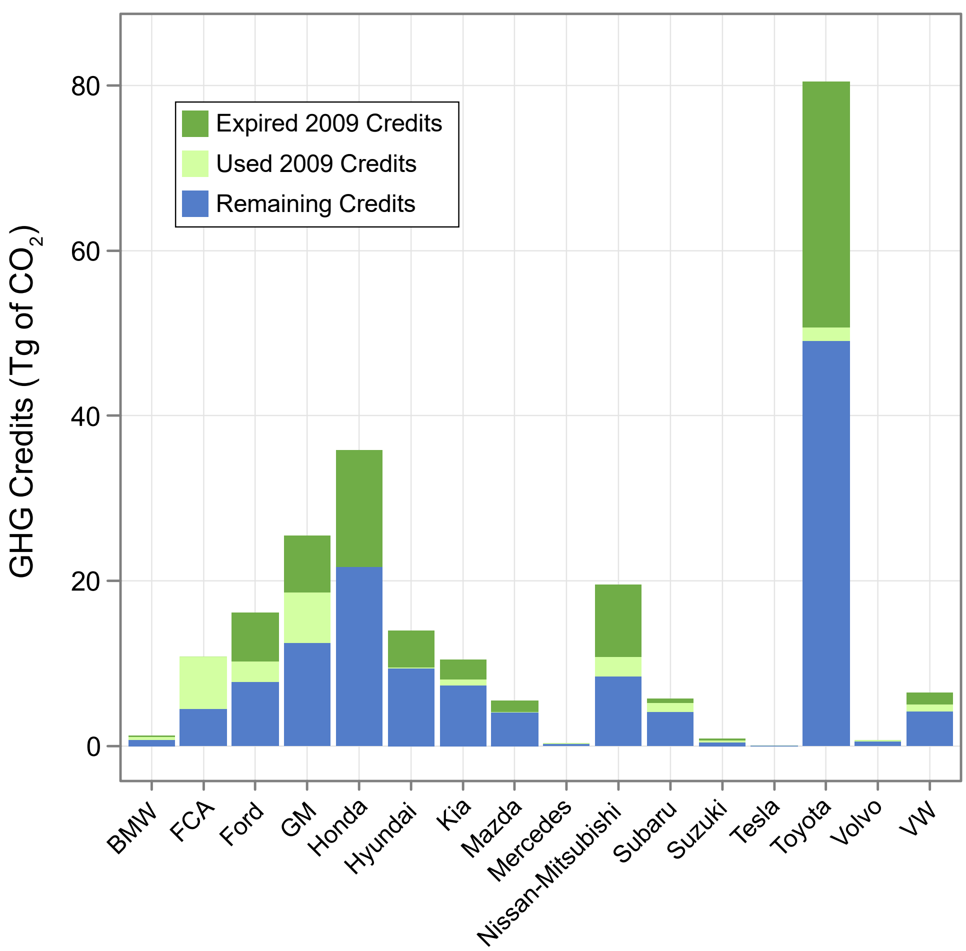
The GHG program included an optional provision that allowed manufacturers to generate credits in the 2009–2011 model years, prior to the implementation of regulatory standards in model year 2012. This flexibility allowed manufacturers to generate credits for achieving tailpipe CO_2 emissions targets or introducing technology before model year 2012. The pathways for earning credits under the early credit program were similar to flexibilities built into the annual GHG requirements, including improved A/C systems, off-cycle credits, and electric, plug-in hybrid, and fuel cell vehicles.

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. The early credits program required that participating manufacturers determine credits for each of the three model years. Thus, even manufacturers with a deficit in one or more of the early model years (i.e., their tailpipe CO_2 performance was worse than the applicable emissions threshold) could benefit from the early credits program if their net credits over the three years was a positive value.

Due to concerns expressed by stakeholders during the rulemaking process, 2009 model year credits could not be traded between companies and were limited to a 5-year credit life. Thus, all credits earned in model year 2009 expired at the end of the 2014 model year if not already used. The remaining 2010–2011 model year credits were banked and may be used until the 2021 model year.

Sixteen manufacturers participated in the early credits program, generating about 234 Tg of credits in total. Figure 5.13 shows the early credits earned, expired, and remaining for each manufacturer. Of the 234 Tg of early credits earned by manufacturers, 76 Tg, or about one-third of the early credits accumulated by manufacturers in the 2009–2011 model years, were 2009 credits that expired. The remaining 2010–2011 model year credits will be available until the 2021 model year. The impacts of credit trading is not accounted for in Figure 5.13, thus the figure does not show how many of these early credits remain for each manufacturer at the end of the 2017 model year.

Figure 5.13. Early Credits Reported and Expired by Manufacturer



Of the 234 Tg of early credits, 85% of those credits were generated from performing better than the tailpipe CO_2 emissions targets established in the regulations. About 10% were due to A/C leakage credits, 4% were due to A/C efficiency improvements, and just over 1% were due to off-cycle credits. Manufacturers can no longer generate early credits (except through applications to the EPA for retroactive off-cycle credits). More details of the early credit program can be found in the "Early Credits Report," which was released by EPA in 2013. [19]

Model Year Performance Versus Standards

Manufacturer-specific standards and performance within the model year were discussed in Sections 5.A and 5.B above. Comparing these two values for each manufacturer's fleet determines the annual net compliance for each fleet. The total credit surplus or shortfall for that model year is determined by manufacturers based on the net compliance and total production of each fleet.

Figure 5.14 illustrates the performance of the large manufacturers in model year 2017, compared to their standards, and prior to the application of banked credits from previous model years or credit transactions between companies. As explained previously, manufacturers have separate car and truck standards, and do not have an overall standard. However, it is useful to calculate and show an equivalent overall standard for evaluating a manufacturer's overall status under the GHG program.

Figure 5.14 is a "snapshot" that shows how manufacturers performed against the standards with their 2017 fleets, but it does not portray whether these manufacturers have ultimately complied with the model year 2017 standards. Most large manufacturers were above (i.e., did not meet) their standard in model year 2017. Three of the 13 major manufacturers were able to achieve compliance based on the emission performance of their 2017 model year vehicles, without utilizing additional banked credits. The fact that manufacturers were above their standards does not mean that these manufacturers were out of compliance with the GHG program, as nearly all manufacturers had more than enough credits to offset the difference, as shown later in this report. While most individual manufacturers were above their individual standards, on average the industry only missed the standards by 5 g/mile and achieved the lowest fleetwide performance of any year of the program thus far.

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

Figure 5.14. Performance and Standards by Manufacturer, 2017 Model Year

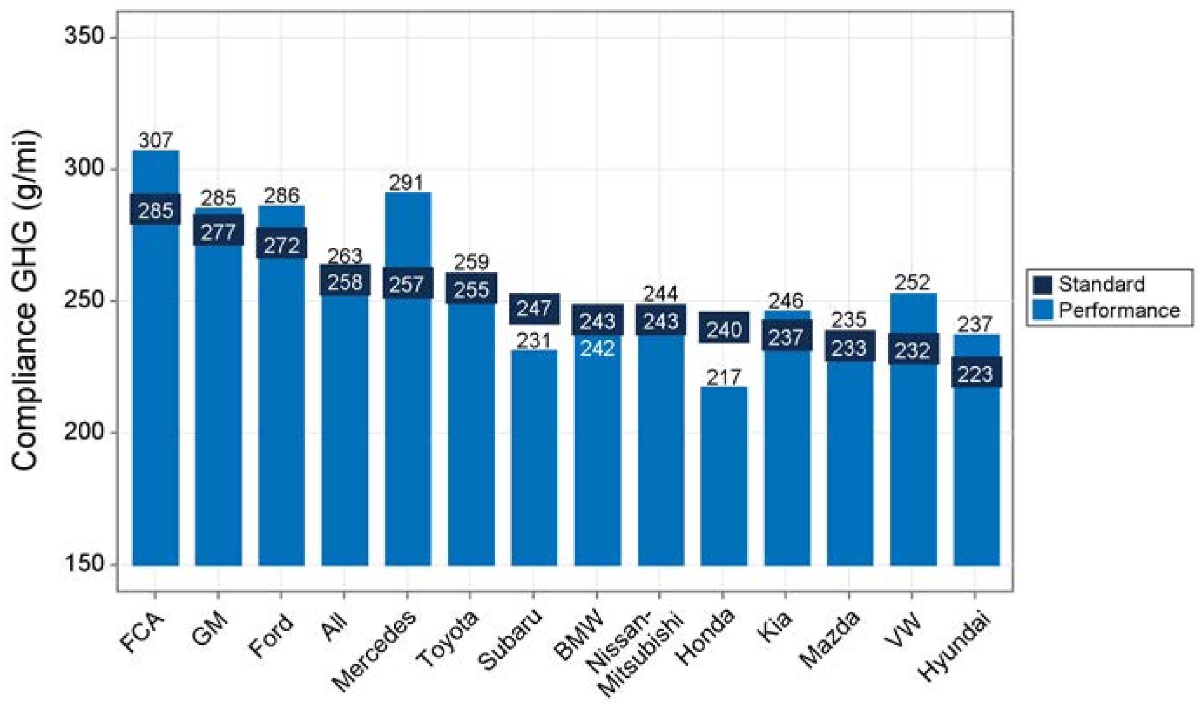


Table 5.11 through Table 5.16 provide a summary of the standards, manufacturer performance, and net compliance by manufacturer for model year 2017, and for the industry as a whole for model years 2009–2012 (including early credits). The net compliance value is the difference between the standard and performance value. A negative value indicates that the manufacturer, or the industry, was below the applicable standard and generated credits. Conversely, a positive net compliance value indicates that the manufacturer, or the industry, exceeded (i.e., did not meet) the standards and generated a credit shortfall.

Toyota, for example, generated a 2017 model year credit shortfall because their overall compliance value of 259 g/mi is above their fleet-wide standard of 255 g/mi. Honda, on the other hand, reported a credit surplus based on a compliance value of 217 g/mi, 23 g/mi lower than their fleet-wide standard of 240 g/mi.

These tables only show 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. It is important to note that the tables showing combined results are aggregated from the passenger car and light-duty truck data and standards—there are no independent standards for the combined fleet.

Table 5.11. Credits Earned by Manufacturers in Model Year 2017, All

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Net Compliance (g/mi)	Production	Credit Surplus/ Shortfall (Mg)
BMW	242	243	-1	335,931	74,068
BYD Motors	-226	226	-452	6	530
FCA	307	285	22	1,919,705	-9,475,132
Ford	286	272	14	2,209,104	-6,740,859
GM	285	277	8	2,792,390	-4,592,921
Honda	217	240	-23	1,624,754	7,571,997
Hyundai	237	223	13	943,992	-2,497,514
Jaguar Land Rover	301	278	23	122,586	-611,459
Kia	246	237	9	610,909	-1,069,577
Mazda	235	233	2	256,948	-129,889
Mercedes	291	257	34	344,679	-2,418,050
Nissan-Mitsubishi	244	243	1	1,812,184	-504,236
Subaru	231	247	-16	679,672	2,364,325
Tesla	-266	252	-518	46,979	4,749,578
Toyota	259	255	4	2,566,856	-2,247,660
VW	252	232	20	660,189	-2,700,414
Volvo	254	270	-16	79,845	273,453
All Manufacturers	**263**	**258**	**5**	**17,006,729**	**-17,953,760**

Table 5.12. Total Credits Earned in Model Years 2009–2017, All

Model Year	Performance Value (g/mi)	Standard (g/mi)	Net Compliance (g/mi)	Production	Credit Surplus/ Shortfall (Mg)	Credit Expiration
2009	-	-	-	-	98,520,511	2014
2010	-	-	-	-	96,699,987	2021
2011	-	-	-	-	38,509,271	2021
2012	287	299	-12	13,445,040	32,913,828	2021
2013	278	292	-14	15,197,270	42,335,732	2021
2014	274	287	-13	15,510,206	41,372,314	2021
2015	267	274	-7	16,735,765	23,665,204	2021
2016	271	263	9	16,276,424	-29,929,366	2021
2017	263	258	5	17,006,729	-17,953,760	2022

Table 5.13. Credits Earned by Manufacturers in Model Year 2017, Car

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Net Compliance (g/mi)	Production	Credit Surplus/ Shortfall (Mg)
BMW	223	221	2	228,971	-69,208
BYD Motors	-226	226	-452	6	530
FCA	267	225	42	371,476	-3,079,993
Ford	237	222	15	1,013,712	-2,980,308
GM	213	221	-8	1,218,645	1,894,311
Honda	196	217	-21	1,081,564	4,421,704
Hyundai	230	219	11	885,043	-1,849,061
Jaguar Land Rover	267	244	23	27,798	-122,883
Kia	219	218	1	442,327	-44,211
Mazda	222	216	6	182,534	-220,221
Mercedes	255	229	26	198,665	-1,010,089
Nissan-Mitsubishi	214	217	-3	1,201,340	653,252
Subaru	236	213	23	181,917	-805,157
Tesla	-266	252	-518	46,979	4,749,578
Toyota	208	216	-8	1,322,377	2,033,559
VW	234	213	21	498,271	-1,994,880
Volvo	236	241	-5	32,690	30,969
All Manufacturers	**218**	**219**	**-1**	**8,934,315**	**1,607,892**

Table 5.14. Total Credits Earned in Model Years 2009–2017, Car

Model Year	Performance Value (g/mi)	Standard (g/mi)	Net Compliance (g/mi)	Production	Credit Surplus/ Shortfall (Mg)	Credit Expiration
2009	-	-	-	-	58,017,205	2014
2010	-	-	-	-	50,742,636	2021
2011	-	-	-	-	8,678,660	2021
2012	249	267	-18	8,655,883	30,438,750	2021
2013	240	261	-21	9,744,776	39,210,720	2021
2014	236	253	-16	9,205,220	29,279,630	2021
2015	230	241	-11	9,597,304	21,260,234	2021
2016	230	231	-1	8,998,957	2,210,184	2021
2017	218	219	-1	8,934,315	1,607,892	2022

Table 5.15. Credits Earned by Manufacturers in Model Year 2017, Truck

Manufacturer	Performance Value (g/mi)	Standard (g/mi)	Net Compliance (g/mi)	Production	Credit Surplus/ Shortfall (Mg)
BMW	278	284	-6	106,960	143,276
FCA	315	297	18	1,548,229	-6,395,139
Ford	322	308	14	1,195,392	-3,760,551
GM	333	315	18	1,573,745	-6,487,232
Honda	253	279	-26	543,190	3,150,293
Hyundai	327	278	49	58,949	-648,453
Jaguar Land Rover	310	287	23	94,788	-488,576
Kia	308	281	27	168,582	-1,025,366
Mazda	263	268	-5	74,414	90,332
Mercedes	333	290	43	146,014	-1,407,961
Nissan-Mitsubishi	294	286	8	610,844	-1,157,488
Subaru	230	258	-28	497,755	3,169,482
Toyota	305	290	15	1,244,479	-4,281,219
VW	301	282	19	161,918	-705,534
Volvo	265	288	-23	47,155	242,484
All Manufacturers	**306**	**295**	**11**	**8,072,414**	**-19,561,652**

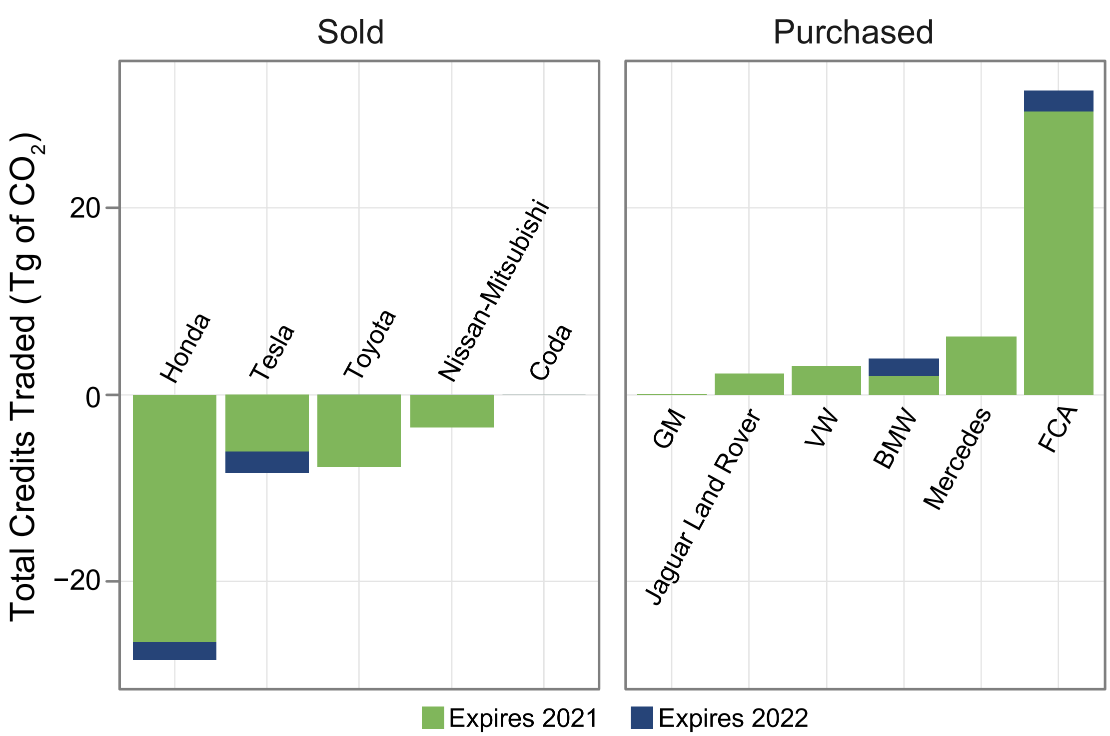
Table 5.16. Total Credits Earned in Model Years 2009–2017, Truck

Model Year	Performance Value (g/mi)	Standard (g/mi)	Net Compliance (g/mi)	Production	Credit Surplus/ Shortfall (Mg)	Credit Expiration
2009	-	-	-	-	40,503,306	2014
2010	-	-	-	-	45,957,351	2021
2011	-	-	-	-	29,830,611	2021
2012	346	349	-2	4,789,157	2,475,078	2021
2013	337	339	-3	5,452,494	3,125,012	2021
2014	321	330	-8	6,304,986	12,092,684	2021
2015	311	312	-1	7,138,461	2,404,970	2021
2016	316	297	20	7,277,467	-32,139,550	2021
2017	306	295	11	8,072,414	-19,561,652	2022

Credit Transactions

Credits may be traded among manufacturers with a great deal of flexibility. There are only a few regulatory requirements that relate to credit transactions between manufacturers, and these are generally designed to protect those involved in these transactions. While it may seem obvious, it is worth stating that a manufacturer may not trade credits that it does not have. Credits that are available for trade are only those available (1) at the end of a model year, and (2) after a manufacturer has offset any deficits they might have. Credit transactions that result in a negative credit balance for the selling manufacturer are not allowed. Although a third party may facilitate transactions, EPA's regulations allow only the automobile manufacturers to engage in credit transactions and hold credits.

Figure 5.15. Total Credits Transactions Through Model Year 2017



The credit transactions reported by manufacturers through the 2017 model year are summarized in Figure 5.15. Credits that have been sold are shown as negative credits, since the sale of credits will reduce the selling manufacturer's credit balance. Conversely, credits that have been purchased are shown as positive credits, since they will increase the purchasing manufacturer's credit balance. The values shown in Figure 5.15 are the total quantity of credits that have been bought or sold by a manufacturer, and likely represent multiple transactions between various manufacturers. Figure 5.15 also shows the expiration date of credits sold and acquired. Credits generated in model year 2017 will expire in 2022; all other credits will expire in model year 2021. As of the close of the 2017 model year, about 48 Tg of CO_2 credits had changed hands.

Note that manufacturers do not report transactions to EPA as they occur; thus, there may be additional credit transactions that have occurred that are not reported here. Transactions reported after the manufacturers submitted their model year 2017 data will be reported in the next release of this report.

Final Credit Balances

At this point, manufacturers calculate their total credit balance at the end of the model year. The final credit balance is the sum of prior credits or deficits, credit surpluses or shortfalls accrued in the current model year, expired or forfeited credits, and credits purchased or sold. Table 5.17 shows the impact of each of these categories for each manufacturer, including their final model year 2017 credit balances. Table 5.18 shows the breakdown of expiration dates for credit balances, and the distribution, by age of credit deficits. All credit deficits must be offset within three years, or a manufacturer will be considered non-compliant with the GHG program.

Table 5.17. Final Credit Balance by Manufacturer for Model Year 2017 (Mg)

Manufacturer	Early Credits Earned 2009-2011	Credits Earned 2012-2016	Credits Earned 2017	Credits Expired	Credits Forfeited	Credits Purchased or Sold	Final 2017 Credit Balance
BMW	1,251,522	85,611	74,068	-134,791	-	4,000,000	5,276,410
BYD Motors	-	4,871	530	-	-	-	5,401
Coda	-	7,251	-	-	-	-7,251	-
FCA	10,827,083	-13,720,576	-9,475,132	-	-	32,675,990	20,307,365
Ford	16,116,453	12,770,167	-6,740,859	-5,882,011	-	-	16,263,750
GM	25,510,557	1,090,478	-4,592,921	-6,933,126	-	7,251	15,082,239
Honda	35,842,334	36,976,814	7,571,997	-14,133,353	-	-28,444,401	37,813,391
Hyundai	14,007,495	11,228,473	-2,497,514	-4,482,649	-169,775	-	18,086,030
Jaguar Land Rover	-	-2,258,202	-611,459	-	-	2,294,494	-575,167
Karma Automotive	-	58,852	-	-	-	-	58,852
Kia	10,444,192	-1,945,739	-1,069,577	-2,362,882	-123,956	-	4,942,038
Mazda	5,482,642	5,282,826	-129,889	-1,340,917	-	-	9,294,662
Mercedes	378,272	-3,586,064	-2,418,050	-	-28,416	6,227,713	573,455
Nissan-Mitsubishi	19,580,536	21,305,077	-504,236	-8,773,270	-	-3,539,063	28,069,044
Porsche	-	426,439	-	-	-426,439	-	-
Subaru	5,755,171	9,237,767	2,364,325	-491,789	-	-	16,865,474
Suzuki	876,650	-183,097	-	-265,311	-	-	428,242
Tesla	49,772	6,038,569	4,749,578	-	-	-8,452,302	2,385,617
Toyota	80,435,498	30,713,921	-2,247,660	-29,732,098	-	-7,762,431	71,407,230
Volkswagen	6,441,405	-2,521,484	-2,700,414	-1,442,571	-	3,000,000	2,776,936
Volvo	730,187	-654,242	273,453	-	-85,163	-	264,235
All Manufacturers	**233,729,769**	**110,357,712**	**-17,953,760**	**-75,974,768**	**-833,749**	**-**	**249,325,204**

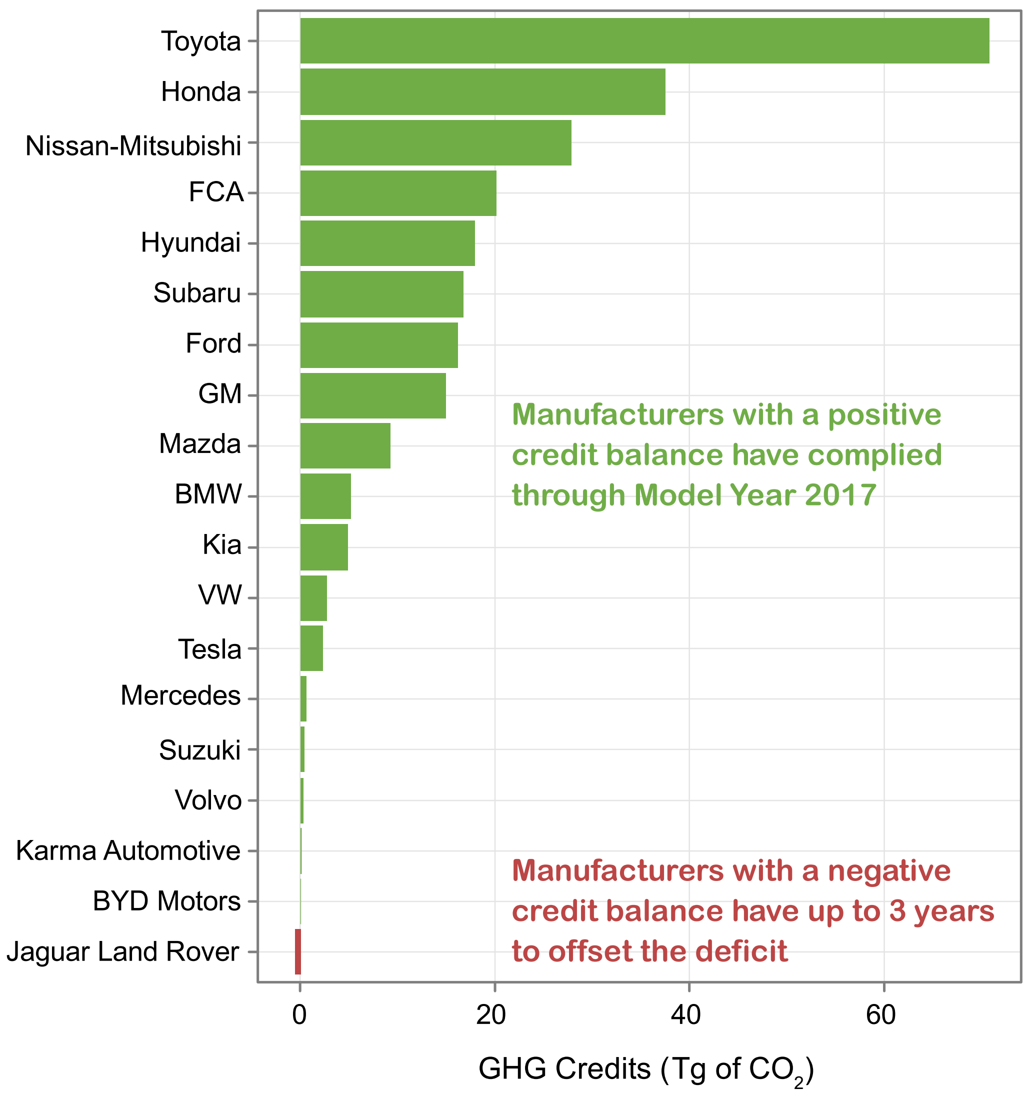
Table 5.18. Distribution of Credits by Expiration Date (Mg)

Manufacturer	Final 2017 Credit Balance	Credits Expiring in 2021	Credits Expiring in 2022	Deficit Carried 1 year	Deficit Carried 2 years
BMW	5,276,410	3,133,134	2,143,276	-	-
BYD Motors	5,401	4,871	530	-	-
FCA	20,307,365	17,942,828	2,363,961	-	-
Ford	16,263,750	16,263,730	-	-	-
GM	15,082,239	13,187,928	1,894,311	-	-
Honda	37,813,391	32,241,394	5,571,997	-	-
Hyundai	18,086,030	18,086,030	-	-	-
Jaguar Land Rover	-575,167	-	-	-575,167	-
Karma Automotive	58,852	58,852	-	-	-
Kia	4,942,038	4,942,038	-	-	-
Mazda	9,294,662	9,204,330	90,332	-	-
Mercedes	573,455	573,455		-	-
Nissan-Mitsubishi	28,069,044	27,415,792	653,252	-	-
Subaru	16,865,474	13,695,992	3,169,482	-	-
Suzuki	428,242	428,242	-	-	-
Tesla	2,385,617	-	2,385,617	-	-
Toyota	71,407,230	69,373,671	2,033,559	-	-
Volkswagen	2,776,936	2,776,936	-	-	-
Volvo	264,235	-	264,235	-	-
All Manufacturers	**249,325,204**	**229,329,819**	**20,570,552**	**-575,167**	-

D. Compliance Status After the 2017 Model Year

To evaluate the overall compliance status of manufacturers, EPA considers the credit balance of each manufacturer at the end of the most recent model year. 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. The credits accrued will be available to that manufacturer until they are used to offset a credit shortfall within a future model year, or until they expire. Figure 5.16 (and Table 5.17) show the credit balance of all manufacturers after model year 2017.

Figure 5.16. Manufacturer Credit Balance After Model Year 2017



All manufacturers, except one, ended the 2017 model year with a positive credit balance and are thus in compliance with model year 2017 and all previous years of the GHG program. Jaguar Land Rover, the sole manufacturer carrying a deficit into the 2018 model year, does not have any outstanding deficits that would result in noncompliance or enforcement actions from EPA. However, Jaguar Land Rover will have to offset the existing deficits in future model years either by producing future efficient vehicles that exceed the standards, or by purchasing credits from other manufacturers.

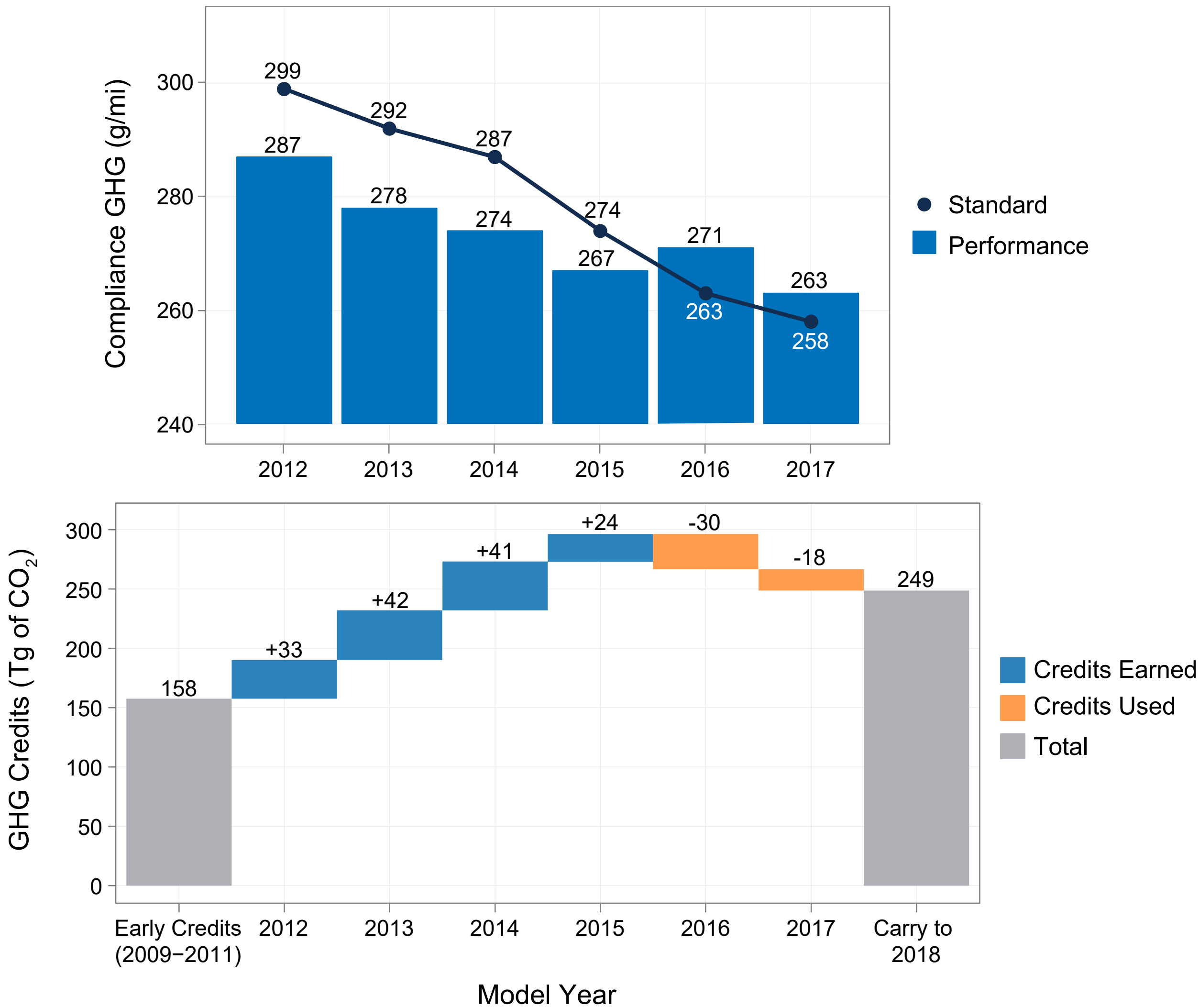
Figure 5.17 shows the overall industry performance, standards, and credit bank for all years of the GHG program. As discussed earlier in this section, the performance of the industry on average was below the standards for the first four years of the GHG program, from model year 2012 through 2015. In model years 2016 and 2017, the industry was on average above the standards. In model year 2017 the industry improved overall GHG performance by 8 g/mi, and while this was not enough to meet the standard, the gap between the GHG standard and fleet average performance narrowed to 5 g/mi from 9 g/mi.

The industry created a large bank of credits using the early credits provision and it continued to grow the bank of credits during the first four years of the program by reducing emissions below the requirements of the standards. For the last two years, the industry has had to use banked credits, reducing the overall credit bank, but the balance of credits remains substantial.

The industry emerges from model year 2017 with a bank of almost 250 teragrams (Tg) of GHG credits to draw upon in future years. Based on their compliance strategy, many manufacturers used credits in model year 2017. As a result, the industry depleted their collective credit bank by about 18 Tg, or about 7% of the total credit balance, to maintain compliance. If applied entirely to model year 2017, the balance of nearly 250 Tg would be equivalent to a fleetwide GHG reduction of about 70 g/mi. Of those credits, 92% will expire at the end of model year 2021 if not used. Additionally, more than half of the current balance is held by three manufacturers, and the availability of these or future credits is inherently uncertain.

After accounting for the use of credits, and the ability to carry forward a deficit in the case of Jaguar Land Rover, the industry overall does not face any non-compliance issues as of the end of the 2017 model year.

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



Appendices: Methods and Additional Data

A. Sources of Input Data

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

National fuel economy standards have been in place in the United States for cars and light trucks since 1978. The Department of Transportation, through the National Highway Traffic Safety Administration (NHTSA), has the responsibility for setting and enforcing fuel economy standards through the Corporate Average Fuel Economy (CAFE) program. Since the inception of CAFE, EPA has been responsible for establishing test procedures and calculation methods, and for collecting data used to determine vehicle fuel economy levels. EPA calculates the CAFE value for each manufacturer and provides it to NHTSA. NHTSA publishes the final CAFE values in its annual "Summary of Fuel Economy Performance" reports at www.nhtsa.gov/Laws-&-Regulations/CAFE---Fuel-Economy. Since model year 2012, NHTSA and EPA have maintained coordinated fuel economy and greenhouse gas standards that apply to model year 2012 through model year 2025[20] vehicles.

The data that EPA collects comprise the most comprehensive database of its kind. For recent model years, the vast majority of the data in this report are reported to EPA using the 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 2018 fleet based on footprint values for

[20] See 75 Federal Register 25324, May 7, 2010 and 77 Federal Register 62624, October 15, 2012.

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.

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

- Explore summary data with interactive figures here: https://www.epa.gov/automotive-trends/explore-automotive-trends-data.
- Download report tables and supplemental data tables (previously called Appendices) here: https://www.epa.gov/automotive-trends/download-data-automotive-trends.

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

Preliminary vs Final Data

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

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

Final data are submitted a few months after the end of each model year and include detailed final production volumes. EPA and NHTSA use this final data to determine compliance with GHG emissions and CAFE standards. These end-of-the-year submissions include detailed final production volumes. All data in this report for model years 1975 through 2017 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 six out of the last seven years, manufacturer projections have led to preliminary estimates that were higher than final data. This could be due to many reasons, but lower than expected gasoline costs and the increasing percentage of SUVs purchased by consumers likely contributed to this overestimation.

It is important to note that there is no perfect apples-to-apples comparison for model years 2011–2014 due to several small data issues, such as 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 (prelim)	*25.4*	-	-

B. Harmonic Averaging of Fuel Economy Values

Averaging multiple fuel economy values must be done harmonically in order to obtain a correct mathematical result. Since fuel economy is expressed in miles per gallon (mpg), one critical assumption with any harmonic averaging of multiple fuel economy values is whether the distance term (miles, in the numerator of mpg) is fixed or variable. This report makes the assumption that the distance term in all mpg values is fixed, i.e., that for purposes of calculating a harmonically averaged fuel economy value, it is assumed that the distance term (representing miles travelled) 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:

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

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

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

Note that 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 0.03333 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[21] 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 included in the Supplemental Tables and Appendix D for reference. It is important to note that these 2-cycle fuel economy values do not exactly correlate to the 2-cycle tailpipe CO_2 emissions values provided in Section 5 for the GHG regulations. There are three methodological reasons for this:

[21] 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 and flexibilities 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 have 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, 8887 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 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 2017 Toyota Prius Eco. The 2-cycle city and highway fuel economy values are direct fuel economy measurements from the 2-cycle tests and are harmonically averaged with a 55% city / 45% highway weighting to generate a combined value. The 2-cycle laboratory tested city fuel economy of the Prius Eco is 84 mpg, the highway fuel economy is 78 mpg, and the combined 2-cycle value is 81 mpg.

Using the 5-cycle methodology, the Toyota Prius Eco has a vehicle fuel economy label value of 56 mpg city and 58 mpg highway. On the vehicle label, these values are harmonically averaged using a 55% city / 45% highway weighting to determine a combined value of 53 mpg. The estimated real-world fuel economy for the Prius Eco, which is the set of values used in calculations for this report, has the same city and highway fuel economy as the label, but the 43% city and 57% highway weighting leads to a combined value of 55 mpg, which is one mpg less than the values found on the label.

Table C.1. Fuel Economy Metrics for the Model Year 2017 Toyota Prius Eco

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

Greenhouse Gases other than CO_2

In addition to tailpipe CO_2 emissions, vehicles may create greenhouse gas emissions in several other ways. The combustion process can result in emissions of N_2O, and CH_4, and leaks in vehicle air conditioning systems can release refrigerants, which are also greenhouse gasses, 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.[22] 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 5 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.[23] To use the derived 5-cycle method, manufacturers are required to evaluate whether fuel economy estimates using the full 5-cycle tests are comparable to results using the derived 5-cycle method. In recent years, the derived 5-cycle approach has been used to generate approximately 85% of all vehicle label fuel economy values.

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

[22] See 71 Federal Register 77872, December 27, 2006.
[23] See 71 Federal Register 77883-77886, December 27, 2006.

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

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

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

Over the same timeframe, EPA phased in a change in the city and highway weightings used to determine a single combined fuel economy or CO_2 value. EPA's analysis of real-world driving activity underlying the 5-cycle fuel economy methodology assumed a "speed cutpoint" of 45 miles per hour to differentiate between (and "bin" the amount of) city and highway driving.[24] Based on this speed cutpoint, the correct weighting for correlating the new city and highway fuel economy values with real-world driving activity data from on-road vehicle studies, on a miles driven basis, is 43% city and 57% highway; this updated weighting is necessary to maintain the integrity of fleetwide fuel economy performance based on Trends data. The 55% city/45% highway weighting is still used for both Fuel Economy and Environment Labels and the CAFE and GHG emissions compliance programs. The authors used the same gradual, linear approach to phase in the change in city and highway weightings along with the phase-in of the 2006 5-cycle methodology.

From model year 2005 to model year 2010, the 2006 5-cycle methodology and the 43% city/57% highway weightings were used to determine the real-world fuel economy values for this report. This required using the derived 5-cycle equations and the 43% city/57% highway weightings to recalculate real-world fuel economy values for model year 2005 to 2007, prior to 2008 when the 2006 5-cycle methodology was first required. Model year 2008 to model year 2010 real-world fuel economy values were the same as the label fuel economy values, except for the city and highway weightings.

Model year 2011–2017: Implementing the model year 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.[25] This

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

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

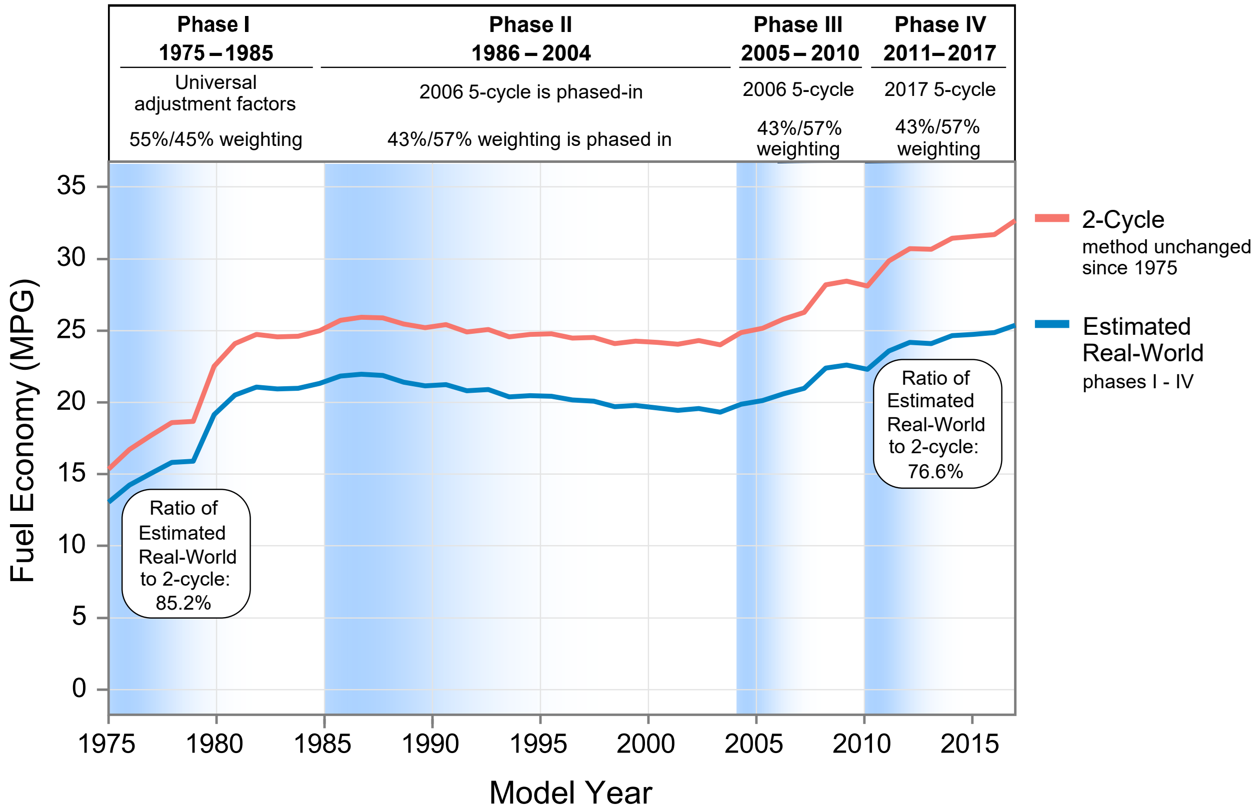
$$\textbf{Label CITY} = \frac{1}{\left(0.004091 + \frac{1.1601}{\text{2CYCLE CITY}}\right)}$$

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

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

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

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



Other Database Changes

Addition of Medium-Duty Passenger Vehicles

Beginning in 2011 medium-duty passenger vehicles (MDPVs), those SUVs and passenger vans (but not pickup trucks) with gross vehicle weight ratings between 8,500 and 10,000 pounds, are included in the light-duty truck category. This coincided with new regulations by NHTSA to treat these vehicles as light-duty, rather than heavy-duty, vehicles beginning in model year 2011. This represents a minor change to the database, since the number of MDPVs is much smaller than it once was (e.g., only 6,500 MDPVs were sold in model year 2012). It should be noted that this is one change to the database that has not been propagated back through the historic database, as we do not have MDPV data prior to model year 2011. Accordingly, this represents a small inflection point for the database for the overall car and truck fleet in model year 2011; the inclusion of MDPVs decreased average real-world fuel economy by 0.01 mpg and increased average real-world CO_2

emissions by 0.3 g/mi, compared to the fleet without MDPVs. The impacts on the truck fleet only were about twice as high, but still very small in absolute terms. Pickup trucks above 8,500 pounds are not included in this report.

Addition of Alternative Fuel Vehicles

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

Changes in Vehicle Classification Definitions

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

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

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

Manufacturer Definitions

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

Differences in Production Data Between CAFE and GHG Regulations

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

Impact of Federal Investigations

The Department of Justice and EPA have reached settlements with Volkswagen and Fiat Chrysler Automobiles based on the sale of certain diesel vehicles equipped with devices to defeat the vehicles' emission control systems. This report includes the original fuel economy and GHG certification values of these vehicles, as EPA believes this is a reasonable representation of how these vehicles were expected to perform. The affected vehicles are certain model year 2009 to 2016 diesel vehicles from Volkswagen and 2014 to 2016 diesel vehicles from Fiat Chrysler Automobiles, and account for less than 1% of production in all affected years. For more information about these investigations, please see https://www.epa.gov/vw or https://www.epa.gov/fca.

E. Electric Vehicle and Plug-In Hybrid Metrics

Electric Vehicles (EVs) and Plug-in Hybrid Vehicles (PHEVs) have continued to gain market share. While overall market penetration of these vehicles is still low, their production share is projected to reach more than 2.5% in model year 2018. This section addresses some of the technical metrics used both to quantify EV and PHEV operation and to integrate data from these vehicles with gasoline and diesel vehicle data.

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

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

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

This section discusses EV and PHEV metrics for several example model year 2018 vehicles. For consistency and clarity for the reader, the data for specific vehicles discussed in this section reflect values from the EPA/DOT Fuel Economy and Environment Labels, which use a 55% city/45% highway weighting for combined fuel economy and CO_2 values. When data for these vehicles are integrated into the data for the rest of the report, the real-world highway and city values are combined using a 43% city/ 57% highway weighting. Additionally, some PHEV calculations are also adjusted, as explained at the end of this section.

Table E.1 shows the label driving range for several EVs and PHEVs when operating only on electricity, as well as the total electricity plus gasoline range for PHEVs. The average range of new EVs is increasing, as shown in Section 4, and many EVs are approaching the range of an average gasoline vehicle. [26] 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 2018 Example EV and PHEV Powertrain and Range

Manufacturer	Model	Fuel or Powertrain	Electric Range (miles)	Total Range (miles)	Utility Factor
GM	Bolt	EV	238	238	-
Nissan	Leaf	EV	151	151	-
Tesla	Model 3 LR	EV	310	310	-
FCA	Pacifica	PHEV	33	570	0.62
GM	Volt	PHEV	53	420	0.76
Honda	Clarity	PHEV	48	340	0.73
Toyota	Prius Prime	PHEV	25	640	0.53
VW	Panamera 4	PHEV	16	480	0.38

Determining the electric range of PHEVs is complicated if the vehicle can operate in blended modes. For PHEVs like the Chevrolet Volt, 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 VW (Porsche) Panamera uses electricity stored in its battery and a small amount of gasoline to achieve an alternative fuel range of 16 miles. Some PHEVs did not use any gasoline to achieve their electric range value on EPA test cycles; however, certain driving conditions (e.g., more aggressive accelerations, higher speeds, and air conditioning or heater operation) would likely cause these vehicles to operate in a blended mode instead of an all-electric mode.

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

Table E.1 also introduces the concept of a utility factor. The utility factor is directly related to the electric range for PHEVs, and is a projection, on average, of the percentage of miles that will be driven using electricity (in electric-only and blended modes) by an average driver. The model year 2018 Volt, for example, has a utility factor of 0.76, i.e., it is expected that, on average, the Volt will operate 76% of the time on electricity and 24% of the time on gasoline. Utility factor calculations are based on an SAE methodology that EPA has adopted for regulatory compliance (SAE 2010).

Table E.2 shows five energy-related metrics for model year 2018 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 2018 Example EV and PHEV Fuel Economy Label Metrics

			Charge Depleting			Charge Sustaining	
Manufacturer	**Model**	**Fuel or Power -train**	**Electricity (kW-hrs/ 100 miles)**	**Gasoline (gallons/ 100 miles)**	**Fuel Economy (mpge)**	**Fuel Economy (mpg)**	**Overall Fuel Economy (mpge)**
GM	Bolt	EV	28	-	119	N/A	119
Nissan	Leaf	EV	30	-	112	N/A	112
Tesla	Model 3 LR	EV	26	-	130	N/A	130
FCA	Pacifica	PHEV	40	0.0	84	32	52
GM	Volt	PHEV	31	0.0	106	42	77
Honda	Clarity	PHEV	31	0.0	110	42	76
Toyota	Prius Prime	PHEV	25	0.0	133	54	78
VW	Panamera 4	PHEV	59	0.4	46	22	27

The fourth column in Table E.2 gives electricity consumption rates for EVs and PHEVs during charge depleting operation in units of kilowatt-hours per 100 miles (kW-hrs/100 miles). As shown on the vehicle label, the electricity consumption rate is based on the amount of electricity required from an electric outlet to charge the vehicle and includes wall-to-vehicle charging losses. The values for all of the EVs and PHEVs reflect the electricity consumption rate required to operate the vehicle in either electric-only or blended mode operation. PHEVs that are capable of operating in a blended mode may also consume some gasoline in addition to electricity. Any additional gasoline used is shown in the fifth column. For example, the VW (Porsche) Panamera PHEV consumes 59 kW-hrs and 0.4 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 0.30 kW-hrs/mile (equivalent to 30 kW-hrs/100 miles) is 112 mpge.[27] Because the VW (Porsche) Panamera 4 consumes both electricity and gasoline over the alternative fuel range of 16 miles, the charge depleting fuel economy of 46 mpge includes both the electricity and gasoline consumption, at a rate of 59 kW-hrs/100 miles of electricity and 0.4 gal/100 miles of gasoline.

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

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

Table E.3 gives vehicle tailpipe CO_2 emissions values that are included on the EPA/DOT Fuel Economy and Environment labels (and reflected in the label's Greenhouse Gas Rating). These label values reflect EPA's best estimate of the CO_2 tailpipe emissions that these

[27] 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.

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 2018 Example EV and PHEV Label Tailpipe CO_2 Emissions Metrics

Manufacturer	Model	Fuel or Powertrain	Tailpipe CO_2 (g/mile)
GM	Bolt	EV	0
Nissan	Leaf	EV	0
Tesla	Model 3 LR	EV	0
FCA	Pacifica	PHEV	106
GM	Volt	PHEV	51
Honda	Clarity	PHEV	57
Toyota	Prius Prime	PHEV	78
VW	Panamera 4	PHEV	260

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

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

Table E.4 Model Year 2018 Example EV and PHEV Upstream CO_2 Emission Metrics (g/mi)

			Tailpipe + Total Upstream CO_2			Tailpipe + Net Upstream CO_2		
Manufacturer	**Model**	**Fuel or Powertrain**	**Low**	**Avg**	**High**	**Low**	**Avg**	**High**
GM	Bolt	EV	76	139	219	17	80	160
Nissan	Leaf	EV	82	149	235	19	87	172
Tesla	Model 3 LR	EV	71	129	204	2	61	135
FCA	Pacifica	PHEV	200	255	326	114	170	240
GM	Volt	PHEV	128	181	248	67	120	188
Honda	Clarity	PHEV	133	184	249	71	122	186
Toyota	Prius Prime	PHEV	134	163	201	81	111	148
VW	Panamera 4	PHEV	387	438	502	294	345	409
	Average Car		**366**	**366**	**366**	**293**	**293**	**293**

Based on data from EPA's eGRID power plant database,[28], and accounting for additional greenhouse gas emissions impacts for feedstock processing upstream of the power plant,[29] EPA estimates that the electricity CO_2 emission factors for various regions of the country vary from 273 g CO_2/kW-hr in California to 783 g CO_2/kW-hr in the Midwest, with a national average of 498 g CO_2/kW-hr. Emission rates for small regions in upstate New York and Alaska have lower electricity upstream CO_2 emission rates than California. However, California is a good surrogate for the "low" end of the range because California is a leading market for current EVs and PHEVs. Initial sales of electric vehicles have been largely, though not exclusively, focused in regions of the country with power plant CO_2 emissions factors lower than the national average, such as California, New York, and other coastal areas. Accordingly, in terms of CO_2 emissions, EPA believes that the current "sales-weighted

[28] Abt Associates 2018. The emissions & generation resource integrated database technical support document for eGRID 2016, prepared for the U.S. Environmental Protection Agency, February 2017.
[29] Argonne National Laboratory 2018. GREET1_2017 Model. greet.es.anl.gov.

average" vehicle operating on electricity in the near term will likely fall somewhere between the low end of this range and the national average.[30]

The fourth through sixth columns in Table E.4 provide the range of tailpipe plus *total* upstream CO_2 emissions for EVs and PHEVs based on regional electricity emission rates. For comparison, the average model year 2018 car is also included in the last row of Table E.4. The methodology used to calculate the range of tailpipe plus total upstream CO_2 emissions for EVs is shown in the following example for the model year 2018 Nissan Leaf:

- Start with the label (5-cycle values weighted 55% city/45% highway) vehicle electricity consumption in kW-hr/mile, which for the Leaf is 30 kW-hr/100 miles, or 0.30 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 239 g/kW-hr, 4.2%, and 9.3%, respectively).
- Determine the regional upstream emission factor (for California 239 g/kW-hr / (1–0.042) * (1+0.093) = 273 g CO_2/kW-hr)[31]
- Multiply by the range of Low (California = 273g CO_2/kW-hr), Average (National Average = 498 g CO_2/kW-hr), and High (Midwest = 783 g CO_2/kW-hr) electricity upstream CO_2 emission rates, which yields a range for the Leaf of 82–235 grams CO_2/mile.

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

The values in columns four through six are tailpipe plus *total* upstream CO_2 emissions. As mentioned, all of the gasoline and diesel vehicle CO_2 emissions data in the rest of this report refer only to tailpipe emissions and do not reflect the upstream emissions associated with gasoline or diesel production and distribution. Accordingly, in order to

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

[31] 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.

equitably compare the overall relative impact of EVs and PHEVs with tailpipe emissions of petroleum-fueled vehicles, EPA uses the metric "tailpipe plus *net* upstream emissions" for EVs and PHEVs (note that this same approach has been adopted for EV and PHEV regulatory compliance with the 2012–2025 light-duty vehicle GHG emissions standards for sales of EVs and PHEVs in model year 2012–2016 and model year 2022–2025 that exceed sales thresholds). The net upstream emissions for an EV is equal to the total upstream emissions for the EV minus the upstream emissions that would be expected from a comparably sized gasoline vehicle; size is a good first-order measure for utility, and footprint is the size-based metric used for standards compliance. The net upstream emissions for PHEVs are equal to the net upstream emissions of the PHEV due to electricity consumption in electric or blended mode multiplied by the utility factor. The net upstream emissions for a gasoline vehicle are zero.

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

The final three columns of Table E.4 give the tailpipe plus net upstream CO_2 values for EVs and PHEVs using the same Low, Average, and High electricity upstream CO_2 emissions rates discussed above. These values bracket the possible real-world net CO_2 emissions that would be associated with consumer use of these vehicles. For the Leaf, these values are simply the values in columns four through six minus the upstream GHG emissions of a comparably sized gasoline vehicle. Based on the model year 2018 CO_2 footprint curve, the 5-cycle tailpipe GHG emissions for a Leaf-sized gasoline vehicle meeting its compliance target would be close to 251 grams/mi, with upstream emissions of one-fourth of this value, or 63 g/mi. The net upstream for the Leaf are determined by subtracting this value, 63 g/mi, from the total (tailpipe + total upstream) emissions for the Leaf. The result is a range for the tailpipe plus net upstream value of 19–172 g/mile as shown in Table E.4, with a more likely sales-weighted value in the 19–87 g/mi range.

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

Alternative Metrics for EVs and PHEVs

Determining metrics for EVs and PHEVs that are meaningful and accurate is challenging. In particular, vehicles capable of using dual fuels, such as PHEVs, can have complicated modes of operation that make it difficult to determine meaningful metrics. Here we've discussed several metrics that are used on the EPA/DOT Fuel Economy and Environment Labels and in a regulatory context, namely mpge, tailpipe CO_2 emissions, and net upstream GHG emissions. There are, however, other ways that alternative fuel vehicle operation can be quantified.

Other energy metric options that could be considered include: (1) mpge plus net fuel life cycle energy, which would also reflect differences in upstream energy consumption in producing the alternative fuel relative to gasoline-from-oil; and (2) miles per gallon of petroleum, which would only count petroleum 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 petroleum metric would yield higher fuel economy values.

Additional Note on PHEV Calculations

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

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

F. Authors and Acknowledgments

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