American Lung Association Energy Policy Development: Summary

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Table of Contents

Overview and Caveats

In July 2010, the American Lung Association began a year-long review to better define the Association's perspective on energy sources used to generate electricity, fuel transportation and produce heat for residences and commercial, institutional and industrial applications, and the impact each has on human and, especially, lung health. A key part of that review brought together volunteers, staff, and experts in a series of workshops focused on energy and transportation issues in the United States. The goal of the workshops was to review available information and explore policy recommendations for the Advocacy Committee and the Board of Directors to consider. **This document provides a summary of key issues discussed in the review to date. Policy statements developed in each workshop were refined further incorporating comments from all the workshops and are submitted to the Advocacy Committee for their consideration.**

For each workshop, the consultants and staff developed background papers to provide an introductory overview. Each paper defined a sector (electricity, heat, and transportation); provided relevant statistics, including air emissions and recent trends; and reviewed the life cycle impacts of energy use in each sector.

From the beginning, the process acknowledged that there would be no perfect solutions to the energy challenges facing the U.S. Trade-offs are inherent with all energy sources. Rather, the workshops provided opportunity for an extended dialogue about existing energy sources, emerging energy sources, and energy efficiency measures that are consistent, or inconsistent, with the American Lung Association's mission. Ultimately, the goal was to develop policy frameworks that considered the major issues associated with energy in the U.S. and served as a foundation for supporting the American Lung Association's energy policy positions. While the focus was on lung health, the discussion maintained a broader perspective and considered the costs and benefits of non-lung health related issues, such as the water and land use impacts of selecting or favoring one energy source over another.

Evidence showed that energy efficiency or conservation could not be the simple solution to all needs, although the American Lung Association recognizes that such issues can impact energy use and therefore impact lung health. The discussions included, but did not focus on, issues such as national security, transmission, land use and other infrastructure concerns. The discussions did not focus on any individual facility, such as a specific power plant. Finally, the discussions did not attempt to resolve all the issues around costs of construction, installation, or operation of facilities, but did include some consideration of financial or funding mechanisms that can enhance or detract from specific energy or transportation policy recommendations.

Introduction to Energy Use in the United States

Most of the energy consumed in the U.S. comes from fossil fuels. Renewable energy resources, including hydropower, provide about eight percent of total U.S. energy consumption and nuclear fuel supplies about nine percent in the form of electric power. Figure 1 shows the percentage of U.S. energy consumption by source for 2009. The unit of measurement normally used to compare sources of energy is the British thermal unit (Btu). One Btu is equal to the amount of heat required to raise one pound of water one degree Fahrenheit. In 2009, total energy consumption in the U.S. was 94.6 quadrillion Btus (EIA 2010a).

Figure 2 (on page 4) shows the interrelationships between the different sources of energy used in the U.S. and their end-use sectors. In this graphic, the energy sources are shown as circles on the left showing comparative size. Lines from each circle link the energy supply in the U.S. by source to the sectors where the energy is used, the demand sectors, shown in boxes on the right. The lines connecting them show numbers that represent the percentage of each source that goes to that use and the percent of the sources from which each demand sector gets its energy. Quantities of energy produced and consumed in the supply sources and demand sectors are shown in quadrillion Btu.

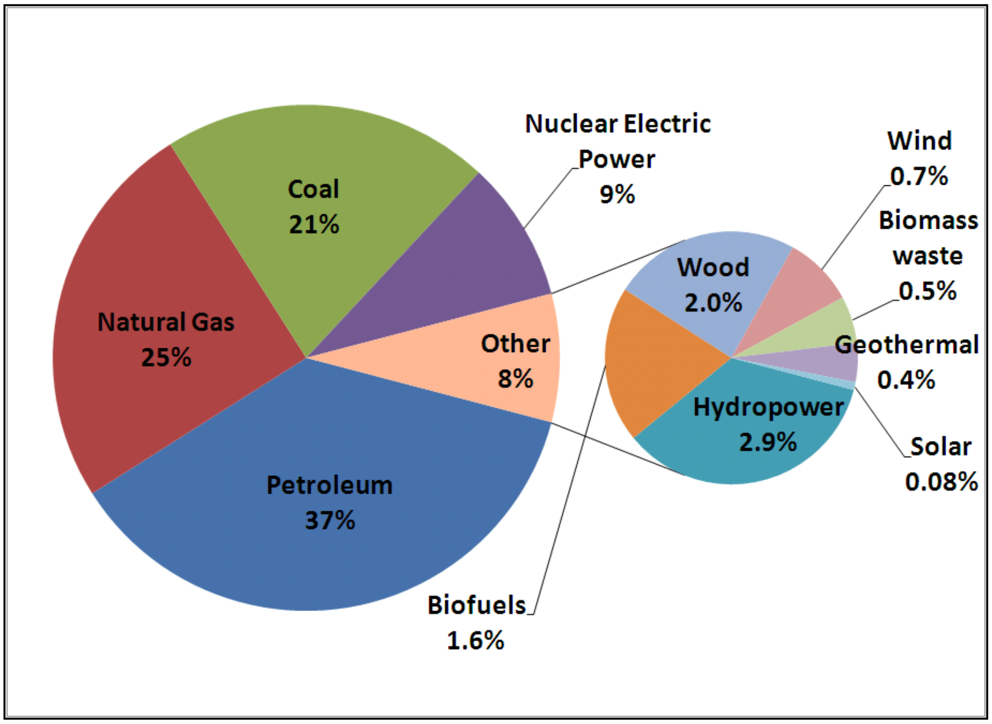


Figure 1. U.S. Energy Consumption by Source, 2009 (EIA 2010a)

As shown in Figure 2, the majority of petroleum (about 72 percent) is used in the transportation sector and the vast majority of coal (over 90 percent) is used in the electric sector. Natural gas consumption is split relatively evenly between the industrial, residential and commercial, and electric sectors, with a limited amount directed to the transportation sector.

According to EIA, from 1949 to 2009, primary energy consumption in the U.S. nearly tripled. In all but 16 of those years, primary energy consumption increased over the previous year. In 2009, however, in part due to the recession, primary energy consumption fell by almost five percent from 2008 levels. Decreases were registered in all four major end-use sectors: industrial, commercial, residential, and transportation (EIA 2010b).

Of the 94.6 quadrillion Btu of energy consumed in the U.S. in 2009, about 30 quadrillion Btus were imported and about 70 quadrillion Btus were produced domestically, with about 7 quadrillion Btus exported. Almost 60 percent of exports were petroleum products, 20 percent were derived from coal, and about 15 percent were derived from natural gas. The remaining exports were biofuels, electricity, and coal coke. Before 1992, coal was the largest component of U.S. energy exports (EIA 2010a).

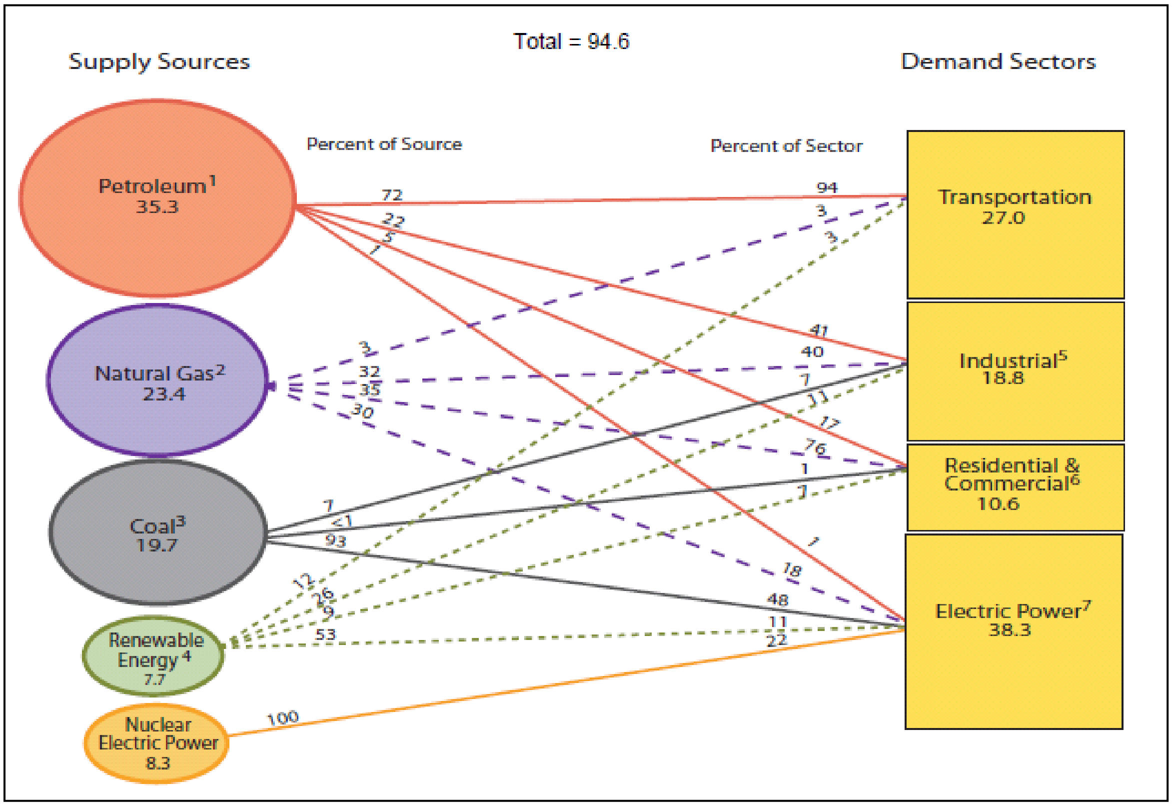


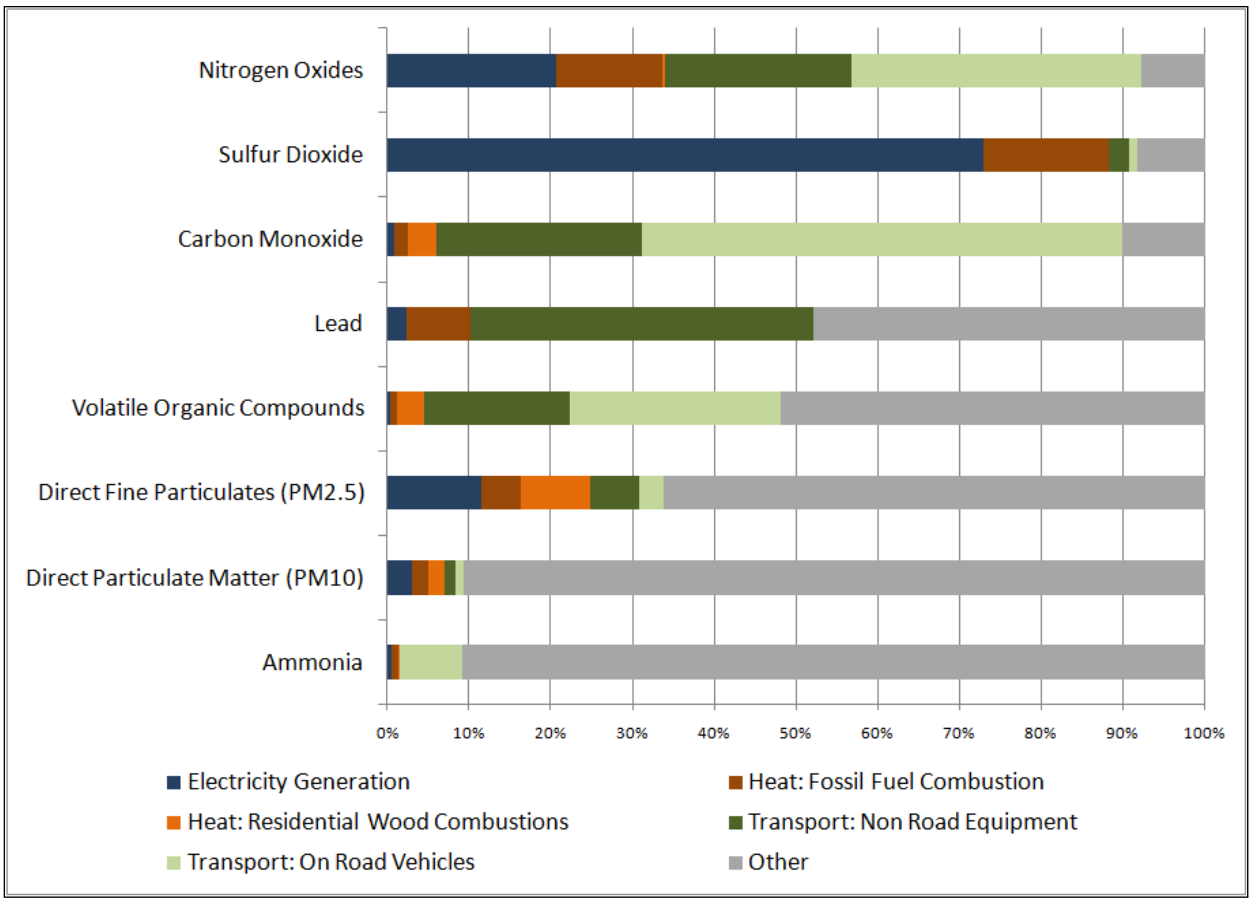
Figure 2. Primary Energy Flow by Source and Sector, 2009 (Quadrillion Btu) (EIA 2010a)1

[1] Sum of components may not equal total due to independent rounding.

1) Does not include biofuels that have been blended with petroleum—biofuels are included in "Renewable Energy."
2) Excludes supplemental gaseous fuels.
3) Includes less than 0.1 quadrillion Btu of coal coke net exports.
4) Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
5) Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
6) Includes commercial CHP and commercial electricity-only plants.
7) Electricity-only and CHP plants whose primary business is to sell electricity, or electricity and heat, to the public.

Air Emissions

Numerous scientific studies have linked air pollution to a variety of health problems including: (1) aggravation of respiratory and cardiovascular disease; (2) decreased lung function; (3) increased frequency and severity of respiratory symptoms such as difficulty breathing and coughing; (4) increased susceptibility to respiratory infections; (5) effects on the nervous system, including the brain, such as IQ loss and impacts on learning, memory, and behavior; (6) cancer; and (7) premature death. Sensitive individuals appear to be at greater risk for air pollution-related health effects, for example, those with heart and lung diseases (e.g., heart failure/ischemic heart disease, asthma, emphysema, and chronic bronchitis), diabetics, older adults, and children (EPA 2010a). As a result of environmental air regulations, air quality in many places has improved, but over 175 million people—roughly 58 percent—still suffer from pollution levels that are too often dangerous to breathe (ALA 2010).



* Other includes agricultural emissions, forest fire emissions, and industrial process emissions, such as metal smelters, petroleum refineries, cement kilns, manufacturing facilities, and solvent utilization but does not include fugitive emissions such as road dust.

Figure 3. Distribution of U.S. Total Emissions Estimates for 2005 by Source Category for Specific Pollutants (EPA 2009)

Figure 3 shows the distribution of direct emissions from sources in the U.S. in 2005. The sources are grouped according to the topic areas for the three workshops: electricity, heat, and transportation. Heat includes fossil fuel combustion in the industrial, commercial, and residential sectors as well as residential wood combustion. Transportation includes both on-road vehicles such as cars, trucks, and buses but also includes non-road equipment such as recreational and construction equipment, marine vessels, aircraft, and locomotives. The "other" category in Figure 3 includes agricultural emissions, forest fire emissions, and industrial process emissions, such as metal smelters, petroleum refineries, cement kilns, manufacturing facilities, and solvent utilization. Emissions from petroleum refineries were considered as part of the lifecycle impacts in the transportation discussion but the remaining sources in the other category were outside the scope of the energy policy discussion.

In addition to these air pollutants, the combustion of fossil fuels results in the release of greenhouse gases, such as carbon dioxide. Greenhouse gas emissions are not shown in Figure 3. In 2007, fossil fuel combustion contributed almost 94 percent of total carbon dioxide emissions in the U.S. Major sources of fossil fuel combustion include electricity generation, transportation (including personal and heavy-duty vehicles), industrial processes, residential, and commercial. Electricity generation contributed approximately 42 percent of carbon dioxide (CO_2) emissions from fossil fuel combustion while transportation contributed approximately 33 percent (EPA 2010a).

Another greenhouse gas of concern is methane. Primary sources of methane emissions include livestock, landfills, and natural gas systems (including wells, processing facilities, and distribution pipelines). In 2007, these sources contributed about 64 percent of total U.S. methane emissions. Other contributing sources include coal mining (10 percent) and manure management (8 percent) (EPA 2010a).

Air Toxics

Toxics are hazardous pollutants that are known or suspected to cause cancer or other serious health effects, including birth defects, or other environmental effects. They differ from ozone, particulate matter and other common air pollutants in the way they are regulated. Examples of air toxics include benzene, asbestos, and mercury.

The Emergency Planning and Community Right to Know Act in 1986 made it possible for people to learn more about toxic emissions in their community. Thanks to that law and the 1990 Pollution Prevention Act, the U.S. Environmental Protection Agency tracks the release of toxics produced by industry and federal facilities through the Toxics Release Inventory (TRI). The TRI is a database containing detailed information on nearly 650 chemicals and chemical categories that certain industrial and federal facilities produce and release through air, water and land disposal or other releases, or recycling, energy recovery, or waste treatment. For 2008, 21,695 facilities, including federal facilities, reported to the TRI Program. They reported 3.86 billion pounds of on-site and off-site disposal or other releases of the TRI chemicals, a six percent decrease from 2007. EPA estimated that 30 percent of all TRI releases were emitted to the air in 2008, totaling 1.14 billion pounds.

Environmental Justice

Underlying the broader health impacts of transportation and the American Lung Association's policy positions are concerns about environmental justice. In its *Interim Guidance on Considering Environmental Justice During the Development of an Action*, EPA has defined environmental justice as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA 2010d). EPA goes on to say:

- Fair treatment means that no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental, and commercial operations or programs and policies.
- Meaningful involvement means that: 1) potentially affected community members have an appropriate opportunity to participate in decisions about a proposed activity that will affect their environment and/or health; 2) the public's contribution can influence the regulatory agency's decision; 3) the concerns of all participants involved will be considered in the decision-making process; and 4) the decision-makers seek out and facilitate the involvement of those potentially affected.

Broad, national-level policy decisions impact public health and air quality, but energy use can impact different communities differently. For example:

- Sulfur dioxide and other hazardous air pollutants emissions from coal-burning plants, including mercury, arsenic, lead and carcinogens, emissions from coal-burning plants can be much higher in communities living near the plants;
- The combination of emissions from mining equipment and vehicles transporting coal can have significant impacts on the health of local populations;
- Heating sources such as outdoor wood boilers have limited national or regional impact, but have a significant impact on users and immediate neighbors;
- Emissions from industrial heating applications can have significant impacts on the health of local populations;
- Poor and disadvantaged communities bear a disproportionate burden of diesel PM exposure because of the location of many major transportation facilities (major highways, rail yards, freight depots, ports) in and near their neighborhoods; and
- While public transportation users are, on average poorer than the average citizen, disadvantaged communities can have limited alternative transportation options for access to services and employment.

Electricity Generation Overview

The United States consumes approximately four billion megawatt hours (MWh) of electricity each year. Most of this electricity is consumed by homes and commercial buildings (75 percent) with much of the balance used by the industrial sector (e.g., petroleum refineries, steel mills, and paper mills). Less than one percent of electricity is used to power cars and other vehicles. A typical household in the U.S. uses about 11 MWh per year to operate lighting and appliances.

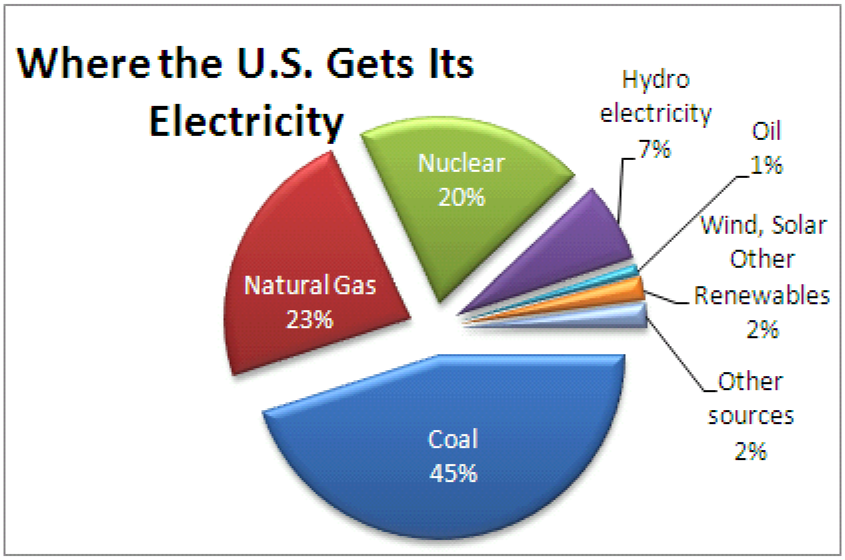


Figure 4. Major Sources of Electricity in the United States (EIA 2010a)

Over 5,500 commercial-scale power plants generate electricity in the U.S.[2] Seventy percent of the nation's electricity was produced by burning fossil fuels (coal, natural gas and oil) resulting in the release of sulfur dioxide (SO_2), nitrogen oxides (NO_x), air toxics, and greenhouse gases (GHGs) into the air. Coal accounted for 45 percent of total power production in 2009, and the remaining fossil fuels – natural gas and oil – accounted for 23 percent and 1 percent, respectively. Nuclear power, the largest non-fossil fuel energy source, generated 20 percent of U.S. electric power. Hydroelectricity accounted for about seven percent of total power production and non-hydroelectric renewables (such as wind turbines and solar photovoltaic cells) accounted for almost two percent. A variety of other fuel sources, including biomass, comprised the remaining two percent of generation (EIA 2010a).[3]

As shown in Figure 5 (on page 9), coal-fired power plants are located across the nation, with the heaviest concentrations of coal plants located along the Ohio and Mississippi Rivers. Natural gas plants are generally smaller than coal plants and are also spread across the country. The heaviest concentrations of natural gas-fired power plants are in Texas and Louisiana, near the Gulf of Mexico, and in California. Most large nuclear plants are located in eastern and upper-Midwestern states, and most hydroelectric facilities are in western states.

Beyond fuel type, there are important distinctions among the different technologies used for the production of electricity. While the product of any electric generating source is the same (electricity),

[2] Based on assignment of ORIS/EIA plant codes by the U.S. Energy Information Administration (EIA). "Power plants" are broadly defined by EIA to include non-traditional sources such as wind farms and solar energy arrays. For example, a wind farm is counted as one power plant.
[3] Other fuel types include municipal solid waste, landfill gas, tire-derived fuels, sludge waste, and various other materials.

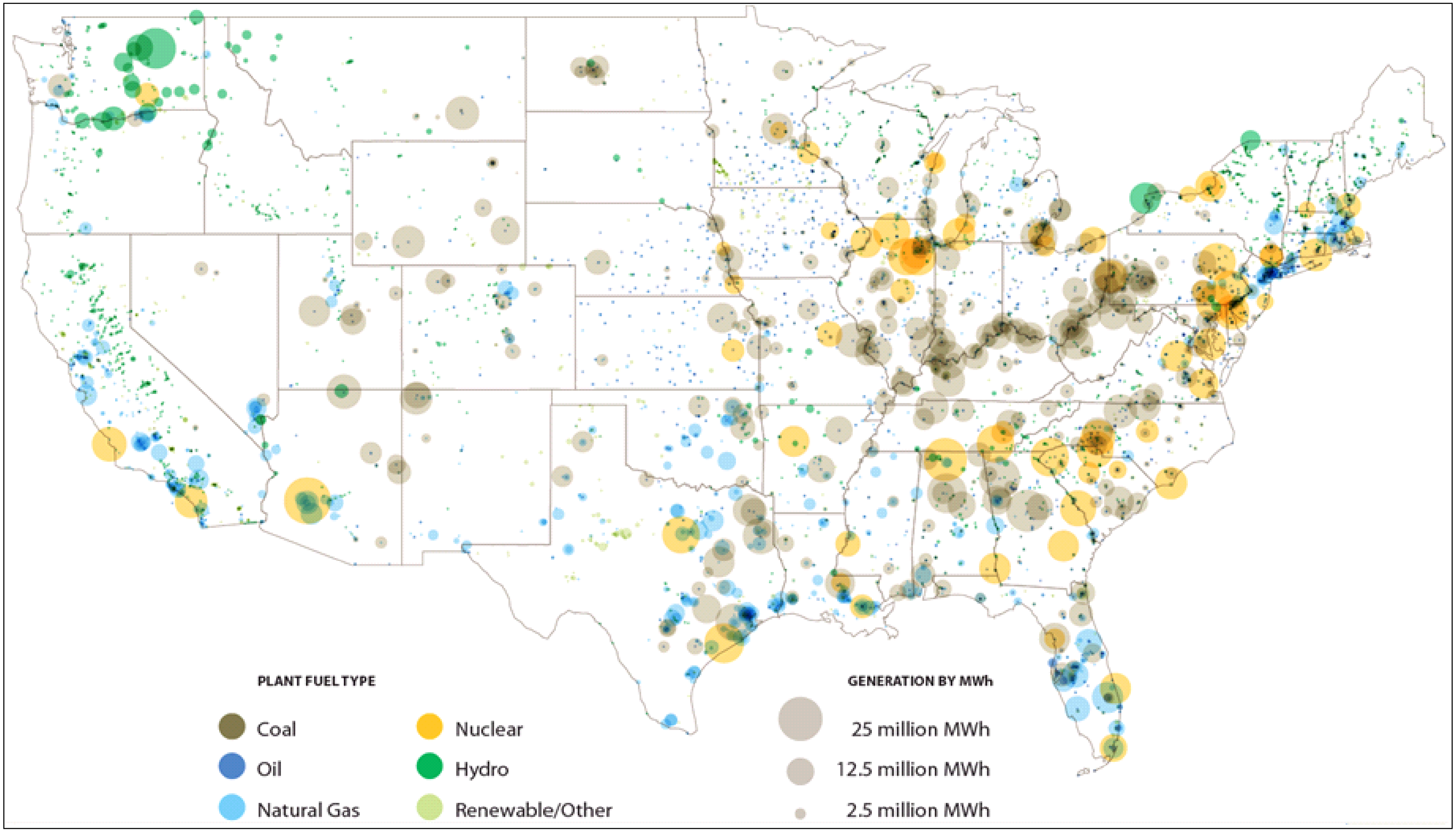


Figure 5. Location and Relative Size of U.S. Power Plants by Fuel Type

one technology cannot always directly substitute for another. Power demand fluctuates throughout the day and throughout the year. On any given day, a certain base demand for power remains constant throughout the day. The power plants that are least expensive to run operate almost continuously to satisfy this minimum level of demand, or base load. Typically, these are large coal-fired or nuclear power plants which are not cycled on and off but are running close to their full capacity. Figure 6 illustrates the different technologies that might be used to satisfy electricity demand over a 24-hour period. In the morning, when customers are going through their morning routine, running their appliances and turning on lights, demand begins to increase and more power plants are called to respond. This increased demand is typically met by smaller natural gas-fired power plants that can be turned on quickly to provide extra power when it is needed. These peaking facilities are generally cheaper to build, but more expensive to operate. Over the course of a year, the highest peak demand in the U.S. occurs in the summer months on hot and humid days. Demand peaks when customers add the increased load of air conditioning on top of the baseload demand for power.

Power plants vary in terms of their ability to quickly respond to increased power loads. As described above, large coal and nuclear power plants are typically run as baseload units (i.e., operating around the clock) because it can be costly and damaging to cycle the facilities. Natural gas turbines can be quickly started (within 10-15 minutes) so they are often used to add power. Also, the industry distinguishes between “dispatchable” (i.e., sources that can be turned on and off as needed) and “nondispatchable” sources of electricity. For example, wind and solar electricity sources are nondispatchable, i.e., intermittent resources, available only when the wind is blowing or the sun is shining.

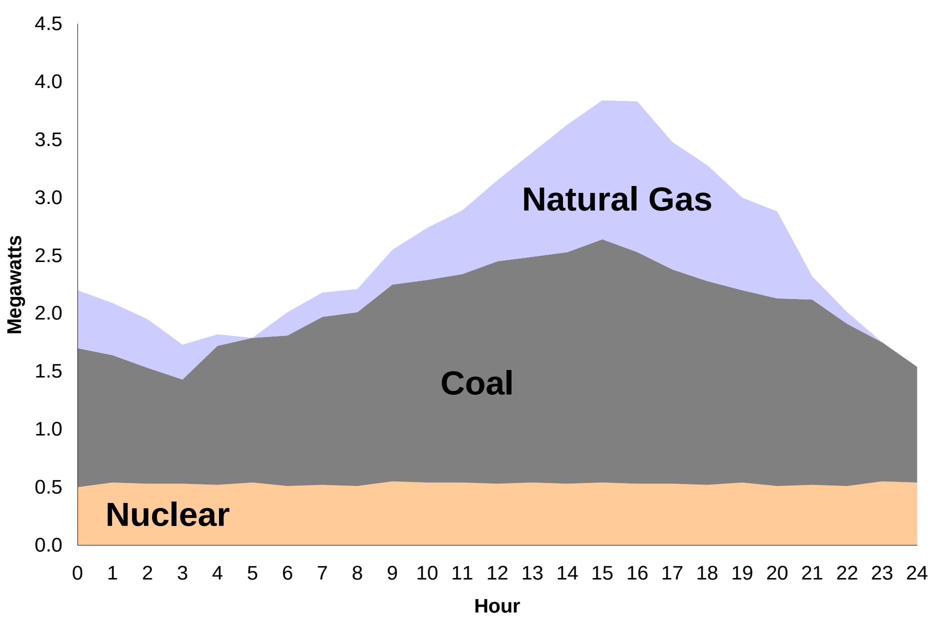


Figure 6. Electricity Generation Profile Illustrating the Addition or Removal of Sources Based on Changes in Demand through a 24-Hour Day

Electricity Generation Air Emissions

The most significant health impacts associated with electricity generation are the air emissions from the combustion of fossil fuels, in particular, though not exclusively from coal-burning power plants. Natural gas, oil, and biomass power plants also contribute to the sector's emissions. Collectively in 2005, fossil fuel-fired power plants were responsible for about 70 percent of SO_2 emissions, 20 percent of NOx emissions, 20 percent of fine particulate matter ($PM_{2.5}$) emissions, 50 percent of mercury air emissions, and 40 percent of CO2 emissions in the U.S. The electric power industry accounts for more CO_2 emissions than any other sector, including the transportation and industrial sectors.

In the electric generating sector, coal-fired power plants account for 99 percent of SO_2 emissions, 94 percent of NOx emissions, and 85 percent of CO_2 emissions (EIA 2008). Since 2004, SO_2 and NOx emissions have decreased by almost 50 percent, with the installation of about 130 power plant scrubbers and other controls, mandated through a combination of enforcement of the Clean Air Interstate Rule (CAIR) and New Source Review provisions of the Clean Air Act, and state laws (CATF 2010). Natural gas-fired power plants produce NOx emissions, relatively small quantities of SO_2 emissions, and negligible mercury emissions. Oil-fired power plants produce NOx emissions, SO_2 emissions, and PM emissions. Biomass power plants produce NOx and PM emissions.

Trading Programs

A number of existing air pollution control programs allow sources to reduce the cost of compliance by "emissions trading." EPA limits overall emissions by distributing a limited number of "emissions allowances" to affected sources. These emissions allowances can be sold or traded. Sources have the option of installing controls and selling any excess allowances they might hold. Alternately, a source can choose to purchase additional allowances in lieu of installing controls. Emissions trading is a popular approach to achieve overall pollution reductions, allowing companies to choose which plants to upgrade with pollution control equipment. The approach is seen as one that allows greater flexibility to sources to target reductions in the most cost-effective manner. Based on the way that they are allocated to existing sources, these allowances have a capital value in the marketplace for companies that hold them (NRC 2004).

However, the same flexibility that improves cost-effectiveness can allow polluting facilities to continue to burden local air quality and disproportionately impact nearby residents. Because such programs allow sites to avoid installing pollution control measures, the transfer of allowances can result in uneven reduction of pollutants from plant to plant. Sources that elect to purchase allowances may not reduce pollution. As a result, populations nearest to the source, who face the greatest exposures, are at continued higher risk, especially to local pollutants like SO_2 from coal-fired power plants. Those communities nearest to power plants frequently include disadvantaged populations such as ethnic or racial groups who have a higher incidence of people with chronic diseases, or low income people who also are at higher risk from air pollution.

Fossil-Based Electricity Highlights

In its recent Hidden Costs of Energy report, the National Research Council (NRC) of the National Academies concluded that emissions from electricity generation account for the majority of external effects associated with fossil fuel combustion, while activities such as mining and drilling play a minor role (NRC 2010).

Coal

No source of electricity produces the human health impact of coal-fired generation. From the resource intensity of mining, to the air pollution associated with combustion, to the disposal of combustion waste, coal use generates a dominant share of the sector's impact. Coal-fired power plants remain among the top contributors to fine particle pollution, particularly SO_2 and NOx, in the country. This pollution is expected to cause over 13,000 premature deaths in 2010, as well as almost 10,000 hospitalizations and more than 20,000 heart attacks per year (CATF 2010).

Over the last decade, significant investments have been made in the research and promotion of advanced coal technologies such as integrated gasification combined cycle (IGCC) power plants and carbon capture and storage (CCS). Coal-based IGCC systems convert coal into "syngas" – a synthetic gas created through a manufacturing process that removes hydrogen sulfide, ammonia and particulate matter. The syngas is burned as fuel in a combustion turbine (much like natural gas is burned in a turbine) and waste heat is recycled and used to drive a steam turbine. This combination, known as combined cycle, can significantly increase efficiency and reduce emissions. Emissions of air pollutants from an IGCC power plant have been reported to be 70 to 80 percent lower than a conventional coal plant (Lee 2001).

CCS is the process by which CO_2 is isolated from the emissions stream, compressed, and transported to an injection site where it is stored underground permanently. While each part of the CCS chain has been demonstrated, the technologies have not been integrated and demonstrated on a commercial-scale (greater than 300 MW) coal-fired power plant. Beyond the greenhouse gas benefits, CCS could also potentially drive SO_2 reductions. The current technologies for removing CO_2 from a power plant exhaust gas are very sensitive to SO_2 levels. As a result, conventional plants would have to install state-of-the-art scrubbers to remove SO_2 from the flue gas prior to installing equipment to capture CO_2.

Neither IGCC nor CCS addresses the upstream impacts of coal use or the solid waste byproducts of the gasification or combustion. Additionally, the use of carbon capture technologies with IGCC or with conventional coal technologies can reduce the power generating capability of that plant by 20 to 30 percent. This penalty increases the amount of coal that must be used to generate a unit of electricity at the plant. However, at a macroeconomic scale, it is not clear if the energy penalty would increase coal use. As the technologies increase the cost of coal-based electricity, they may dampen the demand for coal-based electricity.

Natural Gas

Natural gas is a cleaner burning fossil fuel than coal; it has lower air emissions and about half of the CO_2 emissions per unit of energy. Natural gas is also a more flexible fuel source and can be dispatched quickly from a peaking plant or used for baseload power at a large combined cycle plant.

An emerging issue associated with natural gas production is the use of an advanced technique called hydraulic fracturing that recovers natural gas from unconventional sources such as shale gas formations. Hydraulic fracturing allows natural gas to move more freely from the rock pores to production wells that bring the gas to the surface. Public health advocates have raised concerns about the types of chemicals that are injected into the ground as part of the hydraulic fracturing process and the potential for those chemicals to seep into drinking water. EPA is in the midst of a $1.9 million research study to investigate the potential adverse impacts that hydraulic fracturing may have on water quality and public health. In addition to the EPA study, there is interest in introducing a bill in Congress that would undo fracking chemicals' current exemption from the Safe Drinking Water Act.

Non-Fossil-Based Electricity Highlights

Non-fossil-based generation includes renewable sources without direct emissions (wind, solar, tidal, and hydroelectric) renewable sources with direct emissions (geothermal, biomass, municipal solid waste, and landfill gas), and nuclear.

Nuclear

Nuclear power plants generate approximately 20 percent of U.S. electricity. The U.S. Energy Information Administration predicts the retirement of more than one-third of existing U.S. nuclear capacity between 2029 and 2035, with a majority of nuclear plants owners applying to extend licenses to the current maximum of 60 operating years. While nuclear power plants generate power without the air quality impacts associated with fossil-based generation, the U.S. does not have a long term solution for dealing with nuclear waste.

The primary environment and health risks associated with nuclear energy are related to radiation exposure, particularly during the mining of uranium. Radiation is an occupational hazard to miners in advanced stages of exploration, such as in tunnels and shafts, as well as in underground and open pit mines. Workers in uranium mills are also exposed to dangerous levels of radiation, as radon. Miners have been the subject of many studies on radiation exposure (NRC 1999) and the evidence from those studies has helped identify radon as the leading cause of lung cancer in nonsmokers, predominantly from indoor exposures.

In addition, uranium mining can create higher risks of exposure to radiation for people who live near or are involved in recreation activities across or around mines or abandoned mines. EPA has explored the health risks associated with such exposures in major reviews, most recently in 2008 (EPA 2008, EPA 1983). EPA identified people who live near the mines and abandoned mines as being at greatest risk, a group that included some from the Navajo Nation.

A growing trend in uranium mining is in situ leaching. In this method of extraction, uranium ores are leached underground by the introduction of a solvent solution. The process does not require the physical extraction of ore from the ground, which makes it a much more economical option in many cases. The leaching agents for uranium mining commonly consist of water containing added oxygen and carbon dioxide or sodium bicarbonate, which mobilize uranium. In situ leaching reduces worker exposure to many of the risks associated with physical extraction, but surface chemical and radiological hazards associated with various types of accidents at the site remain. The risks to the general public result from the contamination of drinking water sources (EPA 2008).

Non-Combustion Renewable Electricity

Non-combustion renewable electricity makes up a small but growing proportion of U.S. generation. The major sources are hydropower, wind, solar and geothermal. Additional sources such as advanced geothermal, marine and tidal are under development.

- Other than nuclear power, hydroelectric power is the largest non-fossil source of electricity in the U.S., accounting for over 6 percent of electricity generation. There are nearly 78 gigawatts of hydroelectric capacity currently operational in the U.S. Although hydropower facilities do not emit any air pollutants as a direct result of electricity generation, reservoirs at dams may emit methane as biological material submerged by flooding decays in the absence of oxygen.
- Wind power accounted for approximately 1.3 percent of the nation's total electricity generation in 2008 (EIA 2010c). Wind turbines have no direct air emissions. Their primary health impacts are caused by noise. Environmental impacts include hazards to birds and bats and land use.
- Solar energy functions through two primary technologies, photovoltaics (PV) and concentrating solar power (CSP). Although solar does not emit direct emissions when converting sunlight to electricity, indirect emissions are generated as part of the manufacturing process.
    - California leads the nation with nearly 740 MW of PV capacity installed: New Jersey is second with a total capacity of almost 130 MW.
    - At the end of 2009, there were approximately 430 MW of CSP capacity operating in the U.S.
- Geothermal energy relies on naturally occurring heat stored beneath the surface of the Earth. Naturally occurring underground reservoirs of sufficient heat are fairly rare and are often associated with geysers or hot springs, although more frequently there is no surface manifestation. In most cases, geothermal electricity generation emits no NOx or particulate matter. However, depending on the composition of the underlying reservoir

and the generating technology employed, geothermal power plants may emit other air pollutants.

Biomass

As of 2008, there were approximately 11 GW of installed biomass capacity in the U.S. These facilities contributed approximately 1.3 percent of the nation's power generation from wood, wood-derived fuels, and other biomass sources (EIA 2010c). A variety of sources, known as feedstocks, can potentially be used for biomass power production, including wood or wood pellets, forest wastes, and agricultural residues, such as corn stover (stalks, leaves, and husks) or wheat stalks. Dedicated energy crops may also be grown to create a "closed-loop" system, but to date no biomass plants in the U.S. employ this strategy. Construction and demolition waste offer other potential feedstocks that are not directly dependent on natural cycles. Paper mill residue and lumber mill scraps may also be considered biomass.

The environmental and health impact of biomass power is directly related to the feedstock from which the energy is derived. The choice of biomass feedstocks often presents a tradeoff between cost, fuel-quality, and environmental and health impacts. For example, urban waste, such as construction or demolition debris, is usually inexpensive relative to other biomass feedstocks, and combusting this debris at a biomass plant diverts it away from landfills. However, such waste may be of low-quality, meaning that more feedstock is required to produce a given amount of electricity, or contain high-levels of impurities, resulting in greater air emissions.

Electricity from Waste

Municipal solid waste (MSW) can be used as a fuel for electricity generation in two ways: direct combustion (waste-to-energy) and landfill gas capture. Landfill emissions are generated by microorganisms that produce methane gas. Landfill gas consists primarily of carbon dioxide, methane, and non-methane organic compounds. The methane carries non-methane organic compounds through the landfill to the atmosphere.

Ash disposal and the air polluting emissions from plant combustion operations are the primary environmental impacts of MSW incinerators. MSW contains a diverse mix of waste materials, some benign and some very toxic. Toxic materials include trace metals such as lead, cadmium and mercury, and trace organics, such as dioxins and furans. The control of toxics and air pollution are key features of environmental regulations governing MSW fueled electric generation.

SO_2 and other oxides of sulfur (SOx) emissions resulting from the landfill gas capture and waste-to-energy alternatives are approximately 10 times lower than the SOx emissions resulting from coal- and oil-fired power plants with flue gas controls. The NOx emissions for waste-to-energy alternatives and for landfill gas capture are also lower than the emissions from coal-fired power plants (Kaplan 2009).

Heating Overview

The discussion of the energy used for heating divided the economy into three general sectors: residential, commercial, and industrial. In the residential and commercial sectors, energy is used for space and water heating. In the industrial sector, energy is used for a number of purposes. This discussion focuses on fossil fuel combustion onsite for process heat including producing, processing, and assembling goods, not on the actual industrial process. For example, in the case of steel making, this discussion dealt with the emissions from the furnace, but not the air pollution emissions released from cooling and quenching of steel.

The charts in Figure 7 show total U.S. energy consumption for the residential, commercial and industrial sectors. The electricity percentages in Figure 7 include energy lost in the generation and distribution of the electricity. The three sectors represent 99 percent of the U.S. demand for electricity, with the remaining demand coming from the transportation sector. While electricity makes up 69 percent and 78 percent of energy consumption in the residential and commercial sectors, respectively, the majority of it is used for non-heating purposes such as running lights and appliances.

Heating of residential and commercial buildings accounts for about 11 percent of total U.S. primary energy demand. Natural gas dominates this demand, making up about 76 percent of primary energy use by residential and commercial buildings. The remainder of demand is fulfilled with petroleum (17 percent), biomass (five percent), renewable energy (less than two percent) and coal (less than one percent). Some residential and commercial buildings use electricity for heating; however, this is considered a secondary use of energy (the electric generation sector is the primary user). There are some significant differences in the usage of non-fossil sources in residential and commercial sectors, with biomass making up about six percent of residential direct energy consumption and only 3 percent of commercial energy consumption. Solar and photovoltaic energy appears in the residential sector but not in the commercial sector because it is used for hot water heating in the residential sector. Solar panels that may be

Definition of Residential, Commercial, and Industrial Sectors

Residential sector: An energy-consuming sector that consists of living quarters for private households. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a variety of other appliances. The residential sector excludes institutional living quarters.

Commercial sector: An energy-consuming sector that consists of service-providing facilities and equipment of: businesses; federal, state, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. The commercial sector includes institutional living quarters. It also includes sewage treatment facilities. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a wide variety of other equipment.

Industrial sector: An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity: manufacturing; agriculture, forestry, fishing, and hunting; mining, including oil and gas extraction; and construction. Overall energy use in this sector is largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting. Fossil fuels are also used as raw material inputs to manufactured products.

Source: NRC 2010

installed at commercial sites are usually owned and operated by local utilities to generate electricity and are captured in estimates of electric sector direct energy consumption.

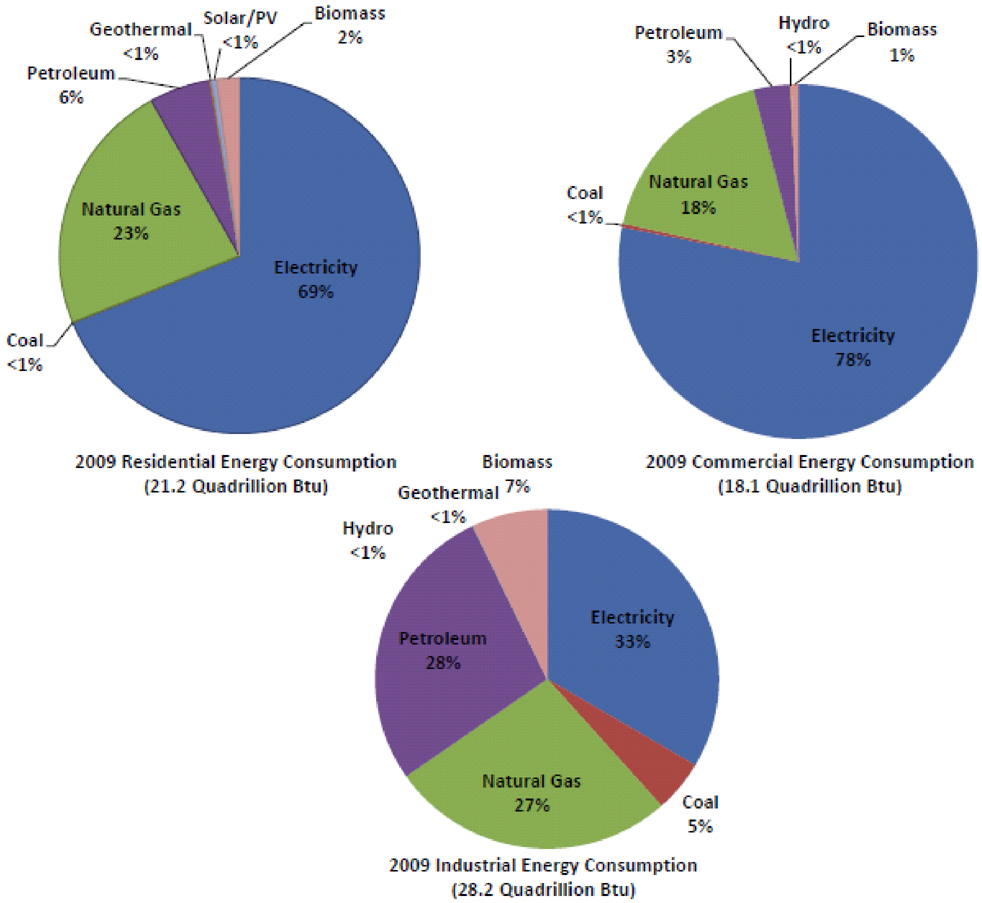


Figure 7. Energy Consumption in the Residential, Commercial, and Industrial Sectors Including Electricity Conversion and Transmission Losses (EIA 2010c)

Within the industrial sector, energy use is largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting. Fossil fuels are also used as raw material inputs to manufactured products such as asphalt, plastics, and chemical products. Figure 7 reflects the total fossil fuel use in the industrial sector including both energy and inputs to manufactured products.

This discussion focuses on the use of fossil fuels and biomass energy sources combusted onsite to generate process heat and cooling and to power machinery and auxiliary services in the industrial sector. This definition does not include the electricity produced offsite and consumed by the industrial sector and it does not include the fossil fuels used as raw material inputs. Sixty percent of the coal, oil, and natural gas used within the industrial sector is used for onsite power generation or heat, and 40 percent is used as raw material inputs (NRC 2010).

Recent Trends

Electricity and natural gas represent the major sources of heating in the residential and commercial sectors as a result of their ease of use for the end user. According to EIA's most recent *Residential Energy Consumption Survey*, natural gas represented 72 percent of household space heating and 68 percent of water heating, while electricity heats eight percent of homes and 21 percent of water heating (EIA 2009). Only 12 percent of U.S. households use a space heating fuel other than gas, electricity, or petroleum products (NRC 2010). In colder climates with greater heating needs, both petroleum products and biomass play a role.

For industrial process heating, electricity, coal, oil, and natural gas are most prevalent. Coal and renewables are rarely used in residential and commercial heating, although the use of small-scale renewables is growing, spurred by financial incentives at the state and federal levels.[4] Anecdotal evidence also suggests the residential use of biomass and coal increased in response to recent price volatility and the recession.

Residential Sector Highlights

The residential sector includes the majority of the locations where people live, such as owned and rented housing, but excludes institutions such as hospitals or dormitories. In 2005, the residential sector in the U.S. consisted of 111 million households, including 80 million single family homes, 24 million multifamily housing units, and nearly seven million mobile homes (NRC 2010).

Household energy consumption for heating and cooling varies by geographic region across the U.S. and is highly affected by differences in climate. Hot summers increase the amount of electricity used for air conditioning and other space cooling, while cold winters in the North increase the amount of energy used for space and water heating, including demand for electricity, natural gas, and heating oil. Other factors that determine the types of energy households consume include access to natural gas service, population density, age and design of homes, building codes, and electricity prices (EIA 2005).

Table 1 summarizes heating emissions by fuel and pollutant in the residential sector. There are a few important notes from these data:

- Natural gas combustion is the dominant source of NOx emissions in the residential sector because of its extensive use.
- Residential oil use, which is most prevalent in the northeast, contributes a dominant share of SO_2 emissions.
- Wood combustion contributes a dominant share of direct PM emissions in the residential sector.

[4] Within this paper, renewables include solar energy, geothermal energy, and hydroelectric power. Wind energy is not included because it is not deployed at residential, commercial, or industrial sites. Every attempt has been made to list biomass separately. However, it is important to note that the Energy Information Agency lists biomass as a renewable energy source.

Table 1. 2005 Residential Heating-Related Emissions (Tons, 2005) (EPA 2009a)

	NOx	VOCs	SO_2	PM_{10}	$PM_{2.5}$	CO
Residential	**379,954**	**565,192**	**173,128**	**402,999**	**393,099**	**3,098,381**
Coal	2,405	2,472	14,887	1,979	1,218	61,461
Oil	61,573	2,013	134,682	7,210	6,238	15,935
Wood	27,108	388,437	4,044	293,799	287,951	1,981,960
Natural Gas	211,206	12,331	1,194	1,390	1,147	92,447
Other	77,660	159,939	18,321	98,621	96,545	946,578

The burning of wood, like traditional heating fuels, produces PM, CO, NOx, and SO_2 in varying amounts. Burning wood in a modern and well-maintained woodchip boiler, for example, produces more PM than burning fossil fuel, but less SO_2 than oil or propane.

Wood-fired heating plays a substantial role in these sectors, particularly residential. There are over 12 million wood stoves nationwide, 75 percent of which are older and higher polluting than stoves currently for sale (EPA 2009b). In addition, alternative stoves using corn, wood, or wood pellets have recently seen an increase in popularity. Pellet stoves are popular with new converts to wood heat because they are cleaner and easier to maintain than traditional wood stoves and include conveniences like timers and thermostats. Wood stoves take longer to heat than pellet stoves, and their smoke emissions can lead to degradation of indoor or outdoor air quality. Additionally, woodstove smoke may violate local ordinances (Washington 2010).

Woodstove use is reportedly expanding as people seek fuel sources they see as being "greener." EPA cites industry sources as estimating that sales of woodstoves rose 28 percent between 2007 and 2008. The recent stimulus funding, the 2009 American Recovery and Reinvestment Act, included a 30 percent tax credit in 2009 and 2010 (up to $1500) for purchasing a biomass-burning stove that was 75 percent efficient. In addition, some states (including Oregon, Montana, and Idaho) are providing tax incentives to change from natural gas and propane stoves to biomass-fueled stoves, in an effort to spur "homegrown" renewable fuels (EPA 2009b).

Figure 8. States Representing 95 Percent of OWBs Sold (2006) (NESCAUM)

Another recent trend is the increasing popularity of outdoor wood-fired boilers (OWBs). Ninety-five percent of OWBs have been sold in the states in orange in Figure 8. Some of those states have begun to enact laws to address OWBs.

OWBs are a wood-fired water heater that provides heat to a single residence. OWBs are most popular in rural areas. OWBs contain large fire boxes that heat water, which is then circulated into the home through underground pipes. These units are typically located outside the buildings they heat in small, insulated sheds with short smokestacks (usually no more than six to ten feet tall). They burn wood to heat water that is piped underground to provide heat and hot water to occupied buildings.

While indoor wood stoves must meet EPA certified emissions levels, OWBs are not required to meet a federal emission standard. EPA initiated a voluntary partnership with manufacturers in 2007 to design and market cleaner, more efficient OWBs (New Hampshire 2010). Some states have established regulations for the sale, installation, and use of OWBs in the under state law, while others, like Washington, have deemed them illegal (Washington 2010). Many states have also initiated complaint hotlines to address OWBs' impacts on neighbors.

Commercial and Institutional Sector Highlights

The commercial and institutional sectors encompass places familiar to most people: offices, grocery stores, sports arenas, schools, shopping malls, hotels, and hospitals. These are the commerce and service industries, as well as educational facilities and institutional residences, including a broad array of building types, including offices, grocery stores, sports arenas, schools, shopping malls, hotels, and hospitals. In 2003, there were about five million commercial buildings in the U.S., with approximately 75 billion square feet of floor space (NAS 2010a).

The energy needs for these different buildings vary but when viewed as a whole, more than half of the energy used in commercial buildings goes to heating (36 percent) and lighting (21 percent). Within this sector, retail stores and service buildings use the most total energy (20 percent), followed by office buildings (17 percent) and schools (13 percent) (NAS 2010a). In commercial buildings, electricity is the most widely used energy source (55 percent), followed by natural gas (32 percent).

Table 2 summarizes emissions associated with on-site fuel combustion, which is typically associated with heating, by fuel and pollutant. There are a few important notes from these data:

- Natural gas combustion is the dominant source of NOx emissions in the commercial sector because of its extensive use.
- Commercial oil use contributes a dominant share of SO_2 emissions.
- Unlike the residential sector, there are not significant emissions from biomass or wood combustion.

Table 2. 2005 Commercial Heating-Related Emissions (Tons, 2005) (EPA 2009a)

	NOx	VOCs	SO_2	PM_{10}	$PM_{2.5}$	CO
Commercial	**324,388**	**20,194**	**402,320**	**56,743**	**24,949**	**198,985**
Coal	34,693	1,871	132,314	36,501	9,059	39,051
Oil	92,774	3,778	266,959	16,227	12,215	22,690
Natural Gas	196,922	14,546	3,046	4,015	3,675	137,244

Industrial Sector Highlights

The industrial sector encompasses a diverse collection of industries with very different energy and feedstock needs to produce products that range from paper to gasoline to pharmaceuticals, and as a result, emissions can vary significantly from industry to industry. Certain industries are particularly energy-intensive, requiring large energy inputs per unit of output. The largest energy-consuming industries in the U.S. are bulk chemicals, oil and gas, steel, paper, and food products. These five industries account for 60 percent of industrial energy use, but only 20 percent of the value of the products (Pew 2009). Other energy-intensive industries include glass, cement, and aluminum. In general, energy-intensive industries have been declining within the U.S. economy with a shift to less energy-intensive products (e.g., from steel to computer equipment) and recent economic conditions have reduced industrial output. The Federal Reserve's measure of capacity utilization showed that the nation's factories were operating at a 70.4 percent rate in 2009, down from 77.5 percent in 2008 (EIA 2010e). Table 3 provides examples of the combustion devices that are used within the industrial sector for on-site electricity generation, steam production, and process heating.

Table 3. Examples of Industrial Combustion Devices (STAPPA 2006)

Industry	Device	Description	Typical Fuel	Primary Emissions of Concern
Petroleum Refining, Chemical Manufacturing, Pulp and Paper	Industrial Boiler	On average smaller than boilers used for electricity generation, industrial boilers provide onsite steam and electricity to industrial facilities. Across the industrial sector, industrial boilers are the largest source of air emissions.	Natural Gas, Oil, Biomass, Coal	SO_2, NOx, PM, Air Toxics (dependent on fuel source)
Pulp and Paper	Recovery Boiler	Several times larger than onsite industrial boilers, recovery boilers combust a biomass-based byproduct of the pulping process called black liquor. The energy from the recovery boilers is used to supplement energy from onsite industrial boilers that typically burn wood waste, natural gas, or oil.	Biomass-based Byproduct	Highly variable, can be a source of SO_2, NOx, PM, and Air Toxics
Cement Manufacturing*	Cement Kiln	Cement kilns are the largest source of emissions at a cement manufacturing facility (which do not have industrial boilers). The	Coal with a limited amount of	SO_2, NOx, PM, Air Toxics (dependent on

Industry	Device	Description	Typical Fuel	Primary Emissions of Concern
		kilns provide heat to a mixture that can include limestone, clay, shale, sand, slag, and iron ore that is turned into clinker which is ground into cement.	natural gas and oil. Some facilities use tire waste.	fuel source)
Iron and Steel	Coke Oven	Coke ovens are used to produce coke with is used in the blast furnace to provide the high temperatures needed to forge steel. Coke is produced by heating coal in the absence of oxygen at high temperatures in coke ovens. The solid carbon remaining in the oven is coke. The smoldering coke is quenched with water.	Coal	Direct particulate emissions, VOCs (significant amounts of VOCs are captured for byproduct use in the process)
Petroleum Refining	Process Heaters	A process heater is an enclosed device in which solid, liquid, or gaseous fuels are combusted for the purpose of heating a process material (e.g., crude oil).	Oil, Byproduct Refinery Gases, Natural Gas	SO_2, NOx, PM, Air Toxics
	Flares	Petroleum refineries use flares to combust vapors rather than discharging them to the atmosphere. Frequent flaring in routine, nonemergency situations or to bypass pollution control systems can produce excess emissions and violate permit conditions.	Refinery Process or Waste Gases	SO_2, NOx, PM, Air Toxics

*EPA issued final rules on cement kilns on August 6, 2010, which tightened emission limits from new and existing kilns. The final decision on what sources can be used to power cement kilns will depend on the outcome of pending EPA rules, including rules which may allow solid waste to be used as fuel.

Table 4 summarizes the combustion-related emissions from the industrial sector by fuel and pollutant.

- Coal combustion in the industrial sector is the largest source of SO_2 emissions. The vast majority of the coal consumed in the U.S. is used for electricity generation. In 2009, the industrial sector accounted for about seven percent of total U.S. coal consumption.

- Natural gas, which is used for fuel in many sectors (including steel, glass, paper, clothing, and brick making), burns cleaner than other fossil fuels, although it does generate a substantial share of the sector's NOx and CO emissions.

- The composition of biomass burned for industrial uses varies widely, but can have relatively high emissions of PM and CO, particularly if combusted with no pollution controls. The "other" category includes industrial fuels such as pulping liquor from paper making, agricultural waste, wood residues from mill processing, and wood-related and paper-related refuse, all of which have widely-varying compositions and emissions, as demonstrated by the high total emissions of many of the major pollutants.

- As significant share of emissions from oil used in the industrial sector are from the petroleum refining industry which consumes petroleum fuels produced by the same refineries that use it (EIA 2002). The pulp and paper and chemical industries also use oil to fire onsite boilers.

Table 4. 2005 Industrial Fuel Combustion-Related Emissions (Tons, 2005) (EPA 2009a)

	NOx	VOCs	SO_2	PM_{10}	$PM_{2.5}$	CO
Industrial Fuel Combustion	**1,897,944**	**134,645**	**1,735,527**	**350,749**	**195,004**	**1,239,392**
Coal	332,250	6,499	1,085,098	193,751	65,082	134,747
Natural Gas	511,559	53,991	228,291	45,953	39,948	411,701
Oil	161,355	5,006	335,394	24,486	16,837	44,565
Other (Wood, other biomass, other waste fuels)	892,780	69,149	86,745	86,559	73,136	648,379

Transportation Overview

This discussion focuses on onroad transportation sources, both light-duty (cars and light trucks used for personal transportation) and heavy-duty (trucks, buses) as well as “nonroad” sources, locomotives, marine vessels, and aircraft used for passenger and freight movement. It does not specifically address diesel equipment used for construction, mining, agriculture, and industry. However, the air impacts and environmental policy issues related to this equipment are similar to the issues addressed here relative to diesel trucks, locomotives, and marine vessels. Transportation defined broadly also includes energy expended to move oil, natural gas, and other fluids through pipelines.

In 2008, the U.S. transportation sector consumed 27 quadrillion British thermal units (Btus) of energy – 28 percent of total energy use in the economy (DOE 2010c). Ninety four percent of this energy was derived from petroleum, and was consumed primarily by vehicles in the form of gasoline and diesel fuel (EIA 2010a). The transportation sector consumes 72 percent of all petroleum used in the U.S.

Highway vehicles include both light-duty vehicles – cars and light trucks used primarily for personal transportation – and heavy-duty trucks and buses which are primarily commercial vehicles and are used for freight and passenger transportation. The vast majority of light-duty vehicles operate on gasoline, while virtually all heavy-duty vehicles, both highway and nonroad, operate on diesel fuel. Aircraft, marine vessels, and locomotives also operate virtually exclusively on diesel fuel.

Pipelines require energy to move liquid and gaseous fuel. Most oil and refined product pipelines are operated by pumps that are driven by electric motors. Most natural gas pipelines are operated by compressors driven by internal combustion engines powered by natural gas (Shell 2010).

Comparing Transportation Modes

As shown in Figure 9, 81 percent of energy used for transportation in 2008 was consumed by highway vehicles; aircraft consumed 9 percent, marine vessels consumed 5 percent, pipelines consumed 3 percent and locomotives consumed 2 percent. The percentage of total transportation energy consumed by highway vehicles has been relatively constant for the last 25 years.

Highway Vehicles. In 2008, there were 238 million light-duty vehicles registered in the U.S. These vehicles traveled 2.7 trillion miles and consumed 133 billion gallons of gasoline. In 2008, the average U.S. light-duty vehicle traveled 11,432 miles and burned 557 gallons of gasoline. In 1970, light trucks (pickups, SUVs, vans) comprised less than 14 percent of the light-duty fleet, but their percentage has risen steadily over time; in 2008, 42 percent of light-duty vehicles were light trucks.

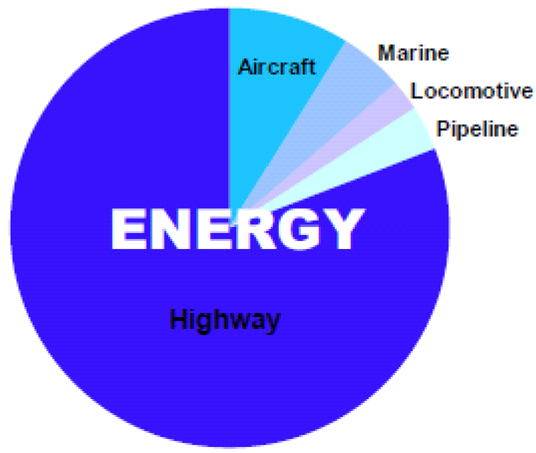


Figure 9. Transportation Energy Use by Mode.

In 2008, there were 9 million heavy trucks registered in the U.S. These vehicles traveled 227 billion miles and burned 37 billion gallons of diesel fuel. In 2008, the average U.S. heavy truck traveled 25,253 miles and consumed 4,718 gallons of diesel fuel.

In 2008, the number of miles traveled by the U.S. highway fleet declined, compared to the previous year, for the first time in 28 years. Between 1985 and 2005, total fleet miles grew at an average annual rate of 3.4 percent.

See Figure 10 for a comparison of highway vehicles, vehicle miles, and fuel use by vehicle type in 2008[5]. As shown, while heavy trucks accounted for less than 4 percent of vehicles and less than 8 percent of vehicle miles, they consumed almost one quarter of all fuel used by the highway fleet. Over the last thirty years, the percentage of total vehicles and fleet miles accounted for by heavy trucks has remained fairly constant, but the percentage of total highway fuel consumed by these vehicles has increased (from 17 percent in 1978), because their fuel economy has remained fairly flat while the fuel economy of light-duty vehicles has increased.

[5] In this figure fuel use is shown as percentage of total energy used, not percentage of total gallons used. This accounts for the fact that a gallon of diesel fuel contains approximately 15 percent more energy than a gallon of gasoline.

Public Transit. According to the American Public Transportation Association (APTA), there are more than 7,700 organizations that provide public transportation in the U.S., some of which operate more than one mode. Seventy two hundred of these organizations (93 percent) provide demand-response "paratransit" bus service, and 1,100 operate fixed-route bus service. There are also 15 heavy urban rail (i.e. subway) systems, 33 urban light rail systems, and 23 commuter rail systems operating from the suburbs into urban areas (APTA 2010). In 2008, five percent of workers used transit for daily commuting, and 59 percent of all transit trips were work related.

In 2008, 53 percent of all public transit trips were taken by bus, 34 percent were taken by heavy urban rail, and 9 percent were taken by light rail and commuter rail (APTA 2010). The largest transit system in the country is operated by the Metropolitan Transportation Authority (MTA) in New York City. MTA's operations encompass the MTA New York City Transit subway system and fixed-route and paratransit bus systems, as well as two commuter rail lines. In 2008, 32 percent of all U.S. public transit trips were taken on MTA buses and trains.

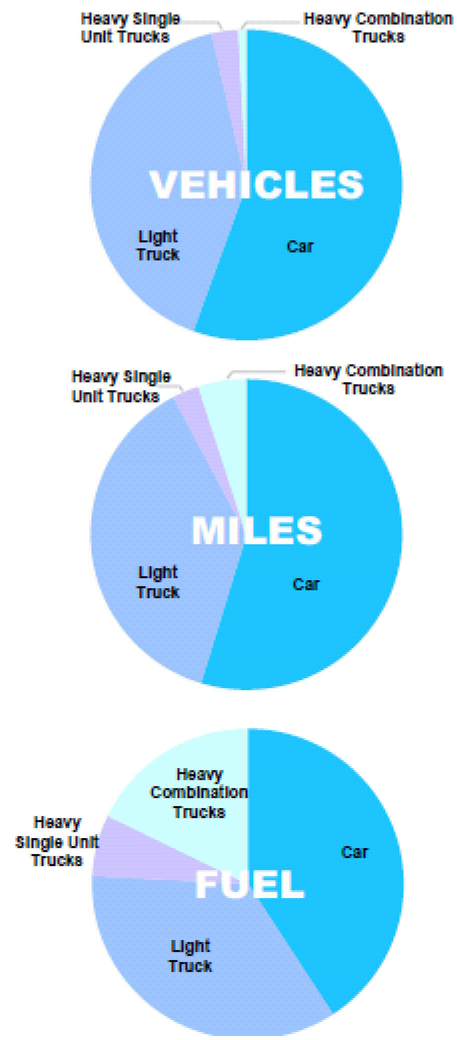


Figure 10. Vehicles, Fleet Miles and Fuel Use for Highway Vehicles

From 1995 to 2008, public transportation ridership increased by 38 percent – out pacing both the increase in the population and the increase in personal vehicle miles traveled (VMT); total ridership in 2008 was the highest it had been in 52 years. Total ridership fell by 3.8 percent in 2009 – likely due to the poor economy and exacerbated by service cut-backs resulting from lower state and local funding (APTA 2010).

Aircraft. In 2008, U.S. and international major air carriers operated over 7,800 aircraft, which flew over eight billion revenue miles (824 billion passenger miles), and carried over 35 billion ton-miles of freight. The general aviation fleet (not-for-hire aircraft with more than 20 seats, on-demand and commuter operations, and agricultural aircraft) contained an additional 228,663 aircraft which accumulated 26 million hours of flight time. Air transportation has been getting steadily more efficient in the last 20 years. The average energy intensity (Btu/passenger-mile)[6] of major air carriers was 37 percent lower in 2008 than it was in 1988. Part of the improvement

[6] One passenger-mile is defined as one passenger carried one mile. This is the metric usually used to compare different passenger transit modes

was due to more efficient aircraft and part of it was due to more efficient operations – the average passenger load factor was 79 percent in 2008 compared to 62 percent in 1988[7].

Marine. In 2008, there were approximately 40,000 marine vessels operating to, from and between U.S. ports. These vessels carried 521 billion ton-miles of freight. Water-borne freight tonnage dropped by 3 percent in 2008, compared to the previous year. The long-term trend, however, is for increased freight shipments by water. Between 1987 and 2007, water-borne freight tonnage increased at an average annual rate of 1.5 percent.

Rail. The seven largest rail companies in the U.S., based on annual gross revenue, are designated Class I railroads; together these companies operate 67 percent of rail industry mileage and take in 94 percent of rail industry revenue. In 2008, the Class I railroads operated 24,000 locomotives and 450,000 freight cars, which they used to carry 1.8 trillion ton-miles of freight. Over the last twenty years, rail freight tonnage has increased at an average annual rate of 1.9 percent, while freight ton-miles have increased at an average annual rate of 3.9 percent. This is because the average length of haul has increased by 30 percent.

Pipelines. There are over 500,000 miles of pipelines installed throughout the U.S. that carry crude oil, natural gas, and refined petroleum products from the well head to the refinery and between regional markets.

Transportation Air Emissions

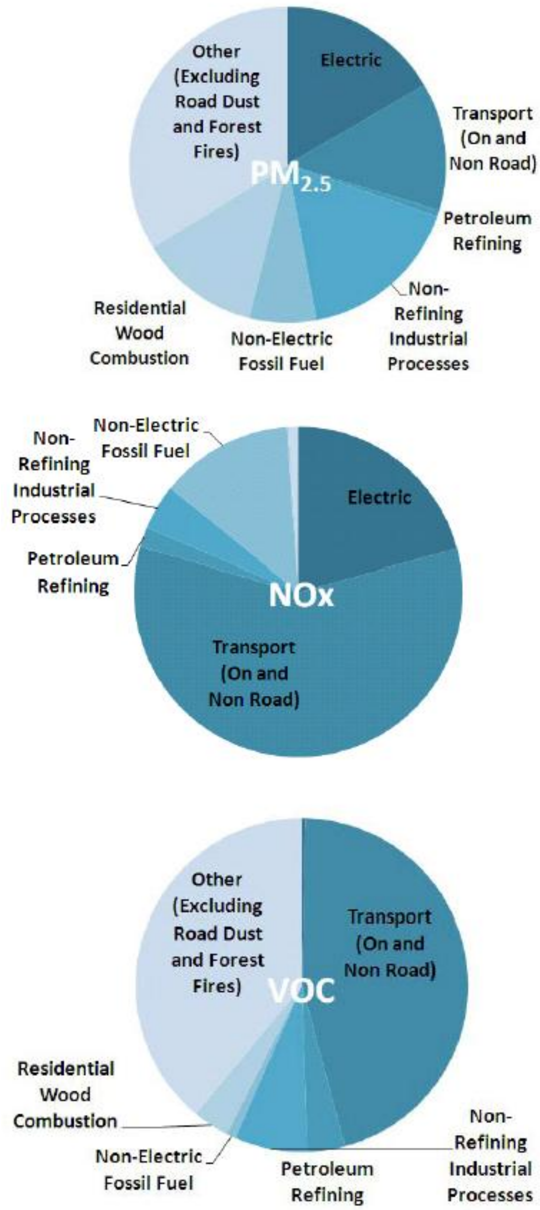
The most significant health impacts associated with transportation are associated with tailpipe emissions from the combustion of gasoline and diesel fuel in automotive engines. As shown in Figure 11, collectively, transportation sector emissions (including both on road vehicles and non road vehicles and equipment) make up about 13 percent of primary fine particulate matter ($PM_{2.5}$) emissions[8], 59 percent of nitrogen oxide (NOx) emissions, and 46 percent of volatile organic compound (VOC) emissions. The transportation sector is responsible for about a third of carbon dioxide (CO_2) emissions from the U.S. economy. Overall, transportation sources are not a significant source of national sulfur dioxide (SO_2) or mercury emissions, which are largely the result of electric power generation. However, because they burn high sulfur residual fuel, ocean-going marine vessels can be a significant local source of SO_2 emissions; this is particularly true in cities with large, active ports, such as Los Angeles, New York, New Orleans, and Houston.

[7] Passenger load factor = occupied seats ÷ available seats

[8] In this figure total $PM_{2.5}$ emissions do not include fugitive dust, such as road dust, or emissions from natural and structural fires.

Emissions from petroleum refining, transport, and storage add another one to two percent of national $PM_{2.5}$ and NOx emissions, and four percent of VOC emissions.

Approximately one third of transportation PM emissions, half of NOx emissions, and 95 percent of VOC emissions come from gasoline engines (mostly cars and light trucks). Approximately two thirds of transportation PM emissions, and half of NOx emissions, come from diesel engines – highway trucks, marine vessels, locomotives, and aircraft.[9]



Source: EPA

Figure 11. Contribution of Transportation to Air Emissions (Excluding Fugitive Emissions, and Forest Fires)

Diesel particles have been studied separately from other ambient particles because of some distinctive characteristics. While mostly carbon, diesel particles also carry with them dozens of hydrocarbons also present in diesel exhaust, which are adsorbed onto the carbon core. More than 40 potential components of diesel exhaust (for example benzene and formaldehyde) are designated as hazardous air pollutants by EPA; 15 of these substances are also listed by the International Agency for Research on Cancer as known, probable, or possible human carcinogens (EPA 2002; IARC 2010). Ultrafine diesel particles in the ambient air carry these toxins deep into the lung when inhaled. There is also growing evidence that diesel exhaust may worsen the effect of inhaled allergens (EPA 2004).

While transportation sources only account for eight percent of total primary $PM_{2.5}$ nationally, the nature and location of these PM emissions magnify their impact on human exposure. While most power plant and many industrial

[9] While aircraft burn diesel fuel, most are powered by turbine (jet) engines. These external combustion engines are very different than the internal combustion "diesel engines" in trucks, locomotives, and marine vessels. Air craft jet engines are similar to the small, natural gas or diesel-fueled "peaking turbines" used to generate electricity.

emission sources release combustion exhaust at the top of tall exhaust stacks, virtually all exhaust from transportation vehicles is emitted at ground level where people live, work, and breathe. Individuals who live or work near heavily trafficked roadways, or near locations with heavy concentrations of diesel vehicles – for example freight truck depots, rail yards, ports, and airports – have the greatest exposure.

These near-roadway exposures are of growing concern, and may affect many more people than previously thought. The Health Effects Institute (HEI) in 2010 published the most recent review of the health effects from exposures to traffic-generated air pollutants. They concluded that as much as 30 to 45 percent of people in large North American cities live in areas that were impacted by traffic-related air pollution, a zone they identified as 300 to 500 meters from the roadside. The HEI review concluded that the evidence showed traffic-generated pollution causes asthma attacks in children and may cause the onset of asthma, premature death, impaired lung function and cardiovascular disease (HEI 2010).

EPA Regulation of Transportation Sources

Under the Clean Air Act, EPA regulates the allowable level of exhaust emissions from new vehicles and engines, as well as the fuel economy and CO_2 from new vehicles and engines.

EPA Regulation of Emissions from New Vehicles and Engines

There are four pollutants regulated for all transportation sources: PM, NOx, carbon monoxide (CO), and VOC. EPA does not yet regulate CO_2 emissions from new engines and vehicles but they have proposed rules to do so in the future – see discussion below.

EPA emission standards for cars and light trucks are expressed as allowable mass of emissions per mile driven – grams per mile (g/mi) – and certification is based on testing of the entire vehicle. EPA uses a different approach with heavy-duty vehicles. EPA regulates emissions from heavy-duty engines, not vehicles; emissions limits are expressed as allowable mass per unit of work done – grams per brake horsepower-hour (g/bhp-hr). Heavy-duty vehicles are regulated differently than light-duty vehicles because heavy-duty vehicle markets are much more complicated. Heavy-duty vehicles and engines come in a much broader range of configurations and sizes. The heavy-duty vehicle industry also has a more complicated structure, with more manufacturers and greater disaggregation in the manufacturing process.

EPA uses a separate regulatory system (testing procedures and numerical emissions limits) for different types of heavy-duty engines. There are separate standards for engines used in heavy-duty highway trucks, nonroad construction and agricultural equipment, locomotives, marine vessels, and aircraft.

Emissions limits for all types of new transportation vehicles have been tightened over the years. While EPA imposed emissions limits on new cars in the 1970s, emissions from heavy-duty highway engines were first regulated in the 1988 model year, and new engines for marine vessels were not regulated until the 2004 model year. The more stringent limits have significantly cut emissions; for example, the average new car sold in 2010, and subject to EPA Tier 2 limits, emits 88 percent less NOx and 90 percent less PM than a car sold ten years ago (subject to Tier 1 limits). Similarly, the average new heavy-duty highway engine sold in 2010 emits 95 percent less NOx and 90 percent less PM than an engine sold ten years ago.

As vehicle fleets turn over to new, cleaner, vehicles total emissions per vehicle and per mile are significantly reduced. However, a lag in the imposition of stricter standards, and slower turn-over rates, means that current diesel fleets – including highway trucks, locomotives and marine fleets - are much "dirtier" than the light-duty highway fleet, and will remain so for many years. EPA estimates that the light-duty Tier 2 regulations will reduce NOx emissions from light-duty vehicles by 42 percent in 2010 and 61 percent in 2015, compared to a baseline projection without them (EPA 1999).

Due to slower turn-over of the heavy-truck fleet, EPA estimates that the EPA 2010 heavy-duty engine standards will take longer to reduce diesel emissions; it will take until about 2025 before virtually all highway truck miles will be operated with "clean" EPA 2010 compliant trucks (EPA 2000). Locomotive and marine fleets will not even begin to turn over to the "cleanest" vehicles until 2015, and will likely not turn over completely until 2045 or later.

Regulation of Fuel Economy & CO_2 from New Vehicles and Engines

Fuel economy standards are separate from EPA emission standards. Since 1975, the fuel economy of new light-duty vehicles has been regulated by the National Highway Traffic Safety Administration (NHTSA) under the Corporate Average Fuel Economy (CAFE) program. Under CAFE not all models sold need to have the same fuel economy; all new vehicle models are tested and each manufacturer has to meet a sales-weighted fleet average fuel economy target. Under this system manufacturers can sell cars that have worse fuel economy than the average target value as long as they sell an equal number of cars with better fuel economy than the average.

Between 1978 and 1990, the CAFE fleet average standard for new cars was increased incrementally from 18 miles per gallon (MPG) to 27.5 MPG – where it remained, unchanged, for the past twenty years (through the 2010 model year). CAFE also includes fleet average standards for light trucks, which for the 2008 model year was 22.5 MPG (DOE 2010c). However, through 2008 light truck fuel economy standards did not apply to vehicles with a gross vehicle weight rating (GVWR) over 8,500 pounds (e.g., large pickups, vans, and SUVs).

In 2006, NHTSA established new requirements for light truck average fuel economy to apply between the 2008 and 2011 model years. In addition to specifically including larger vehicles with GVWR between 8,500 and 10,000 pounds, the new format applied different numerical standards for vehicles with different "footprint" (footprint = width x wheel base). The "reformed" standard rose to 24.1 MPG (fleet-wide average) for the 2011 model year (DOE 2010c).

In March 2010, NHTSA and EPA issued a joint rulemaking which establishes a new program to regulate fuel economy and greenhouse gas emissions from new cars and light trucks for model years 2012 – 2016. This new program assigns both a fuel economy target (MPG) and an equivalent target for CO_2 emissions in terms of maximum allowable grams CO_2 per mile (g/mi)[10]. The new program assigns different average fuel economy targets for vehicles with different footprints. The larger the vehicle, the lower the targets are for fuel economy, and the higher they are for CO_2 emissions.

EPA and NHTSA have begun to develop two new rules for fuel economy and greenhouse gas reductions. One program would further develop fuel economy and CO_2 standards for light-duty vehicles from model year 2017 through model year 2025, and the other would set CO_2 emission and fuel economy standards for the first time for heavy-duty highway vehicles, beginning in the 2014 model year (EPA 2010b). In October 2010, the two agencies issued an interim technical report that reviewed the status of technologies that could be used to further improve light-duty vehicle fuel economy. The agencies expect to propose a rule for both programs by the end of September 2011, and issue final rules by the end of July 2012 (EPA 2010b).

EPA also announced its intention to review "for adequacy" the current non-greenhouse gas emissions regulations for new motor vehicles, new motor vehicle engines, and motor vehicle fuels, including tailpipe emissions standards for nitrogen oxides and air toxics, and sulfur standards for gasoline. If the EPA Administrator finds that new emissions regulations are required, EPA intends to promulgate such regulations "as part of a comprehensive approach toward regulating motor vehicles."

Alternative Vehicle and Fuel Highlights

The vast majority of light-duty vehicles on the road today, as well as new vehicles being purchased, are powered by conventional gasoline engines and operate on petroleum-derived gasoline fuel. Over the past twenty years, various alternative fuels and engine/drive train technologies have been developed and promoted for both light-duty and heavy-duty vehicles.

Some of these alternative fuels and technologies have the potential to reduce emissions of NOx, PM, and VOCs from transportation sources, but many are more specifically targeted toward reducing CO_2 emissions and reducing petroleum use. Efforts to reduce petroleum use in the transportation sector are intended to enhance energy security by using locally produced energy sources rather than imported petroleum.

The discussion below highlights the current status and potential benefits of the most significant of these alternative fuels and technologies, including natural gas, bio-derived fuels, electric vehicles, and hydrogen fuel cell vehicles.

[10] Assuming a constant value for the amount of carbon contained in a gallon of gasoline.

Alternative Fuels

With relatively minor modifications, a gasoline engine (i.e. a spark-ignited, homogenous charge internal combustion engine) can operate on a range of volatile fuels, including natural gas, an alcohol such as ethanol or methanol, or a blend of petroleum-derived gasoline plus an alcohol.

Despite laws and incentives to encourage their use, alternative transportation fuels, including natural gas and bio-derived fuels such as biodiesel and E85 ethanol are in limited use today. In 2008 they accounted for less than 0.5 percent of the fuel used for transportation; all alternative fuels together totaled only 750 million gasoline-equivalent gallons[11], compared to 132 billion gallons of gasoline consumed (DOE 2010c).

Natural Gas

Natural gas engines can be used to power both light-duty vehicles and heavy-duty trucks. For light-duty vehicles, natural gas engines are virtually identical to gasoline engines. A number of companies convert gasoline cars to natural gas or bi-fuel operation by adding a natural gas fuel system and making minor modifications to the engine (NGV 2010). Bi-fuel vehicles have both a natural gas fuel system and a gasoline tank and can operate on either fuel. Diesel engines are less easily converted to natural gas because the ignition systems differ.

Natural gas engines have approximately the same efficiency as gasoline engines, but due to the lower carbon content of natural gas they produce approximately 25 percent lower CO_2 emissions per mile.

New model year 2010 and later heavy-duty natural gas engines are certified to the same emission standard as new heavy-duty diesel engines and have approximately the same emissions per mile. Heavy-duty natural gas engines are not as efficient as diesel engines, and natural gas trucks and buses typically use more fuel energy per mile than diesel trucks and buses. Testing has shown that per-mile CO_2 emissions from natural gas buses range from 6 percent to 30 percent lower than CO_2 emissions from diesel buses (SAE 2004).

Ethanol

The U.S. is the largest producer and user of ethanol fuel in the world. Most ethanol in the U.S. today is produced from corn. Other countries, such as Brazil, use sugarcane to produce ethanol. There are also many companies working to perfect processes to produce “cellulosic ethanol” from fibrous sources such as grass or wood chips. Cellulosic biomass requires more pre-treatment than starchy biomass, to allow for effective fermentation (NREL 2007).

Much of the gasoline sold in the U.S. today has up to 10 percent ethanol blended into it. This is done for one of two reasons: 1) the ethanol acts as an oxygenate in reformulated gasoline (RFG), or 2) the ethanol allows refiners to comply with renewable fuel mandates.

[11] A gasoline-equivalent gallon is an amount of fuel that contains the same amount of energy as one gallon of gasoline (approximately 115,000 Btu).

The addition of fuel-borne oxygen in gasoline helps cars to run cleaner, reducing NOx, VOC, and CO (EPA 2010c). The Clean Air Act requires counties in fourteen states plus the District of Columbia to burn "reformulated gasoline" (RFG) because they are in noncompliance with ambient air quality standards for ozone. Five additional states have opted into the program.[12] The current limit of 10 percent ethanol in standard gasoline and RFG is set by EPA, which has determined that this level of ethanol will not harm in-use engines. In separate decisions announced in October 2010 and January 2011, EPA granted a waiver request sought by several major ethanol producers to increase the allowable limit of ethanol in gasoline to 15 percent, but only for model year 2001 and newer cars (EPA 2011). These decisions have been controversial, and have been opposed by refiners, auto manufacturers, and some environmental groups, including the American Lung Association. Auto manufacturers have raised a concern that higher levels of ethanol may damage the three-way catalysts (i.e. catalytic converters) used on older cars. The American Lung Association has testified about concerns that the air quality and public health may be harmed by the increased use of mid-range blends of ethanol and urged more research.

The Energy Policy Act of 2005 mandated that U.S. refiners use increasing amounts of "renewable fuels" in motor gasoline and diesel between 2006 and 2012 in order to enhance U.S. energy security. Refiners were required to sell 4 billion gallons of renewables in 2006, with the mandate increasing to 7.5 billion annual gallons in 2012 (Holt 2006). This mandate has increased the use of ethanol in gasoline, even in areas not required to use RFG.

In 1997, some manufacturers began selling "flex fuel" vehicles designed to operate on either gasoline or an E85 blend of 85 percent ethanol and 15 percent gasoline. In the 2010 model year, there were 34 models of flex fuel E85 vehicles available from major auto manufacturers, mostly large sedans, pickups, SUVs, and mini-vans (DOE 2010b). The DOE Energy Information Administration estimates that in 2007 there were 7.1 million E85 vehicles on the road, but only about 6 percent of them routinely operated on E85, with the remainder being fueled primarily by gasoline (DOE 2010c). In 2008, there were 162,000 U.S. retail outlets selling gasoline, but there were only 1,980 locations in the country where one could get E85 fuel (1.2 percent), and some of these sites are fleet fueling locations that are not available to the public (DOE 2010c).

The use of ethanol as a transportation fuel increased from 1.95 billion gallons in 2003 to 7.26 billion gallons in 2008. In 2008, less than 1 percent of this ethanol was used in E85 blends – more than 99 percent was blended into standard gasoline and RFG (DOE 2010c).

However, there has been increasing attention from the environmental community on the lifecycle impacts associated with using corn as the primary feedstock for ethanol in the U.S.

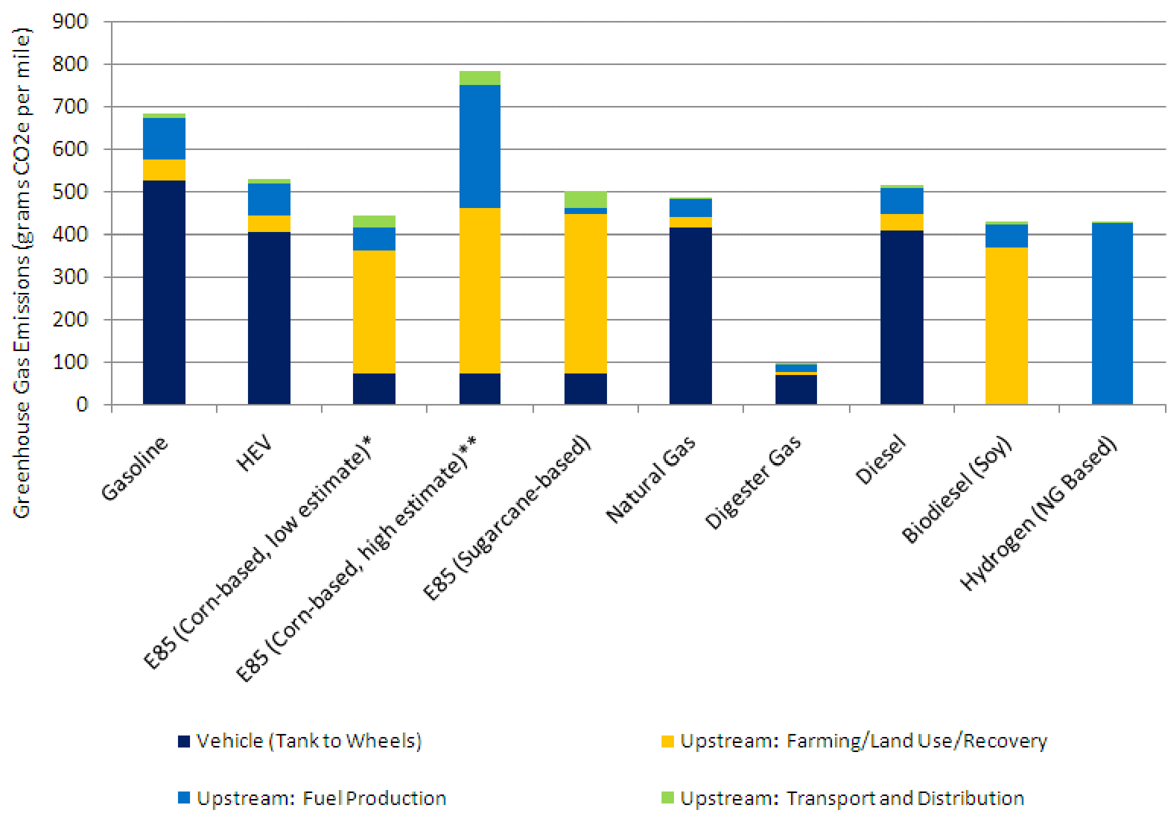
[12] Mandatory: California, Connecticut, Delaware, DC, Georgia, Illinois, Indianan, Louisiana, Maryland, New Jersey, New York, Pennsylvania, Texas, Virginia, and Wisconsin; Opt-in: Kentucky, Missouri, Massachusetts, New Hampshire, and Rhode Island

Skeptics of the benefits of corn-based ethanol point to the significant greenhouse gas emissions that are released as corn is farmed, harvested and processed into ethanol.

As a way to capture the impact of these upstream emissions, California is finalizing a Low Carbon Fuel Standard (LCFS) for vehicle fuels that mandates a 10 percent reduction in the lifecycle carbon intensity of vehicle fuels by 2020 (a group of Northeast and Mid Atlantic states are currently considering a similar standard).

Using data developed in support of the California LCFS, M.J. Bradley & Associates estimated total lifecycle emissions on a per mile basis for a variety of different fuels/propulsion systems. The analysis used a modeled Chevrolet Tahoe Sport Utility Vehicle to determine the amount of energy used per mile. The results of this analysis are shown in Figure 12. While an E85 blend of ethanol and gasoline yields low greenhouse gas emissions from the vehicle tail pipe[13], the upstream emissions associated with farming and land use significantly impact the benefits of E85 relative to other alternatives. In addition, the per-mile lifecycle GHG emissions of an SUV burning E85 produced from corn are almost as high as emissions from the same SUV burning conventional gasoline. Not shown in Figure 12 are more advanced forms of ethanol such as cellulosic ethanol that are still in the demonstration stages, but which hold promise to produce ethanol with fewer lifecycle greenhouse gas emissions.

[13] A vehicle burning E85 would in fact emit significant CO_2 emissions from the tail pipe, but it is the convention to treat tail pipe CO_2 emissions from bio fuels as zero, because this CO_2 is recycled back into biomass as more plants are grown to produce the bio fuel. The tail-pipe emissions shown in Figure 13 for E85 come from the 15 percent petroleum gasoline in the blend.



*There is significant variability in estimates of the carbon intensity of corn-based ethanol. The low estimate is based on the CA LCFS look-up table for ethanol dry milled from CA-sourced corn powered by 20% biomass and 80% natural gas. It also uses revised land use impacts estimate of 13.9 grams of CO_2e per MJ.

**The high estimate is based on the CA LCFS look-up table for ethanol wet milled from midwest-sourced corn powered by 100% coal. It also uses the original land use impacts estimate of 30 grams of CO2e per MJ.

The CA LCFS look-up table is available at: http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf

Figure 12. Average Life-cycle Greenhouse Gas Emissions Using Various Fuels in a Modeled Vehicle (grams CO_2e per mile)

Biodiesel

Biodiesel is a transportation fuel produced from vegetable oils or animal fats. During production of biodiesel, glycerin is removed from the oil, leaving behind methyl esters, which are used for fuel. Biodiesel has very similar chemical and physical properties as petroleum diesel, though it has higher oxygen content and virtually no sulfur. In the U.S., biodiesel is usually produced from soy bean oil, but it can also be produced from a range of vegetable oils including rapeseed oil, palm oil, and jatropha. There is ongoing research into using algae as a potential biodiesel feedstock because it is expected to produce high yields from a smaller area of land than vegetable oils (DOE 2010a).

Figure 12 includes the lifecycle greenhouse gas emissions, on a per-mile basis, of soy-based biodiesel. Soy-based biodiesel produces approximately 17 percent lower life-cycle GHG emissions per mile than petroleum-based diesel fuel. Advanced forms of soy-based biodiesel show promise of being even less greenhouse gas intensive, and are being marketed as "renewable" biodiesel.

Advanced Vehicles

In the early 1990s, the California Air Resources Board (CARB) introduced a Zero Emission Vehicle (ZEV) Mandate. This mandate originally required that the six largest automobile manufacturers ensure that 10 percent of the products they sold in California were "zero emission vehicles" by 2003 and encouraged a focus on developing electric vehicles (EVs). CARB has relaxed the original mandated 2003 introduction date for ZEVs several times, and has made other changes to the program which has changed the focus of manufacturer efforts from battery vehicles to fuel cell vehicles. In response all major manufacturers cancelled their EV development programs and discontinued the sale of the EV models they had produced.

The commercial success of the Toyota Prius, introduced to the U.S. market in 1999 (along with the Honda Insight hybrid), caused auto manufacturers to focus on gasoline hybrid-electric cars. In the last few years some major auto manufacturers have also turned their attention back to pure EVs, which will, in limited volume, again be available for purchase in 2011.

Hybrids

The commercial success of the Toyota Prius, introduced to the U.S. market in 1999 (along with the Honda Insight hybrid), caused auto manufacturers to focus on gasoline hybrid-electric cars. Hybrids combine a gasoline engine with a small battery to significantly improve fuel economy. Hybrids are not truly electric vehicles (EVs) because they get all of the energy required to drive the vehicle from an on-board gasoline engine. Hybrids do take advantage of drive train electrification to improve over-all driving efficiency, which also reduces tail pipe emissions.

Hybrid technology has also been deployed on heavy trucks, most notably on transit buses and medium-duty work trucks. Heavy-duty hybrids typically use a diesel engine, but there are some gasoline-hybrid transit buses operating in California. Every major North American transit bus manufacturer offers a diesel hybrid version of their buses. Over 4,000 hybrid transit buses are in service or on order today.

Plug-in Hybrids

With the addition of a larger battery and a charging port, a hybrid car can also be turned into a "plug-in" (i.e. charge-depleting) hybrid, which can pull some of the energy required to drive the vehicle from the electric grid. Plug-in hybrids have a larger battery pack than a regular hybrid, and also have a charging port. They are designed to be able to travel a certain distance – say 20 miles - using only energy from the battery, without turning on the gasoline engine (EV mode). After the energy in the battery pack is depleted the gasoline engine turns on and the vehicle acts like a regular hybrid.

Electric Vehicles (EVs)

In the last few years some major auto manufacturers have also turned their attention back to pure EVs, which will, in limited volume, be available for purchase in 2011. While these vehicles have no tailpipe emissions, the power plants that produce the electricity used to charge them do emit a wide range of harmful air pollutants, including SO_2, PM, NOx, mercury and other air toxics, as well as CO_2. The net air quality benefit of an electric vehicle or a plug-in hybrid depends on the method used to produce electricity where they are used.

Transportation Policy and Funding

Congress is due to take up the next formal authorization for funding the nation's transportation system. The most recent authorizations legislation, the SAFETEA-LU, expired in September 2009, so new authorization is under discussion. The federal authorization funds not only highways but transit programs, allocating 20 percent or less of the total funding to transit. Under the SAFTEA-LU, highway programs received about $40 billion annually, while transit programs received about $9 billion. Since 1991, the authorization has also included funding for "Congestion Mitigation and Air Quality" programs, which funds air pollution control efforts and alternative transportation projects, such as pedestrian and bike paths.

In the 111th Congress, the Surface Transportation Authorization Act of 2009 was proposed but did not succeed. The bill recognized the need for a national plan for transportation. With the 112th Congress, the debate over the transportation bill is expected to resume. Meanwhile other groups have urged a national transportation strategy that would encourage more dense development, greater integration of public transportation and alternative transportation.

Another question to be resolved is how the money is raised. The 18.3 cent per gallon gasoline tax no longer provides adequate resources. Keeping adequate funding requires increased gasoline use to grow, unless the fees are increased, which has not happened since 1993. An alternative funding system is one that would charge a fee based on the miles driven, not the fuel consumed. More research would be needed to put such a system in place, but Transportation for America and others urge that it be explored as a long-term funding mechanism.

As governments look to alternatives for funding needed transportation projects, public-private partnerships are growing. Private companies now own and operate toll roads and public transportation, as well as other transportation infrastructure. No clear guidance exists for structuring the relationship between the private companies and government entities to ensure that the projects meet requirements to reduce emissions and provide access.

In addition, groups including the Transportation for America and Urban Land Institute are supporting the expansion of intercity rail as part of an interconnected public transportation system and one way to supply future transportation needs outside of adding highway and air transportation capacity.

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