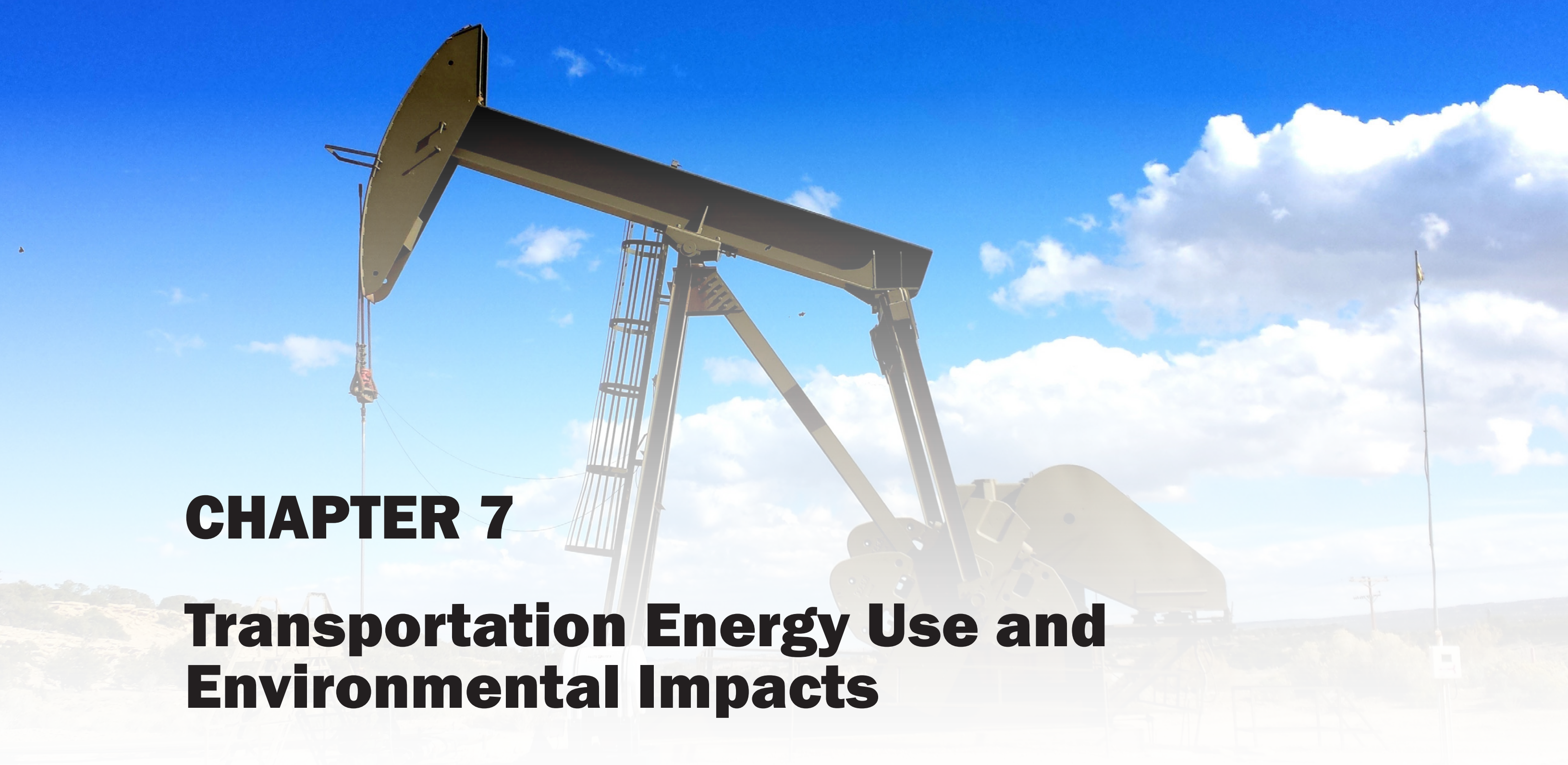


CHAPTER 7

Transportation Energy Use and Environmental Impacts

Highlights

- The energy required to move one person one mile or one ton of freight one mile has generally declined over time.
- Transportation continues to rely almost entirely on petroleum to move people and goods. However, the sector's dependence has decreased from a peak of 97.3 percent in 1978 to 92.2 percent in 2016. This is due in part to increased blending of domestically produced ethanol in gasoline and improved fuel economy.
- Increased domestic oil production sharply reduced transportation's dependence on imported oil, from a high of 60.3 percent in 2005 to 24.8 percent in 2015.
- The highway mode continues to dominate transportation energy use, accounting for 61.6 percent of total transportation energy use.
- Transportation is the second largest producer of greenhouse gas emissions (GHG), accounting for 27.0 percent of total U.S. emissions in 2015.
- Overall, greenhouse gases and the six other most common air pollutant emissions from transportation, with the exception of particulate matter (PM-10), are below their 2000 levels, and continued to decline from 2009 to 2016 due to many factors, including motor vehicle emissions controls and technological advancements, such as electric vehicles have contributed to considerable reductions.
- Reductions in transportation's air emissions have contributed to improved air quality in the Nation's urban areas. On average, air quality was good for 247 days in 2015 compared to 192 days in 2000.
- Over 97 percent of the U.S. population has potential to be exposed to aviation and interstate highway noise at levels below 50 decibels (equivalent to the sound of a humming refrigerator).

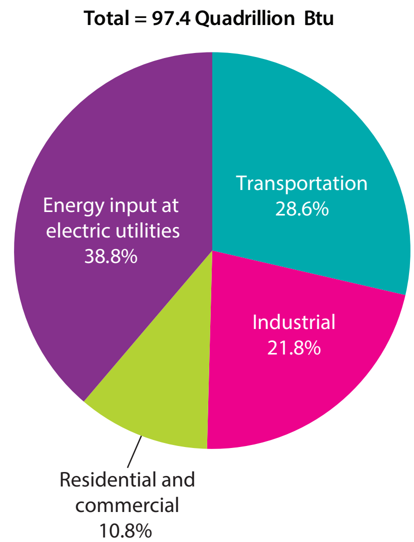
This chapter reviews the patterns and trends in transportation energy use, other aspects of energy associated with our Nation's transportation system, and transportation's impact on the environment. Energy use is closely tied to the transportation sector because most vehicles in the U.S. rely on petroleum as a fuel. Therefore, developments in domestic oil production, alternative fuels, and improvements in vehicle energy efficiencies play a critical role in the vitality of the transportation system. Environmental impacts under consideration include greenhouse gas (GHG) emissions caused by the transportation sector, petroleum spills, noise, and other impacts. These energy and environmental aspects of the transportation system are also important measures of performance, along with such primary measures as system reliability, efficiency, and safety.

U.S. dependence on imported oil is trending lower than in prior years as a result of increased domestic production, improved fuel economy for vehicles, and the growth in alternative energy sources. U.S. dependence on imported oil peaked at 60.3 percent in 2005, but has since decreased by more than half, to 24.8 percent in 2015 [USDOE EIA 2017c]. In 2015 this dependence was at its lowest since 1971, but with increasing fuel efficiency and reduced fuel prices, people are driving more miles on average and demand for less fuel-efficient sport utility vehicles (SUVs). Car and truck SUVs achieved a record market share of 38 percent in model year 2015 [US EPA 2017f].

In 2016 the U.S. transportation sector used 27.5 quadrillion Btu (British thermal unit) of energy, second only to electricity generation, but down from the peak of 28.8 quadrillion Btu in 2007 (figures 7-1 and 7-2). Transportation activities relied on petroleum for 92.2 percent of the transportation-related energy used in 2016, down from a record 97.3 percent in 1978. In 2016, the U.S. consumed more than 19.6 million barrels of oil per day, of which 13.9 million barrels (70.9 percent) were consumed by the U.S. transportation system [USDOE EIA 2017c]. Despite transportation's continued dependence on petroleum, recent trends show small reductions in greenhouse gas emissions and sharply reduced emissions of other air pollutants.

Greenhouse gas (GHG) emissions (carbon dioxide, hydrofluorocarbons, methane, and nitrous oxide) have historically closely paralleled transportation energy use and, as a result, were 4.9 percent lower in 2015 than in 2010, while transportation sector GHG emissions decreased by 1.2 percent [USEPA 2017a]. Overall, the transportation sector contributed 27 percent of total U.S. GHG emissions in 2015, second only to electricity generation at 29 percent. Transportation sector GHG emissions peaked in 2005, but trended downward in the following years with a low point in 2012. The decline was due to increased use of alternative fuels and improved fuel economies related to manufacturers' efforts to make driving more affordable as fuel prices were increasing. Since then GHG emissions have begun to increase due to increases in both miles traveled and use of sport utility vehicles (SUVs) and light trucks associated with lower fuel prices mentioned earlier [USEPA 2017a].

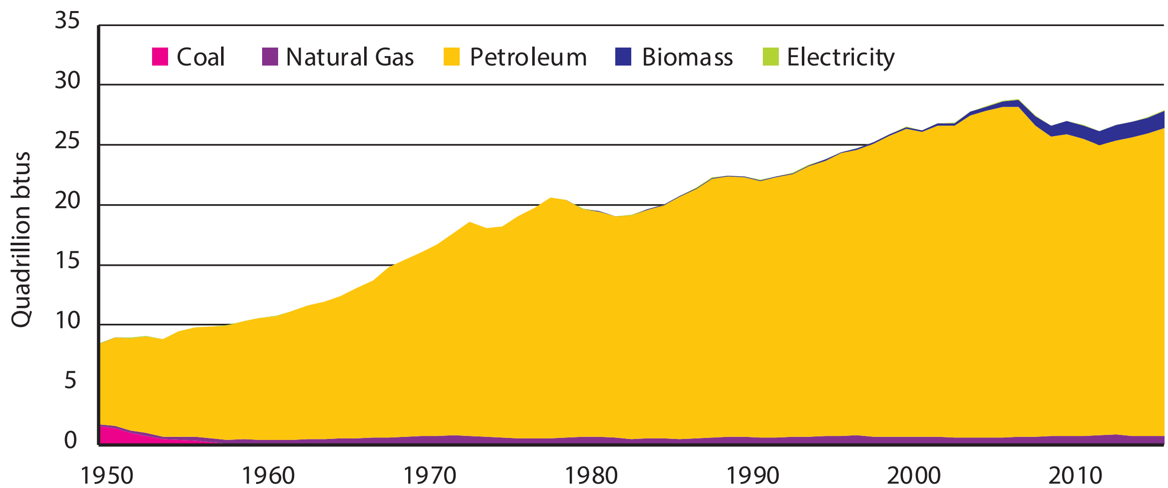
FIGURE 7-1 U.S. Energy Use by Sector: 2016



NOTES: The data for *Residential, Commercial, and Industrial* sectors include only fossil fuels consumed directly. Most renewable fuels are not included. The data for the *Transportation* sector includes only fossil and renewable fuels consumed directly. The data for *Electric* utilities includes all fuels (fossil, nuclear, geothermal, hydro, and other renewables) used by electric utilities.

SOURCE: U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, Table 2-1, Available at http://www.eia.gov/totalenergy/ as of April 2017.

FIGURE 7-2 Transportation Energy Use by Energy Source: 1950–2016



SOURCE: U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, table 2.5. Available at http://www.eia.gov as of April 2017.

Energy Use Patterns and Trends

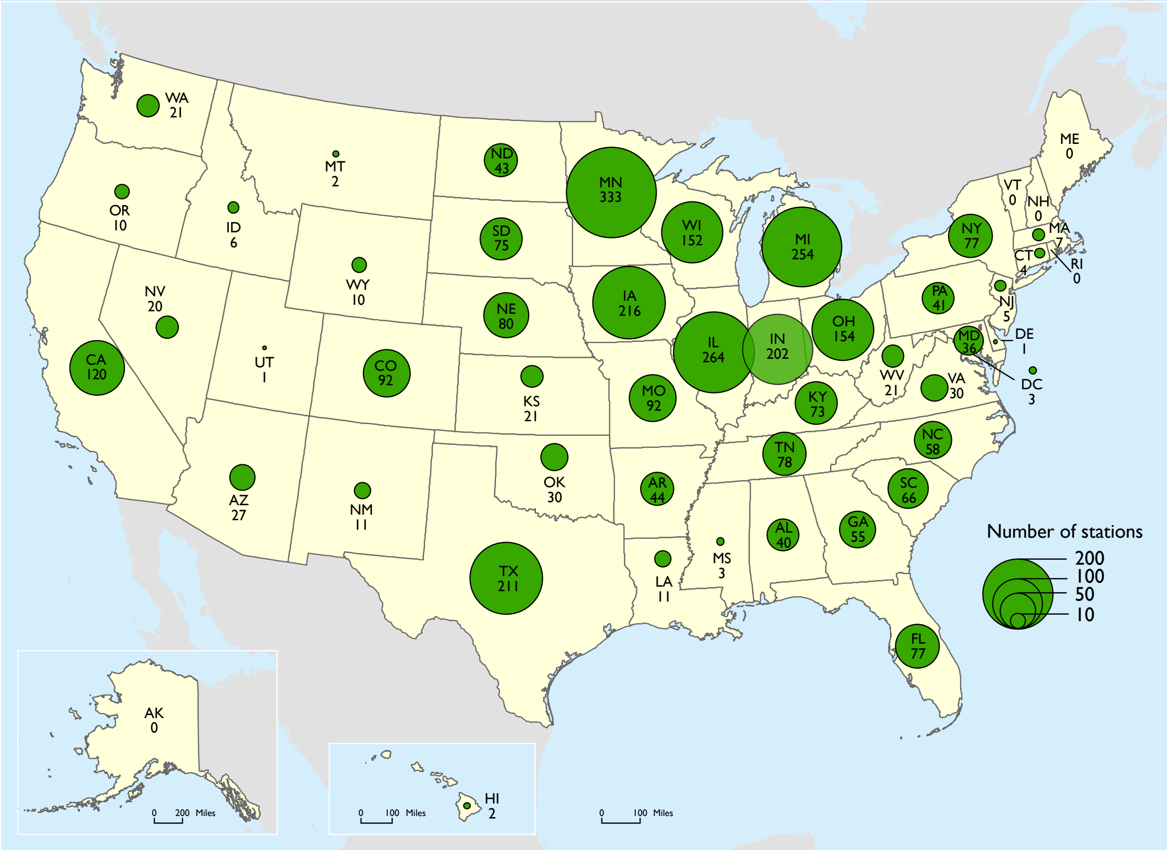
Transportation's petroleum dependence decreased from 96.5 percent in 2005 to about 92.1 percent in 2016, chiefly due to increased blending of domestically produced ethanol from biomass in gasoline [USDOE EIA 2017c]. Today almost all gasoline sold in the United States contains 10.0 percent ethanol (E10). Nearly all transportation-related natural gas consumption, shown in figure 7-2, is used to fuel pipeline compressors. Natural gas use by motor vehicles remains a small fraction of total transportation energy use (figure 7-2).

Transportation's petroleum use is expected to remain at about 13.5 million barrels per day through 2050 and beyond, even though more stringent fuel economy standards may produce decreases in the amount of gasoline used by personal vehicles [USDOE EIA 2017a]. Additionally, as vehicles become more fuel efficient and new technologies for alternative fuel sources to power vehicles continues to grow including all electric vehicles (box 7-A), less petroleum will be required for a similar level of personal travel miles (see sections 7-4 through 7-6). This improvement in fuel efficiencies and a drop in fuel prices recently has led to an increase in personal vehicle miles traveled contributing to the relatively stable petroleum use. This leveling off of petroleum consumption is also expected because declining personal vehicle petroleum use is projected to be offset by growth in petroleum demand by other modes, particularly medium- and heavy-duty trucks and air. For example, U.S. domestic air carrier miles flown has increased by 10 percent since 2000, but this has been somewhat offset by increased fuel efficiencies of the aircraft.

Alternative fuel use (excluding gasohol) by motor vehicles increased by 12.7 percent from 2010 to 2011 (the latest year for which data are available) [USDOE EIA 2017b]. Total alternative fuel use exceeded 500 million gasoline-equivalent gallons in 2011. In comparison, gasoline consumption in the United States grew from about 134 billion gallons in 2011 to more than 140 billion gallons in 2015—approximately 385 million gallons per day [USDOE EIA 2017c]. In terms of overall energy consumption, compressed and liquefied natural gas accounted for almost one-half of the total alternative energy used by transportation activities, followed by E85, propane, electricity, and hydrogen. E85 is a blend of between 51 and 85 percent denatured ethanol and gasoline and can be used safely by approximately 20 million flex-fuel vehicles operating on U.S. roads [USDOE AFDC 2017a]. However, E85 is predominantly available in the Midwest corn-belt states as indicated in figure 7-3.

The highway mode dominates transportation energy use (figure 7-4). Highway vehicles accounted for 84.0 percent of the total and used five times more energy than all other modes combined in 2015. Light-duty vehicles (passenger cars, SUVs, minivans, and pick-up trucks) accounted for 73.3 percent of highway energy use and 61.6 percent of total transportation energy use. Air transport came in a distant second with 6.5 percent of transportation energy use, but this number excludes energy for international flights. Jet fuels supplied to international flights originating in the United States amounted to 931.6 trillion Btu [USEPA 2015a], which is nearly five times the amount of fuel used by

FIGURE 7-3 E85 Refueling Stations by State: 2016



SOURCE: U.S. Department of Energy, Alternative Fuels Data Center, *Alternative Fueling Station Counts* (as of 03/16/2017), available at http://www.afdc.energy.gov/fuels/stations_counts.html as of March 2017.

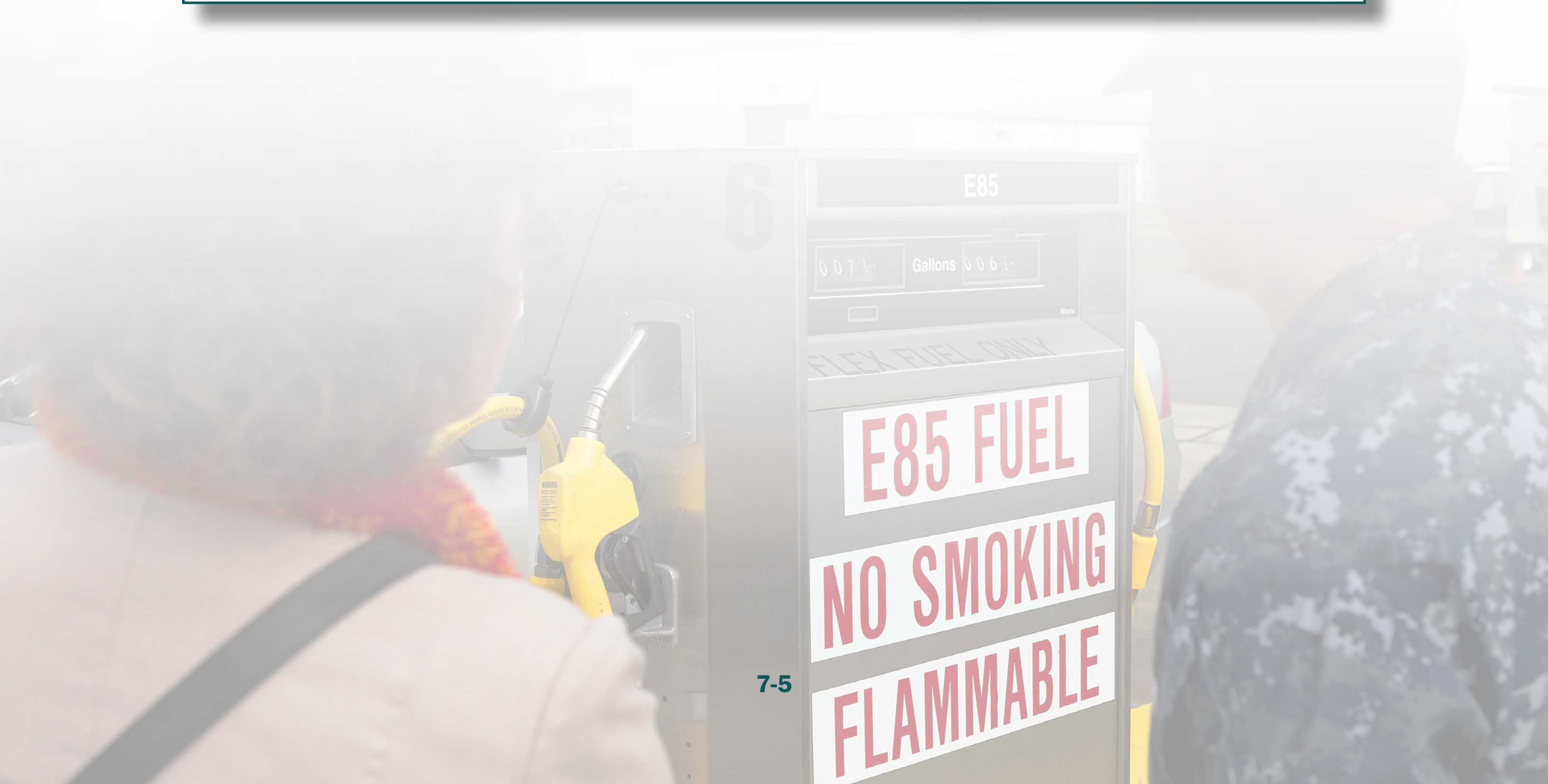
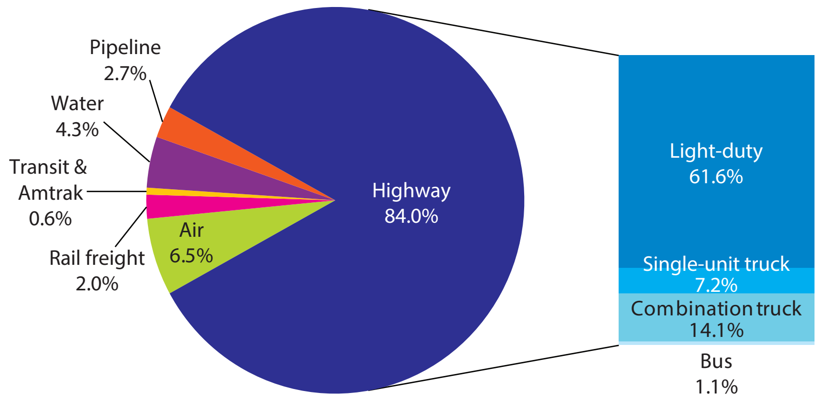


FIGURE 7-4 Energy Use by Mode of Transportation: 2015



NOTES: The following conversion rates were used: Jet fuel = 135,000 Btu/gallon. Aviation gasoline = 120,200 Btu/gallon. Automotive gasoline = 125,000 Btu/gallon. Diesel motor fuel = 138,700 Btu/gallon. Compressed natural gas = 138,700 Btu/gallon. Distillate fuel = 138,700 Btu/gallon. Residual fuel = 149,700 Btu/gallon. Natural gas = 1,031 Btu/ft3. Electricity 1kWh = 3,412 Btu, negating electrical system losses. To include approximate electrical system losses, multiply this conversion factor by 3.

SOURCE: Air–Bureau of Transportation Statistics, Office of Airline Information. **Rail**–Association of American Railroads. **Transit**–Federal Transit Administration. **Amtrak**–National Railroad Passenger Corporation (Amtrak), personal communication with Energy Management Department and Government Affairs Department. **Water**– U.S. Department of Energy, Energy Information Administration and U.S. Department of Transportation, Federal Highway Administration. **Pipeline**– U.S. Department of Energy, Energy Information Administration. **Highway**– Federal Highway Administration as cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics*, table 4-6, available at www.bts.gov as of March 2017.

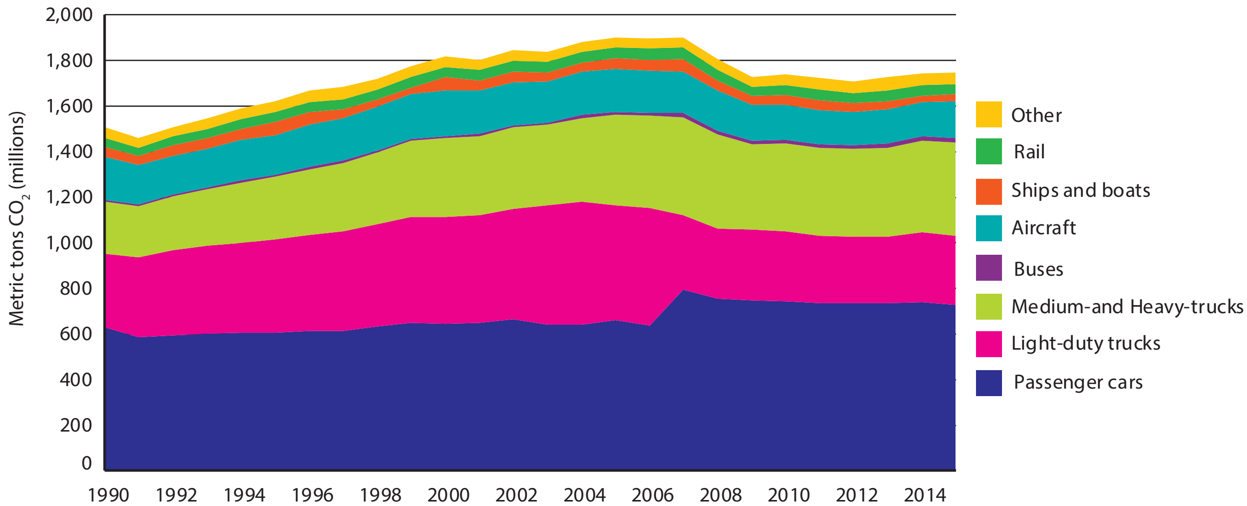
domestic flights. Water transportation is third with 4.3 percent, but once again most of the energy used in international shipments is not included in this figure. An estimated 455.2 trillion Btu were supplied to international ships at U.S. ports [USEPA 2015a], an amount more than double that used by domestic waterborne shipping. Rail freight accounted for 2.0 percent of transportation energy use, although it carries roughly 30 percent of U.S. freight ton-miles. Pipelines used 2.7 percent of transportation energy, much of which is natural gas to fuel pipeline compressors. Transit operations accounted for 0.6 percent of transportation energy use.

Greenhouse Gas Emissions

Total transportation greenhouse gas (GHG) emissions were 4.0 percent lower in 2015 than in 2000. Both the recession and the improvements in availability of energy efficient vehicles likely contributed to this reduction [USEPA 2017a].

Despite the long-term emissions decrease, the transportation sector remains the second largest producer of greenhouse gas (GHG) emissions, accounting for approximately 27.0 percent of total U.S. emissions in 2015 [USEPA 2017a]. Electricity generation is the highest GHG producer. In recent years, transportation-related GHG emissions have been trending upward, but are below the 2005 peak (figure 7-5). Carbon dioxide (CO_2) produced by the combustion of fossil fuels in internal combustion engines is the predominant GHG emitted by the transportation sector. In 2015 passenger cars were the largest source of CO_2 from transportation, accounting for

FIGURE 7-5 CO_2 Greenhouse Gas Emissions by Mode: 1990–2015



NOTES: *Other* greenhouse gas emissions are from motorcycles, pipelines, and lubricants. International bunker fuel emissions (not included in the total) result from the combustion of fuels purchased in the United States but used for international aviation and maritime transportation. *U.S. Total, all modes; Aircraft; and Ships and boats* include emissions data for only domestic activity only as do all other data shown. International emissions from bunker fuels purchased in the United States are not included. Alternative-fuel vehicle emissions are allocated to the specific vehicle types in which they were classified (i.e., Passenger cars, *Light-duty trucks, All other trucks,* and *Buses*).

SOURCE: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015* (2017), table 2-13, available at http://epa.gov/climatechange/emissions/usinventoryreport.html as of March 2017.

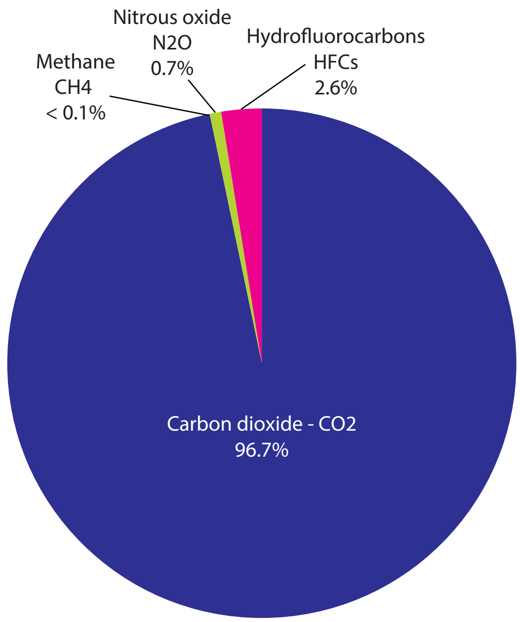
41.6 percent, followed by freight trucks (23.5 percent) and light-duty trucks (17.4 percent). Domestic operation of commercial aircraft produced 9.1 percent of transportation CO_2 emissions; however, as mentioned in chapter 2, there are now more air passenger miles in international flights originating and ending in the United States than there are domestic passenger miles, leaving much of the air travel emissions unaccounted for. Pipelines were responsible for 3.0 percent of emissions, followed by rail (2.5 percent) and ships and boats (1.8 percent) [USEPA 2017a].

Hydrofluorocarbons (HFC), methane (CH_4), and nitrous oxides (N_2O) are the other principal GHGs emitted by the transportation sector. Each GHG is reported using a common metric of equivalent grams of CO_2 for each emission (figure 7-6). HFCs, such as those once used in automotive air conditioners, are second in abundance behind CO_2. HFCs are the most detrimental GHGs known. GHG emission regulations for personal vehicles give manufacturers credits for reducing these HFC emissions, and it is likely that these emissions will decrease in the future. Nitrous oxides are chiefly produced in the catalytic converters of motor vehicles, and a very small quantity of methane emissions is produced by incomplete combustion of fossil fuels or by leakage.

Because 96.7 percent of transportation GHG emissions are CO_2 produced by fossil fuel combustion and because petroleum comprises 92.2 percent of transportation energy use,

FIGURE 7-6 CO_2 Greenhouse Gas Emissions by Mode: 1990–2015

Total = 1,804 Teragrams or million metric tons of CO_2 Equivalent Units



NOTES: The data for the transportation sector includes only fossil and renewable fuels consumed directly. The data for Non-Transportation includes the Residential, Commercial, and Industrial sectors, which include only fossil fuels consumed directly, and electric utilities, which includes all fuels (fossil, nuclear, geothermal, hydro, and other renewables) used by electric utilities. Most renewable fuels are not included. Totals may not add to 100% due to rounding.

SOURCE: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015*, **table 2-12 and table ES-6, available at** http://epa.gov/climatechange/emissions/usinventoryreport.html **as of March 2017.**

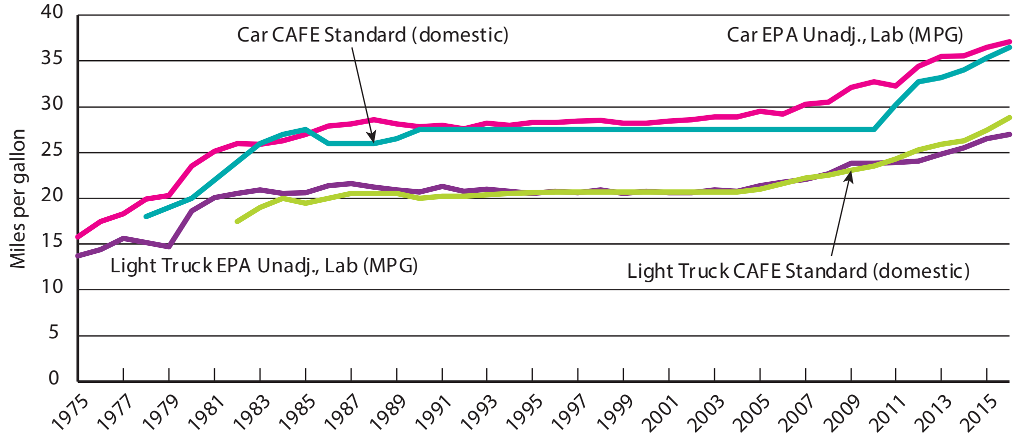
modal GHG emissions closely track modal energy use. Transportation GHG emissions increased from 2000 to 2007 (figure 7-5), fell by 5.0 percent during the economic recession in 2008, and then stabilized at slightly under 1,800 teragrams (million metric tons) in the 2009 to 2015 period with a slight increase from 2014 to 2015 [USEPA 2017a]. The short-term decrease in economic activity and the related decline in transportation demand contributed, in part, to the decrease in CO_2 emissions during the recession.

Evident in figure 7-7 are the results of the U.S. Environmental Protection Agency's (EPA's) decision to change the definitions of passenger cars and light trucks in 2007. Many vehicles formerly classified as light trucks, but designed predominantly for passenger transportation, were reclassified as passenger cars, causing an apparent jump in passenger car emissions that were offset by a compensating drop in light-truck emissions.

Energy Efficiency

Historically, improvements in the efficiency in energy use have reduced energy consumption in the transportation sector. Fuel economies of passenger cars and light trucks have closely tracked the Corporate Average Fuel Economy

FIGURE 7-7 Car and Light Truck Corporate Average Fuel Economy (CAFE) and Miles per Gallon (MPG): Model Years 1975–2016



KEY: MPG = Miles per Gallon; EPA = U.S. Environmental Protection Agency; P = preliminary; R = revised.

NOTES: Corporate Average Fuel Economy (CAFE) standards, which must be met at the manufacturer level were established by the *U.S. Energy Policy and Conservation Act of 1975* (PL 94-163). EPA Unadjusted, Laboratory (MPG) estimates are based upon standardized laboratory tests and do not account for factors that may affect actual roadway fuel economies such as aerodynamics, climate, etc.

SOURCE: All Car and All Truck CAFE Stds: Davis, S.C., S.W. Diegel and R.G.Boundy. *Transportation Energy Data Book*, Edition 35 (October 2016), Oak Ridge National Laboratory, Oak Ridge, TN. Tables 4-21 and 4-22. Available at cta.ornl.gov/data as of April 2016. **Car and All Truck EPA MPG**: U.S. Environmental Protection Agency (EPA), **Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 - 2016**. Table 9.1. Available at http://epa.gov/otaq/fetrends.htm as of March 2017.

(CAFE) standards since they took effect in 1978 (figure 7-7). The miles per gallon (mpg) values shown in figure 7-7 are the unadjusted, laboratory test values on which compliance with the standards is based. These values do not account for factors that affect highway fuel efficiency such as wind and vehicle aerodynamics. The actual mpg values seen on window stickers and in public advertising are adjusted downward to better represent the fuel economy drivers will likely experience on the road.[1]

The average 25.6 mpg (preliminary estimates) for model year 2016 for all models was down slightly from 24.8 mpg in 2015, due to increased consumer demand for less fuel efficient light trucks and SUVs associated with low fuel costs as discussed earlier [USEPA 2017f]. These mpg results are up significantly from 1975, the start of the era of fuel economy improvements as vehicle-miles traveled grew faster than fuel consumption (figure 7-8). However, drops in fuel use are tempered somewhat by increases in travel stimulated by improvements in fuel economy, a phenomenon known as the "rebound effect." Fuel price declines have been a factor in an increase in individual miles driven on an annual basis.

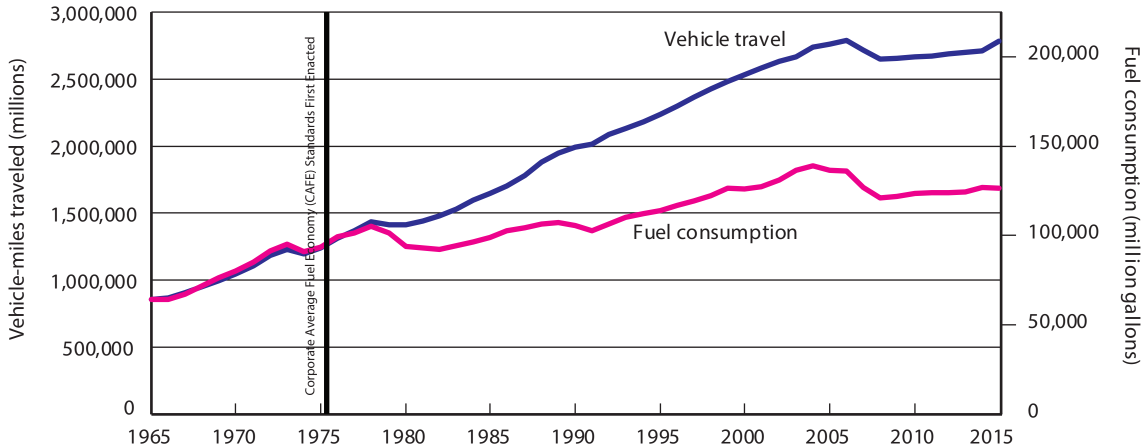
[1] The apparent decrease in on-road fuel economy estimates after 2005 more likely reflects a change in the definitions of passenger cars and light trucks and the methods used to estimate their travel and fuel use than an actual decrease in mpg. Another change in reporting occurred when the U.S. Department of Transportation (USDOT), Federal Highway Administration (FHWA), started using the classifications of short- and long-wheelbase light-duty vehicles in 2007 rather than the previous categories of passenger cars and two-axle, four-tire trucks. As a result, the post 2006 on-road fuel economy data are not consistent with the data from 2006 and earlier years, unless the categories are combined

For example, regular gasoline prices in the U.S. dropped to an average of $2.14 per gallon in 2015 down from $3.62 per gallon in 2012, the highest annual average since 2000 [USDOE EIA 2017d]. When gas prices were at high levels, auto manufacturers focused on small, fuel-efficient vehicles. With the price decline, drivers are again demanding the large trucks and SUVs of earlier years, but due to CAFE standards, they are now more fuel efficient with the new diesel and hybrid and/or electric options today (see sections 7-4 to 7-6) [WOODYARD 2015].

On August 28, 2012, the USDOT and the EPA set fuel economy and GHG emissions standards for passenger cars and light trucks through 2025. Nominally, the standards require a total fleet average of 54.5 mpg (163 grams of CO_2 equivalent) for new personal vehicles by 2025 [USEPA 2012]. However, these standards are based on laboratory test cycles rather than real world driving and do not consider the many ways manufacturers can earn fuel economy credits. Credits may be earned for solar panels on hybrids, engine shut off at idle, and other features that improve on road fuel economy but which are not reflected in the test cycle.

Furthermore, the new standards vary with the size of the vehicles a manufacturer produces. Medium- and heavy-duty highway vehicles (e.g., combination trucks and buses) are the second largest energy users among modes, accounting for 23.0 percent of transportation energy use in 2015 [ORNL 2015]. In 2011 the USDOT and the EPA announced the first fuel economy and emission standards for this vehicle class for model years 2014 –2018

FIGURE 7-8 Vehicle-Miles of Travel and Fuel Use by Personal Vehicles: 1965–2015



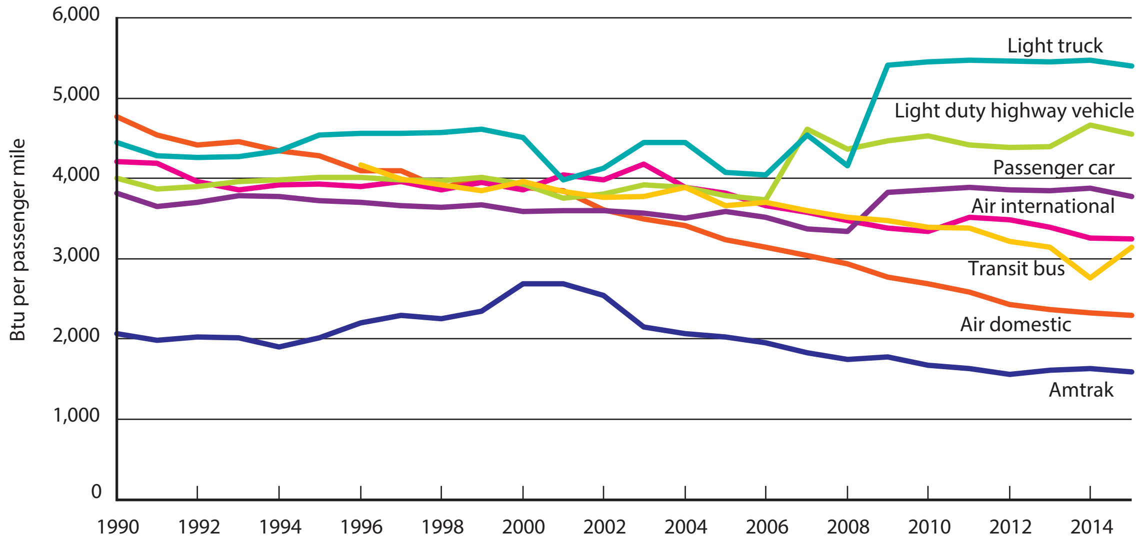
NOTES: Includes passenger cars, light trucks and motorcycles for year 1965. The definition of light-duty vehicle was changed after 2006, affecting the vehicle types included in the personal vehicle category.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (multiple years), Table VM-1, available at http://www.fhwa.dot.gov/policyinformation/statistics.cfm as of March 2017.

[USEPA 2011]. By 2018 the requirements for combination tractor trailers specify fuel economy improvements ranging from 9 to 23 percent, depending on the truck type. Similar improvements are required for the diverse class of single unit commercial trucks and buses—vehicles as various as delivery trucks, dump trucks, cement mixers, and school buses. If a manufacturer produces mostly large vehicles, then its actual fuel economy requirement will be lower than if it produces mostly small vehicles. Taking all these factors into account, USDOT and EPA estimated that manufacturers would achieve fuel economy levels of 46.2 to 47.4 mpg on the laboratory test cycles [FEDERAL REGISTER 2012]. Fuel economies achieved in actual driving would likely be 15 to 20 percent lower. New fuel-economy standards were developed for model years 2022-2025 that would be even more stringent than before, but at present are on hold as they are being re-reviewed.

The energy intensities of passenger modes have generally declined over time, with five out of six passenger modes now averaging less than 4,000 Btu per person-mile, or about 30 person-miles per gallon of gasoline equivalent (figure 7-9). These declines are largely the result of more aerodynamic vehicles and efficient engines as well as improved operating efficiencies (e.g., higher air carrier load factors). From 2000 to 2014, the energy intensity of short- and long-wheel base light-duty vehicles and bus transit rose likely due to increased fuel efficiencies, while the energy intensity of other passenger modes—air and Amtrak—declined. The energy intensity of rail freight transport decreased from 14,826 Btu/car-mile in 2000 to 14,421 in 2014. Moving one ton of freight one mile in 2014 required 88.4 percent as much energy as it did in 2000. This reduction was accomplished mostly through reducing energy use per freight car-mile by about 2.1 percent [USDOT BTS NTS

FIGURE 7-9 Energy Intensity of Passenger Modes: 1990–2015 (Btu per passenger mile)



NOTES: Light-duty highway vehicles include passenger cars, light trucks, vans, and sport utility vehicles. Highway data for 2007-2011 were calculated using a new methodology and are not comparable to previous years. A change in vehicle occupancy rates derived from the National Household Travel Surveys results in a shift of highway passenger-miles between 2008 and 2009. Energy Intensity (Btu per Passenger mile) = Energy Use (Btu) / Passenger Miles, Energy Use calculated by using fuel and electricity usage and converting to energy by using BTS conversion rates. The following conversion rates were used: Diesel =138,700 Btu/gallon. Compressed natural gas = 22,500 Btu/gallon. Bio-Diesel = 126,200 Btu/gallon. Liquefied natural gas = 84,800 Btu/gallon. Gasoline = 125,000 Btu/gallon. Liquefied petroleum gas = 91,300 Btu/gallon. Methanol = 64,600 Btu/gallon. Ethanol = 84,600 Btu/gallon. Bunker fuel = 149,700 Btu/gallon. Kerosene = 135,000 Btu/gallon. Grain additive = 120,900 Btu/gallon. Electricity 1KWH = 3,412 Btu, negating electrical system losses. This table includes approximate electrical system losses, and thus the conversion factor is multiplied by 3.

SOURCE: Highway–Federal Highway Administration. **Air**–Bureau of Transportation Statistics, Office of Airline Information. **Amtrak**–National Railroad Passenger Corporation (Amtrak), personal communication with Energy Management Department and Government Affairs Department and Association of American Railroads. **Transit**–Federal Transit Administration as cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics*, table 4-21, 4-22, 4-24, and 4-16, available at www.bts.gov as of November 2017.

2017]. To reduce both fuel consumption and emissions, ships are now are using alternative power sources to power air conditioning and other functions while docked. Trucking fleets are both leveraging new hybrid diesel technology as well as platooning where they utilize automated driving technology allowing them to drive less than 1 second apart to reduce fuel consumption and improve efficiencies.

Alternative Fuels and Vehicles

A large part of the growing use of biofuels (represented as biomass) in transportation, an over 900 percent increase from 2000 to 2016, shown in figure 7-2, can be attributed to the requirements of the Federal Renewable Fuels Standard (RFS). Enacted as part of the *Energy Policy Act of 2005* (Pub. L. 109-58) and extended by the *Energy Independence and Security Act of 2007* (Pub. L. 110-140), the RFS requires the introduction of increasing amounts of renewable energy into gasoline and diesel fuels each year, ultimately reaching 36 billion gallons by 2022 [USLOC CRS 2013b and 2015]. At least 16 billion gallons are required to be cellulosic ethanol, and no more than 15 billion gallons can be ethanol produced from corn starch. In 2014 the U.S.

consumed nearly 13.5 billion gallons of fuel ethanol and 1.4 billion gallons of biodiesel [USDOE EIA 2017c]. Therefore, we are near the goal for ethanol already, but not so in terms of biodiesel.

More than 39 billion gallons of diesel fuel were consumed by vehicles in 2015 compared to 33 billion gallons in 2000 [USDOE EIA 2017e]. Diesel vehicles offerings, including new, clean diesel technologies are hitting the market, and these vehicles are providing more fuel efficiencies than similar-sized gasoline engines. Diesel fuel can provide up to 15 percent more energy than the equivalent amount of gasoline [USDOE and US EPA 2016]. These vehicles are a small percentage of the Nation's fleet of motor vehicles, mostly medium and heavy trucks. In 2015 there were an estimated 1.74 million turbocharged direct injection (TDI) light-duty diesel vehicles in the United States out of 210.2 million conventional cars and light-duty trucks [USDOE ORNL 2017].

Flexible-fuel vehicles (FFVs) can safely use mixtures of up to 85 percent ethanol (E85) with gasoline. FFVs accounted for 75.7 percent of the nearly 19.7 million alternative fuel vehicles operating on U.S. roads in 2015 [USDOE EIA 2017a]. However, most on-road FFVs are fueled with gasoline or gasoline/E10 blends only. Until 2016 automobile manufactures could earn extra credits toward meeting CAFE standards by making and selling FFVs. Future FFV sales are uncertain because the credits will be largely phased out unless actual use of E85 increases substantially. Together, liquid petroleum gas/propane and compressed/liquefied natural gas-powered vehicles accounted for approximately 4.5 percent of alternative fuel vehicles in use in 2015 [USDOE EIA 2017a].

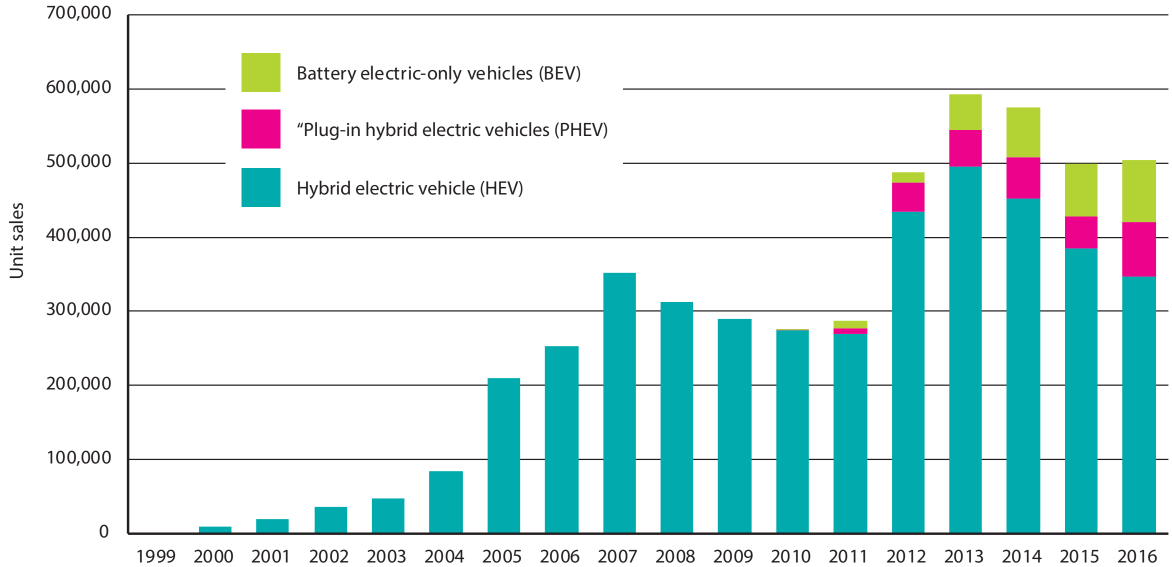
Alternative Refueling/Recharging

The first mass-produced hybrid electric vehicle (HEV), powered by an internal combustion engine and an electric motor, was introduced in 1999. Hybrid vehicles have become popular as a replacement for traditional gasoline- or diesel-fueled vehicles. HEV sales grew from 17 vehicles in 1999 to a high of 592,000 in 2013 (including plug-in hybrid and battery-powered vehicles) before declining, likely due to a drop in gasoline prices that made these vehicles less attractive to buyers. In 2016 about 504,000 HEV/electrics were sold in the United States (figure 7-10).

In 2010 just 19 electric-only and 326 plug-in hybrid vehicles were sold. By 2016 these numbers were 84,000 and 73,000, respectively [HYBRIDCARS 2017]. Over the same period, the number of new to the market makes and models of battery electric-only vehicles increased from 3 to 15, while plug-in hybrid offerings increased from 1 to 17 [USDOE and USEPA 2017b]. Electrically driven motor vehicles are gaining popularity in the consumer market.

The first mass-produced "plug-in" hybrid electric vehicles (PHEV), able to draw electric power from the utility grid and store it on-board, were sold in 2010. Hybrid electric vehicles (HEV), PHEVs, and battery electric vehicles (BEV) saw a 69.1 percent rise in sales from 2015 to 2016 and comprised about 2.9 percent of the 17.5 million vehicle sales in 2016 [HYBRIDCARS 2016]. However, automakers share must reduce costs, overcome the market's

FIGURE 7-10 Sales of Hybrid, Plug-in Hybrid and Battery Electric Vehicles: 1999–2016



SOURCE: HybridCars, December Dashboards, Annual Issues, available at www.hybridcars.com as of March 2017.

Box 7-A Electric Vehicles

All-electric vehicles (i.e., those powered solely by an electric motor not requiring other fuel) have a long history, with the earliest battery powered vehicles produced prior to 1900 before losing out in the market to gasoline powered vehicles [USDOE 2016].

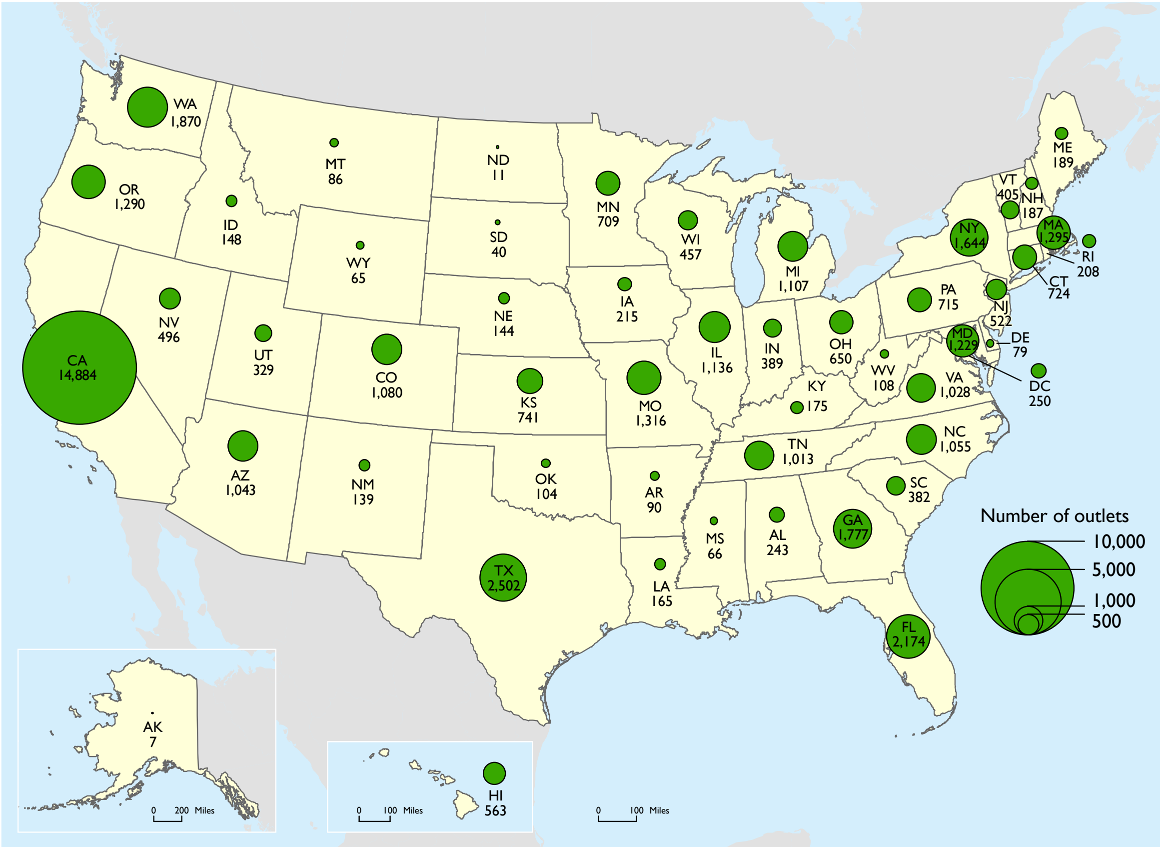
Today, all-electric vehicles are taking a larger share of the market with over 87,000 units sold in 2016 compared to over 70,000 plug-in hybrid electric vehicles. For model year 2017, at least 12 models of all-electric vehicles and 17 models of plug-in hybrid electric vehicles (PHEVs) exist [USDOE ORNL 2016].

Today, the typical driving range for all-electric vehicles is 60 to 120 miles [USDOE 2017f]. Today's batteries hold more charge and take up less space in the vehicle. Battery capacities in all-electric vehicles today range from 22 kW-hrs to 100 kW-hrs, which exceed the capacity range for PHEVs (7.1 to 33 kW-hrs). Battery costs continue to go down for consumers as new technologies emerge. Public electric charging stations/outlets have increased from about 3,500 in 2011 to over 42,000 in 2016 [USDOE ORNL 2016].

The EIA's Annual Energy Outlook projects that battery-electric vehicles will surpass PHEVs sales nearly doubling PHEV sales by the year 2040. This demand is partially driven by incentivized programs such as California's Zero-Emission Vehicle regulation that has been replicated in 9 other states. The trend is expected to continue to combat air quality concerns and mitigate climate change [USDOE ORNL 2016].

Considerable progress has been made in creating a nationwide recharging infrastructure. As of May 2017, there were more than 18,000 recharging stations including privately owned stations with more than 49,000 nonresidential charging outlets across the United States, up from almost 3,400 outlets in 2011 [USDOE AFDC 2017c]. The distribution of electric vehicle recharging stations (figure 7-11) tends to favor states that have opted into California's Zero Emission Vehicles (ZEV) standards.

FIGURE 7-11 Electric Vehicle Refueling Stations by State: March 2017



SOURCE: U.S. Department of Energy, Alternative Fuels Data Center, *Alternative Fueling Station Counts* (as of 03/16/2017), available at http://www.afdc.energy.gov/fuels/stations_counts.html as of March 2017.

unfamiliarity with the new technology, decrease the length of time required for recharging batteries, increase the distance that can be driven on one charge and further, develop recharging infrastructure to increase market share.

Liquid petroleum gas/propane and compressed/liquefied natural gas-powered vehicles accounted for approximately 4.5 percent of alternative fuel vehicles in use in 2015 [USDOE EIA 2017a]. California, Texas, Oklahoma, and New York have wide distribution and availability of compressed and liquefied natural gas refueling stations (figure 7-12). These states have among the highest number of CNG/LNG vehicles registered.

Transportation's Energy Outlook

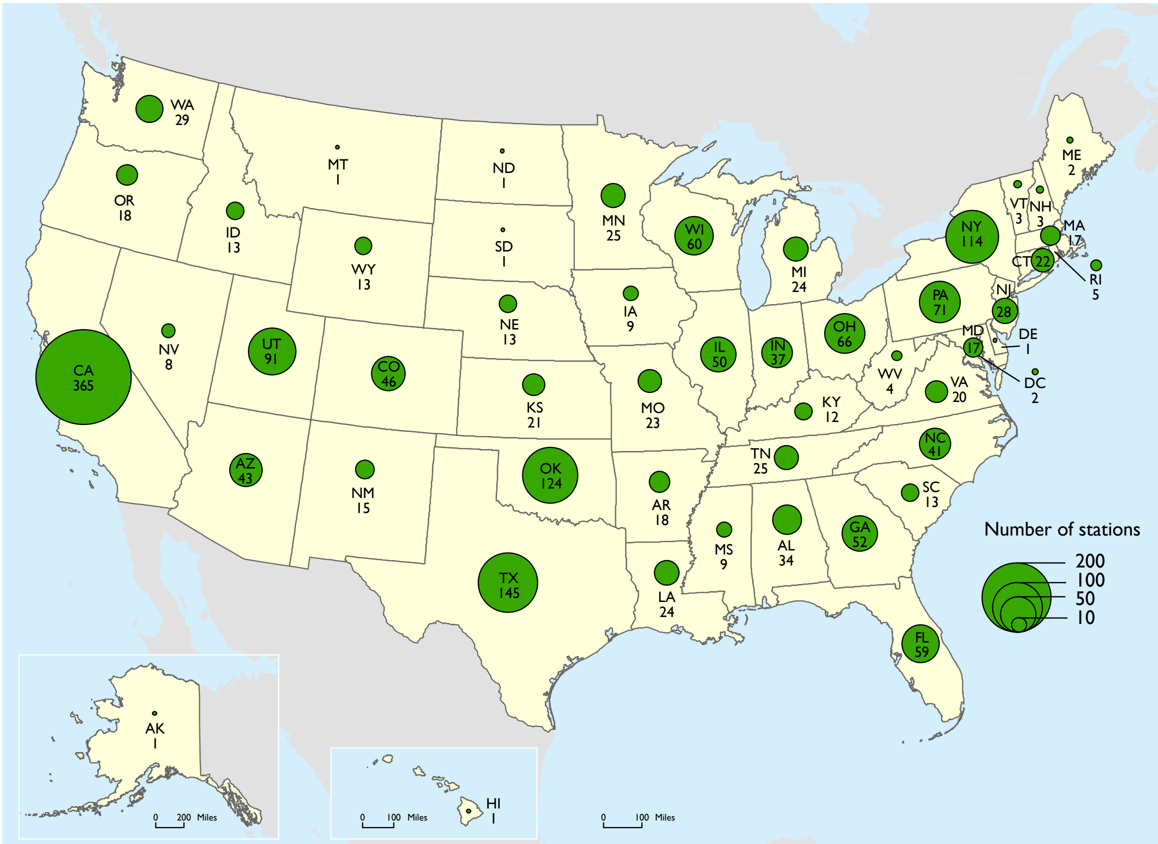
The EIA has projected the likely effects of current trends and existing policies on transportation's future energy use and GHG emissions. Transportation energy use is projected to remain at or near the current level of 27 quadrillion Btu through 2050 [USDOE EIA 2017a]. Existing fuel economy and GHG emissions standards are expected to decrease light-duty vehicle energy use by 15.8 percent by 2050, resulting in approximately 13.5 quadrillion Btu of energy use for 2050 (figure 7-13). Most of this reduction is expected to be offset by growth in energy use by medium- and heavy-duty trucks, although that could change if fuel economy and emissions standards for those vehicles are further tightened.

For all other modes, activity growth is approximately balanced by improvements in energy efficiency. These projections are based on existing policies and increasing oil prices which have declined in recent years; therefore, the projections are subject to change as has been seen in recent years with the decline in petroleum prices. Natural gas use by motor vehicles in compressed and liquefied form is projected to increase from just 0.06 quads in 2015 to 0.52 quads by 2050 [USDOE EIA 2017a]. EIA attributed all of the projected increase in natural gas use by motor vehicles to medium- and heavy-duty trucks and buses.

According to the EIA, the 2011–2025 fuel economy standards coupled with the anticipated second phase of fuel efficiency regulations are planned to take effect in 2027. Together with the market's response to higher gasoline prices, these fuel efficiency regulations are projected to save personal vehicle owners about 26 billion gallons of motor fuel in 2050, if consumption would have remained at the same level of vehicle travel without any increase in fuel economy (figure 7-14).

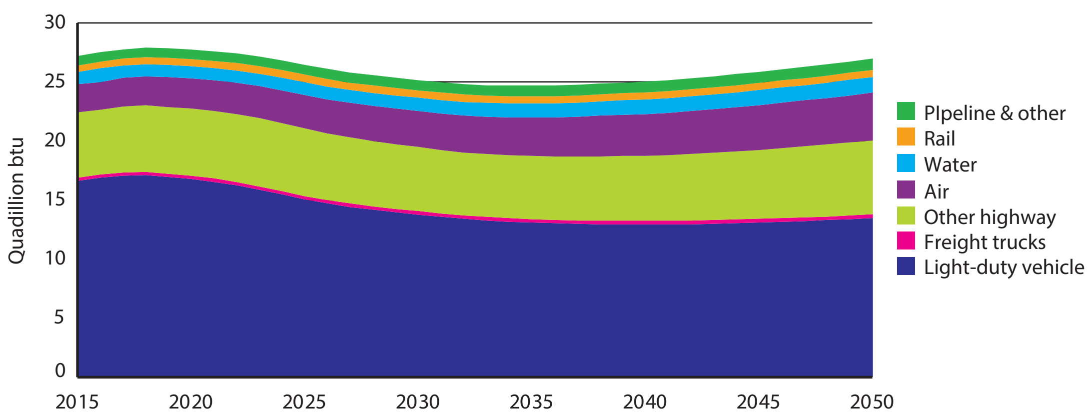
By fuel type, EIA projects gasoline use to decline from 17.0 quads in 2015 (actual) to 13.4 in 2050, in line with light-duty vehicle energy use. Diesel fuel use is projected to increase from 6.6 in 2015 to 7.0 quads in 2050, which is consistent with the growth of truck freight energy use. E85 will increase but will still amount to only 0.17 quads of transportation energy in 2050. Interestingly, electricity is anticipated to have the second highest increase next to gasoline over the 2015 to 2050 time period, going from 0.03 quads to 0.41 quads per year. Hydrogen is projected to lead in terms of growth, from 0.0 at present to 0.08 quads per year [USDOE EIA 2017a]. The growth in new technologies that make

FIGURE 7-12 Alternative Fuel Stations by State: March 2017



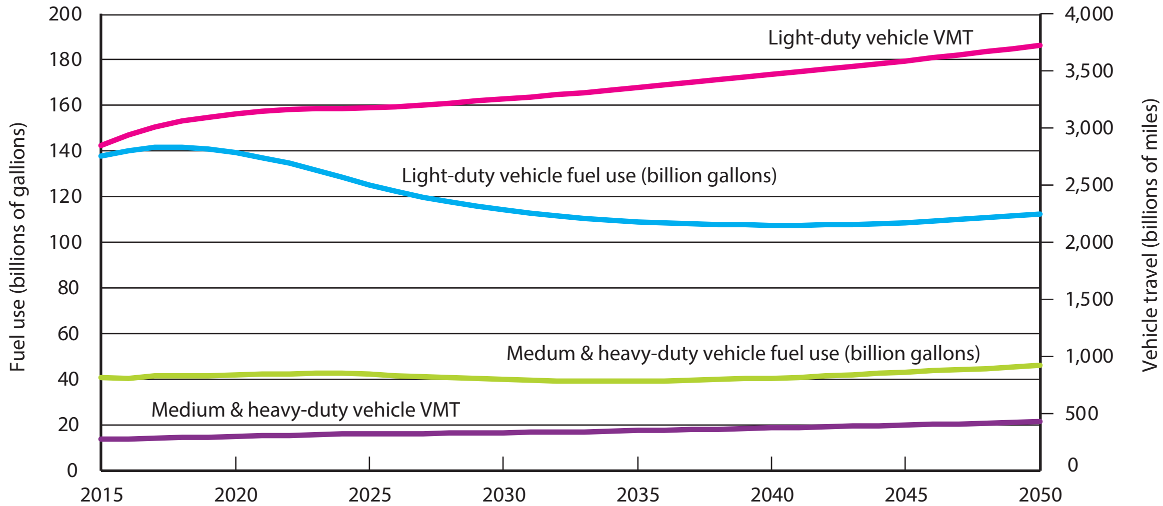
SOURCE: U.S. Department of Energy, Alternative Fuels Data Center, *Alternative Fueling Station Counts* (as of 03/16/2017), available at http://www.afdc.energy.gov/fuels/stations_counts.html as of March 2017.

FIGURE 7-13 Transportation Energy Use: 2015 Projected to 2050



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2017*. Transportation Sector Energy Use by Mode and Type. Available at http://www.eia.gov/forecasts/aeo/ as of March 2017.

FIGURE 7-14 Highway Vehicle Fuel Use and Travel: 2015 Projected to 2050



KEY: VMT = Vehicle-miles Travelled.

SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2017*. Reference Case table 7. Available at http://www.eia.gov/forecasts/aeo/ as of March 2017.

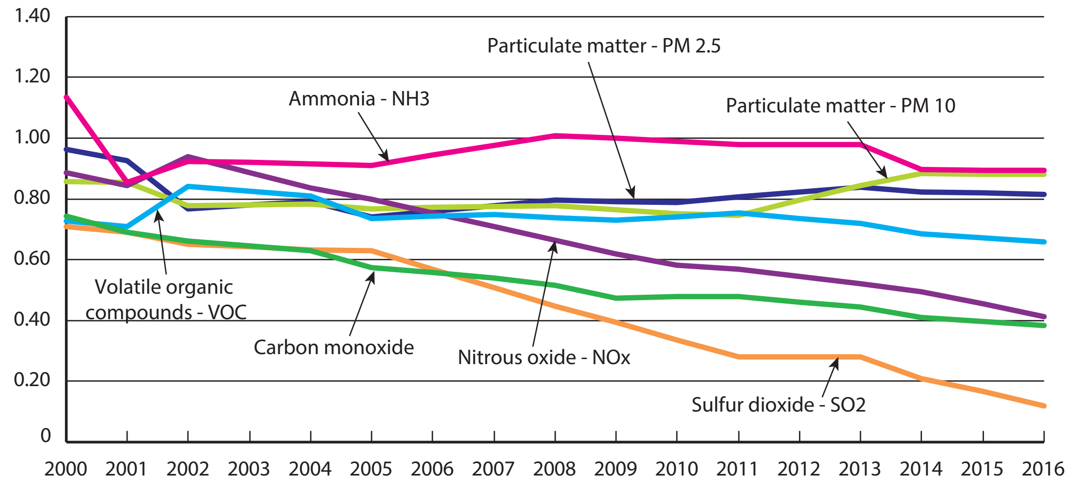
these fuel sources more affordable and easily accessible for both electric and hydrogen-powered vehicles are the driving forces behind this projected trend.

Air and Water Quality, Noise, and Habitat Impacts

Beyond the greenhouse gases addressed earlier in the chapter, vehicle emissions controls and other policies have reduced transportation's other six most common criteria air pollutant emissions to below 2000 levels, a trend that continued through 2016 with the exception of particulate matter 10 (PM-10), which have remained constant from 2014 to 2016 (figure 7-15). PM-10 refers to small, inhalable particles smaller than 10 micrometers in diameter that form from complex reactions of chemicals, such as sulfur dioxide (SO_2) and nitrogen oxides (NOx). Particulate matter can also be emitted directly from sources such as construction sites, smokestacks, or fires. Transportation's share of total U.S. PM-2.5 emissions decreased by 15.4 percent from 2000 to 2016, while the share of PM-10 emissions increased by 2.9 percent over the same period.

Smog-forming emissions of volatile organic compounds (VOC) and NOx were 9.4 and 53.6 percent lower, respectively, in 2016 than they were in 2000. In recent years, NOx emissions have decreased more rapidly, partly due to more advanced diesel emission controls and the use of cleaner, ultra-low sulfur diesel fuel. Diesel-fueled vehicles make up 4 percent of the total transportation fleet with the majority of the diesel vehicles being medium and heavy trucks [USDOE EIA 2015].

FIGURE 7-15 Indexes of Key Air Pollutant Emissions from U.S. Transportation: 2000–2016



SOURCE: U.S. Environmental Protection Agency, *National Emissions Inventory Air Pollutant Emissions Trends Data, 1970-2016*, Average Annual Emissions All Criteria Pollutants, Available at https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data as of March 2017.

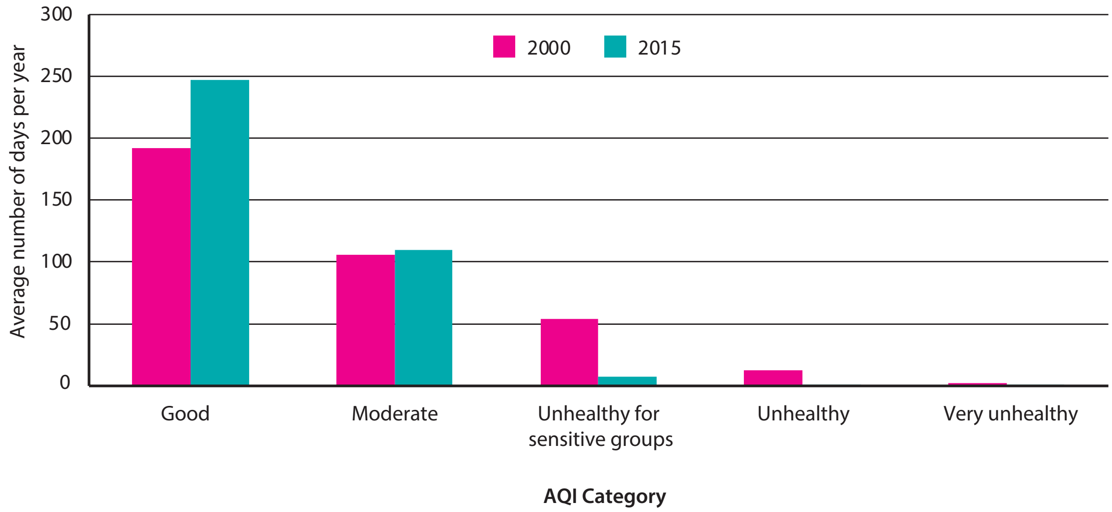
Emissions of SO_2 were 83.4 percent lower in 2016 than in 2000, due in large part to reductions in the sulfur contents of gasoline and diesel fuel. The *Clean Air Act of 1970* led to the reduction in lead emissions, once a major air pollutant from transportation; lead is not shown in figure 7-15 because it has been virtually eliminated from transportation with the phase-out of leaded gasoline.

Emissions of ammonia (NH3), another air pollutant, also shows a significant decline from 2000 levels with a reduction of 21.4 percent in 2016 [USEPA 2017d]. Transportation comprised 2.4 percent of total U.S. emissions of ammonia in 2014 [USEPA 2016b].

Reductions in transportation's air emissions have contributed to improved air quality in the Nation's urban areas. Figure 7-16 compares air quality days for 169 continuously monitored urban areas in 2000 and in 2015. The average number of days from the 169 urban areas in which air quality was reported to be unhealthy for sensitive groups (e.g., people with lung disease, young children, and older adults) dropped from 53.6 in 2000 to 6.9 in 2015; the average number of days with unhealthy air quality for the population as a whole declined from 12.2 in 2000 to 0.9 in 2015, and the total number of very unhealthy days (which could trigger health emergency warnings for the public) decreased from an average of 1.8 in 2000 to 0.1 in 2015. The great majority of days had good or moderate (192 good and 106 moderate) air quality in 2000 and again in 2015 (247 good and 110 moderate). On average, air quality in these cities was good for 247 days in 2015, which was a substantial increase compared to 192 days in 2000 [USEPA 2017b].

Pipelines, ships and barges, railroad cars, and tank trucks are among the sources of spills of

FIGURE 7-16 Air Quality Index (AQI) Across 169 U.S. Cities: 2000 and 2015



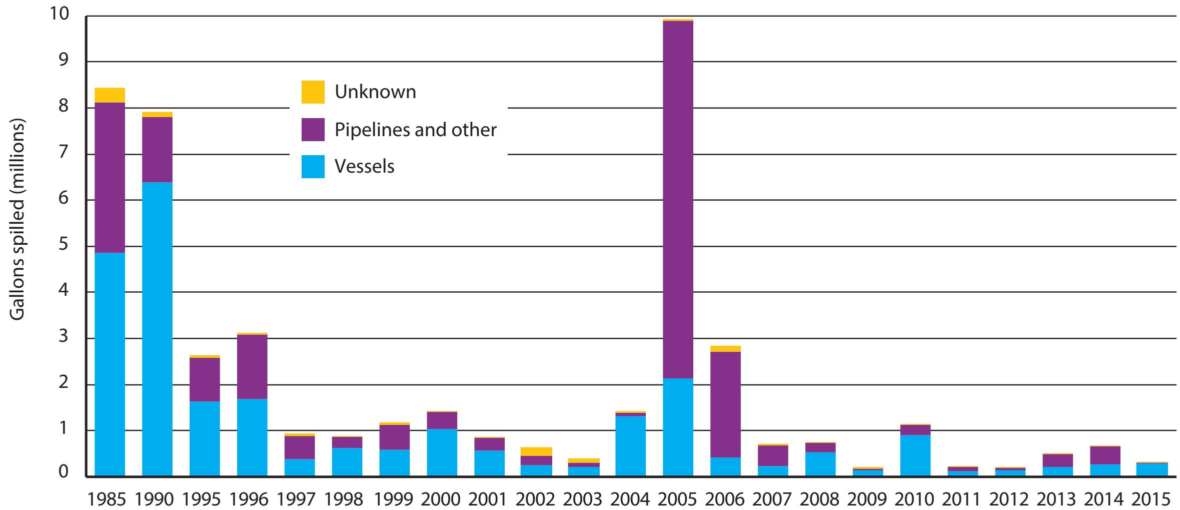
NOTES: Based on number of days in the year in which an AQI measurement was reported from any monitoring site in the county or Metropolitan Statistical Area to the Air Quality Statistics database.
Days Good: number of days in the year having an AQI value 0-50
Days Moderate: number of days in the year having an AQI value 51-100
Days Unhealthy for Sensitive Groups: number of days in the year having an AQI value 101-150
Days Unhealthy: number of days in the year having an AQI value 151-200
Days Very Unhealthy: number of days in the year having an AQI value greater than 201. This includes the AQI categories very unhealthy and hazardous.

SOURCE: U.S. Environmental Protection Agency, Air Quality Index Information. Available at http://www.epa.gov/airtrends/aqi_info.html as of June 2016.

crude oil and petroleum products into surface waters and navigable waterways. The annual volume spilled varies greatly from year to year and is strongly affected by infrequent, large events (figure 7-17). For example, in 2005 Hurricane Katrina caused numerous spills into navigable waterways from a variety of sources in Louisiana and Mississippi as the volume of petroleum spilled jumped to 9.9 million gallons, more than three times the amount of petroleum spilled in any other year from 1995 through 2015. While the number fluctuates from year-to-year, the 1,375 spill incidents from vessels in 2015 were slightly less than the 1,508 incidents in 2010 of and considerably less than the 5,560 in 2000. The 681 spill incidents from pipelines and other non-vessel sources into navigable waters in 2015 show a similar declining trend from the 1,008 incidents in 2010 and 1,645 in 2000, indicating improvements in safety measures for all petroleum transport modes.

Additionally, the USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA) reports that the number of serious pipeline incidents from 2010 to 2015 was trending down from 34 to 28, until increasing to 37 in 2016. Many of these incidents were either by excavation equipment or vehicles not involved in excavation intersecting with gas pipelines (or gas transmission pipelines). As mentioned in chapter 6, pipeline-related fatalities averaged about 16 deaths per year

FIGURE 7-17 Petroleum Spills Impacting Navigable Waterways: 1985, 1990, and 1995–2015



NOTES: The spike in Gallons spilled for 2005 can be attributed to the passage of Hurricane Katrina in Louisiana and Mississippi on Aug. 29, 2005, which caused numerous spills approximating 8 million gallons of oil in U.S. waters. The largest spill in U. S. waters began on April 20, 2010 with an explosion and fire on the mobile offshore drilling unit (MODU) DEEPWATER HORIZON. Subsequently, the MODU sank, leaving an open exploratory well to discharge crude oil into the Gulf of Mexico for several weeks. The most commonly accepted spill amout from the well is approximately 206.6 million gallons, plus approximately 400,000 gallons of oil products from the MODU. The totals in this table may be different from those that appear in the source, due to rounding by the source.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics*, Table 4-54, Available at http://www.bts.gov as of May 2017.

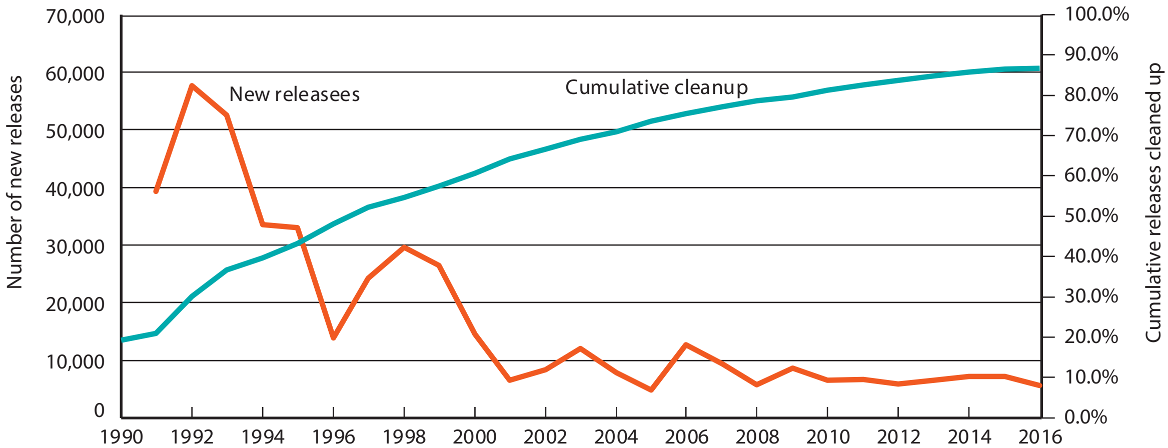
in the period of 1997 to 2016. In 2016 there were 17 fatalities across all types of pipeline incidents [PHMSA 2016].

In 1985, in response to a congressional requirement, EPA began an effort to regulate underground storage tanks that can contaminate ground water, to clean up leaks, and prevent future leaks [USEPA 2017c]. Since then, the number of new leaks from storage tanks has been reduced by nearly an order of magnitude, and over 86 percent of all leaks have been cleaned up (figure 7-18).

Pollution of waterways from spills, however, is not the only environmental challenge posed by marine transportation. Port and vessel operations can negatively impact air quality and have other detrimental impacts on the environment through emissions during idling, moving cargo from one mode of transport to the other, etc. But recent trends in alternate marine power (AMP), such as ships shifting to shore-side power while docked for basic ship functions such as lights and air-conditioning, and low-sulfur fuel are helping lesson the impacts [MARINE INSIGHT 2016].

As rainwater or snowmelt runs off transportation infrastructure, like roads, parking lots, and bridges, it picks up de-icing salts, rubber and metal particles from tire wear, antifreeze and lubricants, and other wastes that may have been deposited on infrastructure

FIGURE 7-18 Leaking Underground Storage Tank Releases and Cleanup: 1990-2016



NOTES: All data are cumulative from the start of the U.S. Environmental Protection Agency's Underground Storage Tank program, which began in 1984. Data represent fiscal year, October 1 through September 30.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics*, Table 4-55, Available at http://www.bts.gov as of March 2017.

surfaces. The runoff carries these contaminants into streams, lakes, estuaries, and oceans. An in-depth study of road-salt impacts on water quality examined U.S. Geological Survey historical data collected between 1969 and 2008 from 13 northern and 4 southern metropolitan areas. During the November to April period, when road salt application is most common, the concentration of chloride (an ingredient of salt) chronically surpassed EPA's water-quality criteria at 55 percent of the monitoring locations in northern metropolitan areas; chloride levels acutely surpassed the criteria at 25 percent of these northern stations. From May to October, only 16 percent of the northern stations chronically exceeded the criteria, and just 1 percent showed acute exceedances. At southern sites, where road salt is less frequently applied, there were few samples in any season that exceeded the chronic water-quality criteria, and none exceeded the acute criteria [CORSI, ET AL. 2010].

Highways and other transportation infrastructure also affect wildlife via road kills, habitat loss, and habitat fragmentation. Numerous projects have been undertaken across the United States to mitigate these impacts, from salamander and badger tunnels to mountain goat underpasses on highways to fish passages through culverts. There are no systematic estimates of the numbers of wildlife killed by transportation vehicles in the U.S. In general, the number of bird kills exceeds the number of mammals killed. Insurance industry records indicate that there are between one and two million reported collisions between animals and vehicles each year. These numbers only include reported incidents; collisions with small animals resulting in no vehicle or human damage are not generally reported [GASKILL 2013].

Transportation noise is pervasive and difficult to avoid in the United States [USDOT FHWA HEP 2006]. It is generated by engines, exhaust, drive trains, tires, and aerodynamic drag. At freeway speeds tire-pavement noise dominates for highway vehicles, while exhaust and aerodynamic noise dominate for aircraft. In the U.S. there are over 2,700 linear miles of noise barriers to protect the public. The known investment by 27 states in noise barrier construction is on the order of $1.2 billion. However, in a survey of states in 2010, many states had difficulty in determining the amounts invested in these efforts [USDOT FHWA 2010].

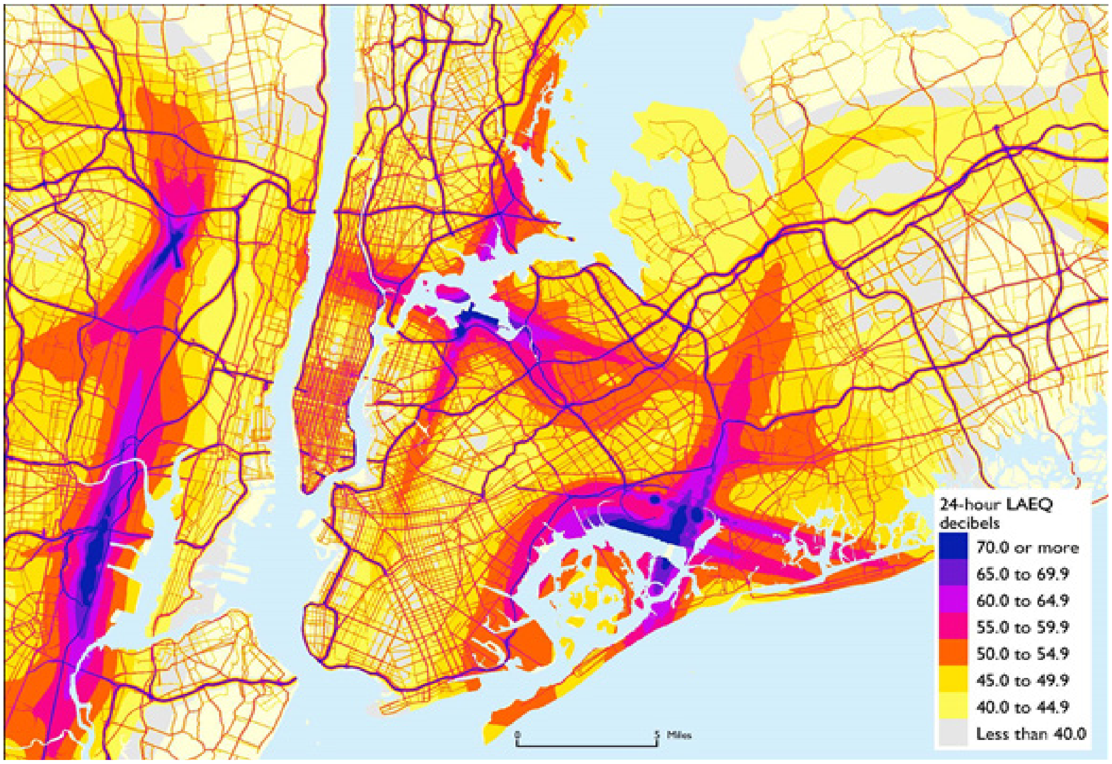
Although highways are the most widespread source of transportation noise, exposure to transportation noise is systematically measured only for aircraft. In 2014, 321,000 individuals lived in high noise (>65 dB) areas around U.S. airports. The number was down from nearly 7 million over 30 years ago and 847,000 in 2000. The number was reduced through a combination of changes in engine and airframe design and operational strategies [USDOT BTS NTS 2017]. Take-off and landing operations are the primary source of annoying aircraft noise, which per dB is generally more annoying to the public than highway or rail noise.

Until recently, a national transportation noise exposure inventory did not exist, but BTS in conjunction with the John A. Volpe National Transportation Systems Center has been working to develop a national, multimodal transportation noise inventory. The outcome of this effort is the recently released National Transportation Noise Map which shows the potential for noise exposure from interstate highways and airports. Over time, additional layers will be added to track and evaluate trends in potential noise exposure at multiple levels (local, State, Federal) and across modes [USDOT BTS NTNM 2017].

The new noise data provides an estimate of the percentage of the U.S. population that has the potential to be exposed to aviation and interstate road noise at both the national and county-level. The data shows that over 97 percent of the U.S. population has potential to be exposed to aviation and interstate highway noise at levels below 50 decibels (equivalent to the sound of a humming refrigerator). Less than one-tenth of a percent of the population has potential to be exposed to noise levels of 80 decibels or more (equivalent to the sound of a garbage disposal). Figure 7-19 shows 2014 aviation and highways noise for the New York City Metropolitan area. Darker areas indicate 24-hour LAEQ (an equivalent continuous level of noise over a given period measured in decibels) decibels of 70.0 or higher. They are near major international airports such as John F. Kennedy, Newark Liberty, and LaGuardia. Table 7-2 provides a comparison of the level of noise in LAEQ in decibels and how it compares with common everyday sounds, aviation noise levels, and highway noise levels as a reference [UDOT BTS NTNM 2017].

Unwanted noise can have a variety of impacts including annoyance, sleep disruption, interference with communication, adverse impacts on health and academic performance, and consequent reductions in property values. There is almost no part of the U.S. in which transportation noise is not noticeable [WAITZ

FIGURE 7-19 Transportation Noise Map: 2014



KEY: LAEQ = Equivalent Continuous Sound Level

SOURCE: U.S. Department of Transportation, National Transportation Noise Map press release, imbedded table, Available at https://www.transportation.gov/highlights/national-transportation-noise-map as of July 2017.

2007; UDOT BTS NTNM 2017]. When transportation noise levels are below 50 decibels (dB), the level of annoyance in the population is negligible, but when noise levels exceed 69 dB, impacts can be severe.

In addition to the primary performance measures of how efficiently, reliably, and safely people and goods move on the system, transportation's energy usage and its environmental impacts are also important measures of how well the transportation system performs. In recognition of this, there have been efforts to mitigate transportation's dependence on petroleum and environmental impacts. As detailed in this chapter, transportation has become more efficient over the past few decades in its use of energy and has reduced many of its environmental impacts even though activity levels have increased. It continues, however, to be the second leading emitter of greenhouse gases in the United States and has had other major impacts on the environment, such as oil pollution, habitat loss, and noise. Going forward, appropriate and accurate data will be needed to monitor progress and determine whether societal efforts to improve the system's performance are having the desired effect.

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