

Energy Consumption in the Transportation Sector



CHAPTER OBJECTIVES

- A. Introduction:
Transportation
Sector Contributors
to Carbon Emissions
- B. Personal Modes of
Transportation
- C. Mass Transit
- D. Freight
Transportation

FIG. 13-1 Siemens
Sapsan Train
Arriving in St.
Petersburg, Russia

A. Introduction: Transportation Sector Contributors to Carbon Emissions

SIEMENS

St. Petersburg, the one-time capitol of Russia, is 396 miles (637 km) from Moscow. Because they are the two largest cities in Russia, the route between them is well traveled. In December 2009, a new opportunity for transportation began to take shape as the Russians implemented high-speed trains purchased from Siemens. The Russian state railway spent \$485 million upgrading the track and \$926 million for eight Siemens Sapsan trains and a 30-year service agreement. German-based Siemens is a multinational firm with more than 430,000 employees working in the industry, energy, and health care sectors. In 2008, Siemens had revenue of €77.3 billion and income from continuing operations of €1.859 billion.¹



Source: © AFP PHOTO/INTERPRESS/NEWSCOM

The Siemens Sapsan (Russian for *peregrine falcon*) train uses a breakthrough technology that stands in contrast to earlier trains. Instead of a locomotive, the Sapsan uses electric motors attached to wheels all along the train cars. The train's top speed is 217 miles (349 km) per hour, but it has reached 255 miles (410 km) per hour in some tests.

The Siemens high-speed trains will compete with airlines. The trip from downtown Moscow to downtown St. Petersburg is estimated to be 3 hours and 45 minutes. Although the actual flying time is shorter, the average travel time including the trips to and from the airport, check-in, and security clearance is five hours². The service will be offered four times per day and will cut 45 minutes from the fastest train service available operating before 2009.

The Russian example is consistent with other markets in which high-speed trains have roundly beaten planes on price, overall travel time, and convenience at ranges up to 600 miles (965 km) between major cities. In addition, using electricity provides the opportunity to use replenishable sources of energy. Due to the benefits of this form of travel, the construction of a high-speed rail route between Paris and Lyons eliminated most commercial flights between the cities. Similarly, the Madrid-to-Barcelona high-speed link cut the air travel market for this route about 50% in a single year.³

Global spending on trains, tracks, and equipment is expected to reach €122 billion (\$182 billion) in 2009—a figure that is up 18% since 2004. Moreover, projections suggest that this figure will rise to €150 billion by 2016, propelled by environmental concerns and stimulus projects.⁴ Currently, Japan, France, Germany, Spain, Britain, Italy, Taiwan, Korea, and China have high-speed trains in operation. Spain plans to surpass Japan with the world's largest network of high-speed routes in 2010, but China and India should surpass Spain before long. France hopes to double its high-speed track to about 2,500 miles by 2020, and Denmark is shifting transportation funding from roads to rail-based public transportation. Four of the largest providers to this market are Siemens, Hitachi, Alstom, and Bombardier. General Electric is a developer of locomotive freight trains, but this company is also committed to serving the high-speed passenger train market.

It is interesting to note that Siemens hopes that the Sapsan will be stopping at platforms in the United States in the near future. President Barack Obama has vowed to spend \$13 billion over five years to build high-speed rail links between major cities. Eight billion dollars are included in the economic-stimulus plan. The United States Department of Transportation has identified 11 corridors where high-speed trains could compete with air and intercity car travel. For example, Siemens Sapsan is a candidate for the Los Angeles-to-San Francisco route slated to be opened in 2020.⁵

The evolving market for high-speed rail travel illustrates how energy consumption is changing in the transportation sector. In order to gain a better understanding of this energy usage, this chapter offers an overview of the role of transportation in global energy consumption. We initially describe the use of energy associated with transportation, and we subsequently outline the use of energy for passenger and freight transportation. In the process, we discuss efforts to enhance the fuel efficiency of alternative modes of transportation. We begin with a description of personal modes of transportation that dominate fuel consumption in this

macroeconomic sector. We subsequently describe current and planned levels of mass transit. We also outline energy consumption associated with freight transportation.

The transportation sector accounts for 26% of worldwide energy consumption and 25% of direct and indirect carbon emissions.⁶ Over the past 15 years, transportation has been the fastest growing macroeconomic sector as energy consumption has risen by 37% and now exceeds 75 exajoules (one exajoule = 10^{18} joules) annually. The increase in carbon emissions correlates with the increase in energy consumption and now stands at more than 5.3 gigatons per year. At 89%, road travel—for freight and passengers—is the largest user of energy, and it is the main contributor to increased transportation energy use. Since 1990, energy consumption via other modes of transportation has increased by 13%, yet the increase in energy use for road travel over the same period is 41%.

Geographic location is significantly associated with the increase in demand for energy. Among Organization for Economic Cooperation and Development (OECD) nations, the increase in demand for energy use since 1990 has been 30%, whereas the increase outside of the OECD has been more than 55%. The rapid growth of the economy in several nations has resulted in increased personal income that is associated with higher vehicle ownership. In addition, the rise in income increases the need for freight transportation. The Chinese economy illustrates some of these trends. Although 15 years ago there were virtually no private cars in China, by the end of 2007, the number of privately owned cars had risen to more than 15 million.⁷ The Chinese began aggressively promoting consumption as a way to balance their export-driven economy in 2000, and the purchase of automobiles was strongly encouraged.

Interestingly, the Chinese consumer has purchased many types of vehicles including cars, sport utility vehicles, and pickup trucks. Both government incentives and consumer preferences prompt ownership of larger vehicles. Many cities ban cars with engines smaller than one liter from entering their downtowns because such cars are typically old and dirty. Some municipalities ban smaller cars from expressways because they claim these cars endanger their owners when traveling at high speed. Consumer preferences also are associated with bigger vehicles. Because many car owners want to appear wealthy enough to have a chauffeur, Chinese autos tend to be slightly longer than their American counterparts. Consequently, Volkswagen, Audi, Honda, and General Motors have been successful in marketing larger cars, passenger vans, and sport utility vehicles. China is Buick's biggest market, where the company had sales of 332,115 vehicles in 2007, compared with 185,791 in the United States.⁸

Although efforts to economize on the use of energy require consideration of energy use and carbon emissions across the globe, complete data for the transportation sector are not currently available. As the Chinese example illustrates, there is a strong rate of change in consumption habits in emerging economies. Estimates suggest that sometime after 2010, greenhouse gas emissions from the developing world will exceed those in the industrialized world.⁹ Nevertheless, comprehensive data addressing all modes of transportation (other than international air travel) are only available for the 18 countries affiliated with the International Energy Agency (IEA). These countries include Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the United States.

The transportation sector includes energy associated with *passenger* travel and *freight* travel. Although similar technologies are associated with both transportation needs, the opportunities to realize energy savings vary across transportation sectors.

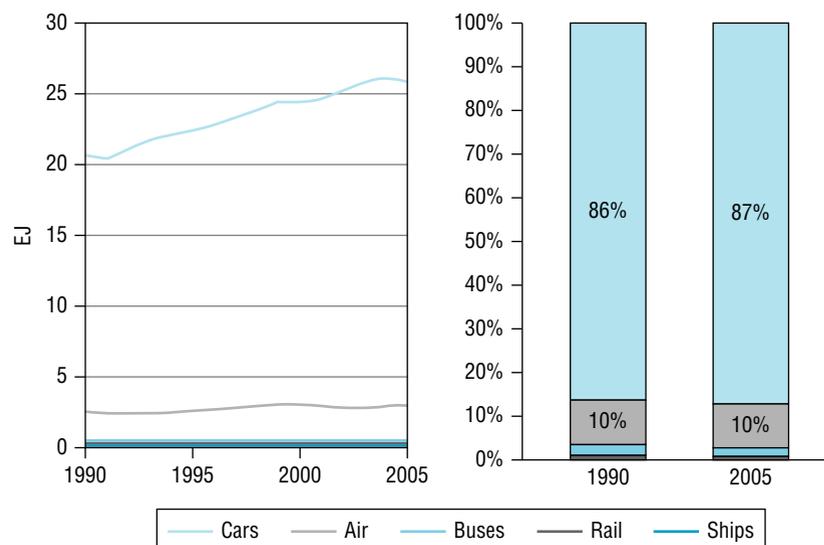
B. Personal Modes of Transportation

In 2005, passenger travel energy use was 30 exajoules, which represents an increase of 24% since 1990. More than 2.1 gigatons of carbon emissions are generated through passenger travel. As Figure 13-2 indicates, automobile transportation accounts for 87% of energy use. Buses, rail, and passenger ships together represent 3% of final energy use, and domestic air travel accounts for the remaining 10%.

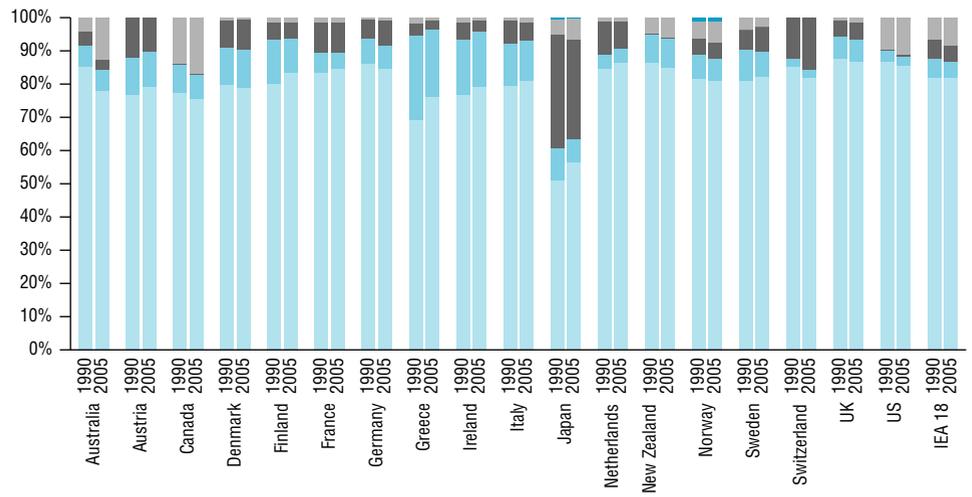
Figure 13-3 indicates that the high percentage of auto travel is consistent across these mature economies. With the exception of Japan, auto travel accounts for at least 75% of passenger travel among countries analyzed by the International Energy Agency. Across countries in the analysis, auto travel accounted for 82% of passenger kilometers in 1990 as well as in 2005. Since 1990, per capita increases in car passenger travel have increased on average 1.1% per year, and air travel has increased by 2.7% per year. Although there have been increases in the amounts of auto travel, these improvements have occurred simultaneously with increases in auto efficiency. Nevertheless, higher passenger transport energy use is associated with a 23% increase in auto-related carbon emissions since 1990. Carbon emissions are greatest in Australia, the United States, and Canada, where vehicles are larger and heavier and travel distances are longer. In contrast, countries such as the Netherlands and Japan have higher population densities and lower levels of travel per capita.

Political aspirations and gas economy have at times been at odds since the 1973–74 oil embargo. This embargo sent a message that countries need to be conservative

FIG. 13-2
Passenger Transport
Energy Use by Mode,
IEA18



Source: International Energy Agency, *Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis* (Paris: France, © OECD/IEA, 2008), figure 6.8, page 65.

FIG. 13-3 Share of Total Passenger Travel by Mode

Source: *International Energy Agency, Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis (Paris: France, © OECD/IEA, 2008), figure 6.4, page 61 (2008)*

in their use of oil and seek alternative sources of energy. In the United States, Congress passed the 1975 Energy Policy and Conservation Act that required the doubling of fuel efficiency to 27.5 miles per gallon by 1985.¹⁰ These fuel efficiency ratings are referred to **corporate average fuel economy (CAFE)** standards. The ratings for automobiles are higher than those for light trucks and SUVs for automobiles.

Although energy efficiency increased, President Reagan rolled efficiency back to 26 miles per gallon. Over the next two decades, the United States witnessed very few modifications to these fuel requirements. Congress deliberated on occasion about the most efficient manner by which to induce conservation efforts. Enhancements to the corporate average fuel economy have been discussed as alternatives to higher gasoline taxes, but the U.S. government has done little to intervene via either mechanism during this era.¹¹ In 2003, fuel economy standards in China moved ahead of U.S. standards¹². It was not until 2007 that Congress moved U.S. standards back to 35 miles per gallon, but this standard is not enforceable until 2020. The United States' 35-mile-per-gallon standard is in the proximity of the standards already in place in Japan and Europe.¹³

The amount of energy used has been increasing, yet the energy use per passenger kilometer is declining. People are traveling more, but technology has enabled individual modes of transportation to run more fuel efficiently. *Car ownership* similarly influences energy consumption. In most IEA countries, the percentage of ownership has increased over the past 15 years, and this increased car ownership generally is associated with higher per capita car energy consumption. *Car usage* refers to the distance traveled by each car. Car usage has fallen as more households increasingly own more than one car. When homes own multiple cars, journeys are shared between cars and travel per car declines. Car ownership and usage provide the total distance traveled per capita. In most IEA countries, reductions in the fuel intensity of cars were not sufficient to offset the increases in car ownership and car use. Thus, car energy use per capita increased in most IEA countries. The exceptions to this were Canada, Finland, Germany, Norway, and the United Kingdom.¹⁴

Efforts to reduce emissions in the transportation sector must recognize that changing transportation energy use takes time.¹⁵ For example, autos and light trucks ordinarily last about 15 years, whereas new aircraft are typically in use for 20 to 35 years. Passenger cars are completely redesigned approximately every eight years, but the essential technologies are in place three years prior to bringing the car to market. New technologies, therefore, often take up to 10 years to be implemented fully into production. In addition, retail marketing must make new fuel technology (e.g., low-sulfur diesel fuel) available across a market.

Given that auto-related usage continues to dominate the transportation sector, one must consider ways to reduce consumption. These ways include changes in personal transportation devices and increased use of mass transit. Personal, motorized modes include diesels, hybrids, and enhanced gasoline technologies. Other technologies (e.g., electric vehicles, natural gas, hydrogen fuel cells) have been proposed as alternatives to gasoline, but these concepts are not currently available at a price level that would capture appreciable market share. The percentage of each diesel, gasoline, and hybrid technology varies markedly from market to market. Although the North American market remains a gasoline market, diesel engines have the dominant market share in Europe.¹⁶ Consider first the use of diesel engines.

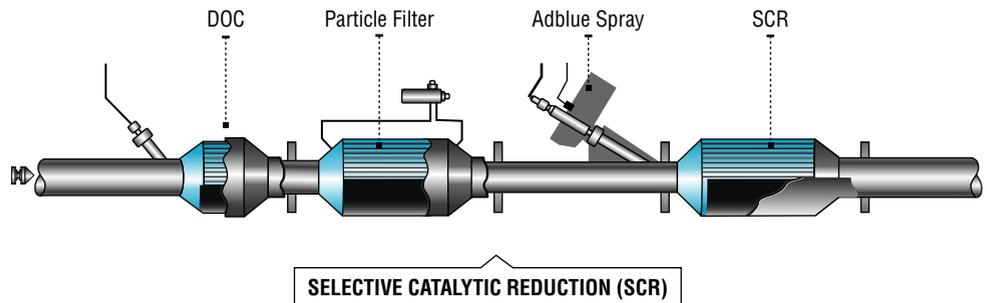
Diesel

The **diesel engine** was invented by Rudolph Diesel in the 1880s as an alternative to steam and gasoline engines.¹⁷ The gasoline engine and diesel developed over time, but for many years the choice between diesel and gasoline technology was a simple decision. While the diesel engines of 20 years ago had better fuel efficiency than gasoline engines, they produced significant amounts of soot. In addition, they were noisy and offered lower pickup relative to gasoline engines.

In order to appreciate the advantages of diesel over gasoline, it is valuable to examine the basic operation of each motor. Both gasoline and diesel engines are internal combustion devices, and both engines use the standard piston-based cylinder engine block. The combustion process is different for the two engines. In a gasoline version, the engine intakes a mixture of gas and air, compresses it, and then ignites the mixture via a sparkplug. In diesel motors, no sparkplug is required because the fuel is ignited by the high temperature generated during compression. Diesel fuel is a heavier and less volatile mixture of hydrocarbons than gasoline and therefore offers more energy per gallon than gasoline. Diesel engines have higher compression ratios, more rapid combustion, and leaner operations. Consequently, diesel engines offer greater thermodynamic efficiency and lower fuel consumption than gasoline engines.¹⁸

Diesel technology has changed dramatically over the past 15 years, and the changes make these new vehicles viable alternatives to gasoline engines. The first issue with diesel has been the high level of sulfur produced by the engines. The U.S. Environmental Protection Agency (EPA) mandates of 2006 required oil refiners to produce a clean diesel fuel with sulfur concentrations no greater than 15 parts per billion. This mandate reflects a 98% improvement over 1970s-era diesel output. The result is substantially lower levels of sulfur dioxide pollutants, and lower sulfur in the air means less acid rain and better engine performance.¹⁹ The exhaust systems also eliminate sulfur and other harmful nitrogen oxide compounds.

A second concern with diesel has been the soot produced by these engines. Diesel soot is **particulate matter**, a mixture of solid and liquid material made up of carbon particles, hydrocarbons, and inorganic material. The American Lung Association

FIG. 13-4 Diesel Exhaust Systems

Source: Adapted from Hewitt (2008)

reports that short-term increases in exposure to particulate matter have been linked to death from respiratory and cardiovascular causes, including strokes, increased numbers of heart attacks, inflammation of lung tissue, and aggravated asthma attacks. Long-term exposure has been associated with increased hospitalization for asthma, stunted lung function growth in children and teenagers, damage to the small airways of the lungs, increased risk of heart attacks and strokes, increased risk of dying from lung cancer, and greater risk of death from cardiovascular disease.²⁰ The U.S. EPA estimates that more than 4,700 premature deaths occur each year in just nine cities analyzed (Detroit, Los Angeles, Philadelphia, Pittsburgh, St. Louis, Boston, Phoenix, Seattle, and San Jose).²¹ The exhaust systems on new diesel motors ensure that the limited levels of soot enter the atmosphere. The selective catalytic reduction (SCR) exhaust system outlined in Figure 13-4 illustrates these enhancements. Initially, the exhaust runs through a diesel oxidation catalyst that minimizes hydrocarbons and carbon monoxide. In the next phase, a urea-based solution is sprayed onto the exhaust flow. The hot exhaust air transforms the urea into ammonia and mixes with nitrogen oxides in the SCR, where the mixture converts to water vapor and harmless nitrogen gas.

These enhancements complement other inherent advantages to diesel power. One of the advantages offered by diesel is the potential to refine the fuel from a variety of sources. The fuel can be derived from crude oil, but it can also be processed from bio waste. Biodiesel is made through a chemical process in which fat or vegetable oil is separated into methyl esters (biodiesel) and glycerin (a by-product used in soaps and other products). In North America, most biodiesel is made from soybean oil, but in Europe rapeseed (canola) oil is the most common source. Biodiesel is biodegradable, nontoxic, and essentially free of sulfur and aromatics.²²

The performance advantages of diesel engines are also noteworthy. The higher compression ratios of these motors mean more energy is derived from the air/fuel combination, and the car also enjoys relatively better power than one powered by a gasoline engine. Although the higher compression ratio means that engines require heavier crankshafts and connecting rods, the stronger design and the low coefficient of friction result in engines that last longer. It is not uncommon to see these engines operating for well over 200,000 miles. Mercedes-Benz, for example, has High Mileage Awards for cars that achieve the 250,000, 500,000, 750,000, one million-kilometer and one million-mile marks. Gregorios Sachinidis, a Greek taxi driver who has driven his 1976 Mercedes-Benz 240 diesel more than 2.8 million miles, is the reigning high mileage champion.

The new fuel systems, the enhanced exhaust mechanisms, the enhanced fuel injection operations, and the inherent physical advantages have resulted in a renaissance for this engine. The initial market for the diesel has been Western Europe. In 2006, diesel engines outsold gasoline engines for the first time in this region. The diesel engine accounted for less than 25% of auto sales in 1998, but this market share doubled in less than a decade. Consequently, most European, Japanese, and North American auto producers offer multiple diesel options in Europe, and these new diesel designs are entering into many other markets.

At the start of 2009, new diesel engine technology was being reintroduced to the United States market. In the United States, the standards established by the state of California are the most stringent, and 16 other states have adopted or have announced their intention adopt the California tailpipe standards.²³ The new diesel technologies offered by Mercedes-Benz, BMW, Honda, and other manufacturers now meet California standards and can be sold throughout the American market. Nevertheless, the market share for these cars is less than 3%.

The Volkswagen VW Jetta TDI exemplifies the challenges associated with marketing these new vehicles. Relative to its gasoline counterpart, the TDI (diesel) offers 30% more fuel economy, 25% less greenhouse gas emissions, and about 50% more power (torque). To the extent that the firm can inform consumers about the environmental and economic advantages of the cars, it has the potential to capture market share in the midsize sedan product class.

VW must contend with price, fuel availability, and quality perceptions. The price of diesel vehicles is due in part to their heavier, more expensive parts. Although the list price of the Jetta TDI is higher than the SE model, the diesel is eligible for a tax credit.²⁴ While some options on diesel vehicles are more expensive than on gas counterparts, the purchase price of this car is not appreciably different. In addition, the resale price of a diesel is expected to be high, but there is no basis for comparison yet in North America.

The other salient price issue concerns the availability and cost of diesel fuel. Of the 175,000 gas stations in the United States, only 45% carry diesel fuel. Moreover, the price of diesel fuel is higher than that of gasoline, and the demand for diesel has been increasing at a more rapid rate. In December 2008, the average price for gasoline in the United States was \$1.69, whereas the per-gallon price for diesel fuel was \$2.45. Thus, the diesel owner pays a higher price for fuel, but the car offers better fuel efficiency and performance. Furthermore, the tank of fuel will take the driver a longer distance in the diesel engine.

While consumers undoubtedly weigh the initial and fuel costs of operations, there remains a substantial portion of the population with strong negative perceptions of diesel cars. These consumers may be previous owners of VW Golfs or Mercedes 240 from an earlier era of diesel technology. The challenge will be to change consumer perceptions of this technology. Manufacturers such as BMW are touting the ecological (low carbon emissions) value of their products as well as the fuel efficiency.

Hybrids

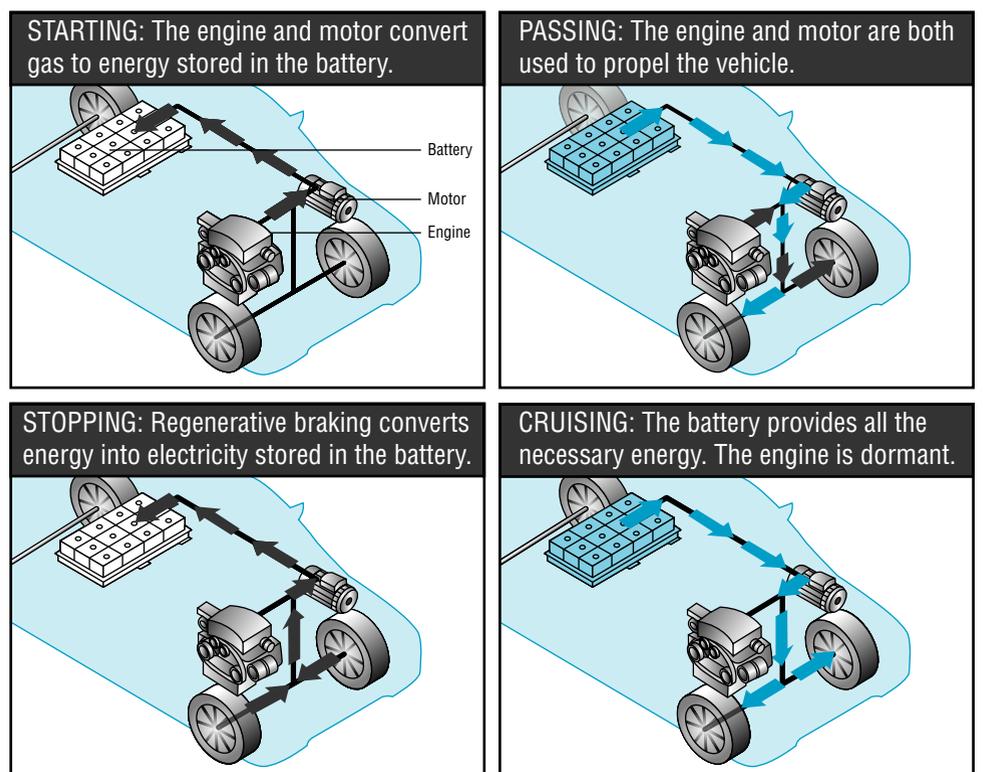
Hybrid technology has drawn substantial attention in North America despite modest sales levels. In 2007, hybrids accounted for 2.6% of the market—a level exceeded by diesel engines.²⁵ Toyota boasts that 10% of its sales are associated with hybrids, but most other manufacturers do not report significant levels of hybrid sales. Estimates indicate, however, that hybrid sales will account for 14% of the worldwide market for automobiles by 2020.²⁶

In order to understand the advantages of hybrid vehicles, it is valuable to examine the manner by which these engines convert and store energy. Hybrid technology includes the standard **hybrid engine** and the plug-in hybrid. Figure 13-5 illustrates the four phases of engine operations for a standard hybrid engine. The hybrid system adds two pieces of equipment—an electric motor and fuel cells. At the point of ignition, the engine sends energy to the electric motor and drive train. The electric motor sends this energy to the fuel cells. During acceleration, energy is provided to the drive train via the electric motor and **gas engine**. When the vehicle is cruising, the gasoline engine is not in operation, and energy is provided by the fuel cells. Finally, the hybrid engine has the ability to capture the energy from the operation of the brakes and store this energy in the fuel cells.²⁷

The standard hybrid offers some advantages and disadvantages relative to gasoline engines. First, the hybrid uses a much smaller engine than the typical gasoline engine. Larger engines require more fuel to carry them, limit acceleration, and use more energy while idling. The lighter engine is complemented with lighter materials throughout the car, and these lighter materials also reduce energy needs. In addition, the plug-ins take advantage of advanced aerodynamics and low-rolling-resistance tires that contribute to fuel efficiency.²⁸

The hybrid engine outperforms the gasoline engine, but for many consumers, the performance advantages do not motivate consumption. Analysts in the auto industry recognize three niche markets for hybrids.²⁹ Environmentalists are those motivated based on the ecological benefits of the product. A second group of

FIG. 13-5 Hybrid Engine Operations



Source: Adapted from <http://www.hybridcars.com/2010> Hybridcars.com, (accessed January 29, 2009)

consumers is motivated to buy them primarily as a fashion statement. The third market is people who budget for gas and do the calculations to determine whether the purchase is economical as well as ecological.

The plug-in hybrid has the advantages of the hybrid but also enables the owner to obtain electricity from a power outlet rather than from the gasoline engine. The use of the power outlet enables the *charged* hybrid to run for some period of time without using gasoline. For example, the 2009 Ford Escape plug-in uses high-voltage lithium-ion batteries that enable the vehicle to travel up to 30 miles on battery power alone.³⁰ Plug-in technology is in its infancy, but the fuel efficiency advantages of this technology are noteworthy. The Toyota Prius averages 42 miles to the gallon, but the plug-in averages 67 miles per gallon.³¹ When the cost to refuel batteries is included, the plug-in averages 53 miles per gallon.

There are notable limitations on this technology in its current form. First, the increased battery usage results in a smaller weight capacity in which four or five adults may overload the vehicle. Second, the current cost to modify a hybrid for plug-in use can exceed \$10,000. At \$4 per gallon for gas, the cost to operate the standard Prius is about 10 cents per mile, but the plug-in cost is about 8 cents per mile. At this 2-cent differential, the break-even point for the plug-in is 500,000 miles. Without rebates or tax incentive, hybrids will not be economical for many consumers.

Enhanced Gasoline

Consumers interested in enhancing fuel efficiency do not necessarily need to move away from gasoline engines. Fuel efficiency can economically be enhanced by buying smaller-engine vehicles, using ethanol, and purchasing cars with new fuel injection systems.

It may seem obvious that one way to enhance fuel efficiency is to buy a smaller vehicle that has much better fuel economy. Given that government average fuel economy requirements are increasing, most manufacturers are bringing new fuel-efficient gasoline-based cars to market. For example, BMW's Mini Cooper has a list price of \$19,200 and averages 32 miles per gallon in the city. The entry-level BMW 328i series (automatic) has a list price of \$33,600 and averages 19 miles per gallon. Thus, one way to lower one's footprint and cut costs is by moving to smaller vehicles.

A related option is to consider the form of gasoline used by new vehicles. Flex fuel cars are designed to run on gasoline or a mixture of gasoline and ethanol.³² Ethanol is a renewable fuel that comes from agricultural feedstocks. Using ethanol results in less pollution and reduces smog-forming emissions by as much as 50% relative to gasoline.³³ Despite the limits on emissions, ethanol has a few limitations. Using corn for fuel rather than food reduces the supply of food without complementary increases in the supply of energy. For example, the United States used 20% of its 2007 corn harvest to produce less than 4% of the demand for auto fuel.³⁴ In some markets, the price of ethanol is greater than that of gasoline, and it is only widely available in the Midwestern United States. Finally, the mixture of gasoline and ethanol contains less energy than a gallon of gas. Consequently, these engines have 20 to 30% lower fuel efficiency when operated using ethanol.

Auto manufacturers are also making improvements in gasoline engines to make them more fuel efficient.³⁵ Ford Motor Co. recently introduced an EcoBoost direct-injection technology that offers greater performance and a 20% increase in fuel economy over comparable traditional engines. By 2012, Ford expects to produce

750,000 EcoBoost vehicles annually worldwide. Ford claims that the premium for EcoBoost—a price Ford has not disclosed—is a better value than a hybrid or diesel. General Motors is also using new direct-injection engines in about 10% of its global production.

Of course, there are multiple technologies in development designed to enhance auto fuel efficiency. Mercedes-Benz, GM, and other makers are developing gas engines that use a homogenous-charge compression-ignition (HCCI) technology. HCCI provides substantial boosts in fuel economy by burning gas faster at lower temperatures and by reducing some of the energy lost during the combustion process. This technology and other digital components will increase the viability of gasoline engines that will be around for the foreseeable future.³⁶

One of the simplest and most cost-efficient means by which to save energy in the auto sector is the education of drivers. Although many U.S. state programs instruct new drivers about fuel efficiency, there is substantial degradation of fuel efficiency apparently due to lost enthusiasm and learning loss by drivers.³⁷ Table 13-1 outlines a number of strategies that drivers can implement to reduce the amount of gasoline used by their vehicles.

TABLE 13-1 EFFICIENT AUTOMOBILE OPERATIONS³⁸

Vehicle Operations

- a. Observe the speed limit and maintain a steady pace. Excessive speed is inefficient and requires more energy for stopping.
- b. Extend one's vision 10 to 12 seconds down the road and anticipate stops as far ahead as possible.
- c. Avoid tailgating; it reduces chances for planning economic modes of driving.
- d. Adjust driving habits to changing road conditions.
- e. Use air conditioning at higher speeds and keep the windows closed. Avoid air conditioner use at lower speeds.
- f. Instead of heavy braking, take advantage of rolling resistance to help slow down. This technique saves a lot of fuel.
- g. Before turning off ignition, turn off all power-consuming accessories (e.g., air conditioning). This action minimizes engine load during startup.
- h. Avoid revving the engine just before turning off the ignition; it costs extra fuel and can cause engine damage.
- i. Limit idling time to 30 seconds, but restarting the engine within 8 to 10 minutes causes little engine wear.
- j. Avoid unnecessary steering wheel movement; sideward movements cause fuel-consuming drag.
- k. Slowly accelerate on slippery pavement and gravel roads.
- l. Avoid quick starts and unnecessary braking.

Vehicle Maintenance

- a. Change oil regularly; dirty oil increases friction and engine wear.
- b. When possible, use multiviscosity motor oil.
- c. Regularly check points and plugs.
- d. Upon fill-up, check the engine oil, coolant, transmission fluid, and battery levels.
- e. Maintain proper wheel alignment.
- f. Maintain tires at maximum pressure, and check pressure when tires are cold.
- g. Reduce the engine's idling speed.
- h. Regularly replace air and fuel filters.
- i. Adjust the automatic choke for proper operation.
- j. Monitor the positive crankcase ventilation (PCV) valve regularly.
- k. Assess carburetor, fuel pump, gas line, and gas tank fuel leaks.
- l. Regularly lubricate the axle and wheel bearings.

Trip Planning

- a. Make sure your vehicle is safe and economically road ready for long trips.
- b. Consolidate short trips to avoid as many cold starts as possible.
- c. Record and monitor gas mileage.
- d. Avoid idling by starting the engine when actually ready to go.
- e. Whenever possible, use the telephone rather than making a trip.
- f. Plan routes to avoid traffic congestion.
- g. Carpool. Multiple parties in the car mean fewer auto trips.
- h. Carry as little extra weight as possible in auto's trunk.
- i. Park in the first reasonable parking place available.

Vehicle Choice

- a. Select a car with a high rear axle ratio and overdrive transmission.
- b. Avoid permanent roof racks and wide-tread tires.
- c. Consider radial tires.
- d. If more than one car is available, use the most economical one as much as possible.
- e. Avoid power-consuming accessories.
- f. Consider a diesel-powered or electric hybrid car.
- g. Choose a streamlined car with a small frontal area.
- h. Use automatic speed control.

Driver Attitude

- a. Always consider fuel economy when driving and drive for fuel economy.
- b. Avoid driving when angry or upset.
- c. Use public transportation whenever possible.
- d. Use a bike or walk for short distances.

Source: *Government of the District of Columbia*.

Importantly, the marketing efforts of auto manufacturers and auto dealers and the efforts of government can be focused on the continuous education of drivers regarding fuel efficiency. Estimates developed in the 1980s indicate that a 10% savings in fuel efficiency can be realized through proper vehicle operations, selection, and maintenance.³⁹ Despite recognition of the merits of conservation, large-scale efforts at continuing driver education have been absent in many markets.

Another means that drivers can use to enhance fuel efficiency is geographic positioning systems (GPS). Drivers equipped with GPS input an address and let the GPS sketch the route. Although these systems can draw the most efficient route, there is tremendous variability in their operations and routing procedures.⁴⁰ Nevertheless, GPS saves energy by indicating wrong turns and highlighting points of interest to consumers.

Another means for saving energy in the auto industry is ride share and carpool programs. Although there have been appreciable efforts to raise the number of shared rides, more than 10 trillion seats remain empty in car trips, and the average number of passengers per car trip marginally exceeds one passenger.⁴¹ One program that increases auto occupancy is **high-occupancy vehicle (HOV)** lanes. Several states have implemented these HOV on freeways to reduce people-hours of travel without significantly increasing vehicle-hours of travel.⁴²

C. Mass Transit

There is a growing consensus that between one fourth and one half of the recoverable resources in conventional oil have been consumed, and the halfway point will be reached in the next 5 to 25 years.⁴³ The use of oil for transportation can be reduced not only through personal modes, but also via mass transportation systems.

Among the International Energy Agency's 18 countries, nonauto transportation currently accounts for 13% of energy consumption. Ten percent of this transportation is associated with domestic air travel.⁴⁴ Together, buses, passenger rail, and passenger ships account for about 3% of energy consumption.

Improvements to mass transit systems are rarely due to progress in one mode of transportation, but often involve consideration of the connecting points among alternative transportation modes. Progress, therefore, is not solely due to the advent of new technology. The effectiveness and performance of these systems is measured in passengers carried, ridership growth, travel speeds, and land development effects.⁴⁵ It can take appreciable amounts of time to integrate new technologies into transportation grids. In the following section, underscore trends in air, bus, and rail technology that have potential to reduce carbon emissions in the transportation sector. Consider first air transportation.

Air Travel

A recent study from the Intergovernmental Panel on Climate Change (IPCC) estimates that the aviation contribution to global warming is 3.5% of the sum of all anthropogenic effects and projects that this contribution will grow.⁴⁶ In the United States, air travel has increased at an average annual rate of more than 5% per year since 1970. Passenger miles per gallon for commercial air travel, however, have increased by 150% since 1975. This increase is primarily due to energy efficiency improvements, but is also associated with increased occupancy rates. Although local, federal, and international entities pressure the aviation industry to enhance fuel efficiency, most efficiency enhancements have been driven by profit motives rather than by regulation.⁴⁷

Peculiarities of air travel contribute to the emissions. More than 90% of the exhaust emitted from aircraft is in the form of oxygen or nitrogen. About 7% of the exhaust is composed of CO₂ and H₂O, and another 0.5% is composed of NO_x, HC, CO, SO_x, other trace chemical species, and carbon-based soot particulates. The combination of these gases is estimated to be a factor of more than 1.5 times that of carbon dioxide alone. The majority of aircraft emissions are injected into the upper troposphere and lower stratosphere at altitudes ranging from 5 to 8 miles above Earth. Consequently, the influence of burning fossil fuels at these altitudes is approximately double that due to burning the same fuels at ground level.

Reductions in climate effects require consideration of the *technological performance* of aircraft as well as the *operational activities*. New technologies from manufacturers have reduced emissions and achieved the largest reductions in energy intensity of any transportation system. These include enhanced engine designs, aerodynamic efficiencies, and structural efficiencies.⁴⁸ For example, Boeing is committed to improving the fuel efficiency of each new generation of commercial airplanes by at least 15%.⁴⁹ Boeing's 787 Dreamliner incorporates new engines, increased use of lightweight composite materials, and modern aerodynamics that yield improvements in fuel use and reductions in carbon dioxide emissions.

Operational activities also contribute to an aircraft's carbon emissions. Airlines have increased the number of seats on each plane by more than 35% since 1950, and they have increased the load factor, or percentage of occupancy, by 15%.⁵⁰ When more people are on a flight, the relative cost of travel is lowered.

Airlines and airports can enhance efficiency by reducing the amount of time that planes are idling on the ground or in holding patterns in the air. The International Air Transport Association (IATA) estimates that air traffic management enhancements

FIG. 13-6 Boeing
787 Dreamliner



Source: © AFP PHOTO/THE BOEING COMPANY/Newscom

could improve fuel efficiency and reduce carbon emissions substantially.⁵¹ Boeing has developed a Tailored Arrival concept that increases airplane arrival efficiency via continuous (versus step-down) descent that lowers fuel usage, noise, and emissions.⁵² Boeing's initial trials suggest that advanced arrival techniques can save up to 800 gallons of fuel per flight and save airlines up to \$100,000 annually in fuel costs per aircraft flying into major airports.⁵³ Airlines and airports also benefit from quick turnaround at the gate. Southwest Airlines, for example, uses quick turnaround at the airport terminal as a strategic competitive advantage. Quick turnaround lowers operational costs and raises customer satisfaction.⁵⁴

Enhancements in technology and operations are essential to the future of air travel. Historically, air transportation growth (5.5% per year) has outpaced reductions in energy consumption (3.5% per year), and research suggests that this trend will continue into the foreseeable future.⁵⁵

High-Speed Trains

Since the introduction of the Shinkansen high-speed train service between Tokyo and Osaka, Japan, in 1964, the **high-speed train** (HST) has increasingly become a vibrant part of transportation in many parts of the globe.⁵⁶ *High-speed trains* are a family of technologies that provide high-capacity, frequent railway services achieving an average speed of more than 200 kilometers per hour (124 miles per hour).⁵⁷

HSTs have been widely used in Asia and Europe and have also been proposed or implemented in the Middle East as well as South and North America. The advent of HST has brought to consideration trade-offs between compatibility and speed. The original Shinkansen HST achieved a speed in excess of 200 kilometers per hour, but it required special tracks due to the narrow design of the light rail system. Other systems developed since the Shinkansen have utilized existing track to varying degrees. The ability to use existing track results in lowered costs of implementation but limits the returns from the HST operations.

As we discussed earlier in this section, cost-benefit analysis of a mode of transportation is context specific and requires consideration of the interface between modes of transportation. Nevertheless, there are some notable benefits associated with HST. Since introduction, these systems have been designed to increase capacity. In the short term, the introduction of another mode of transportation increases the opportunities to travel. The costs of alternative reasonable travel modes and travel conditions influence long-term term capacity and acceptance of HST.

A second notable advantage is the reduced travel time relative to other rail systems. The Shinkansen line reduced rail travel between Osaka and Japan to 2½ hours from 7 hours.⁵⁸ HST draws travelers from trains, but it also gains travelers from air and car travel. For example, an analysis of the potential of the HST to free runway capacity at London Heathrow indicates that the HST could lead to travel time savings on 10 routes currently served from the airport.⁵⁹ If the airport became a rail station, the substitution of HST for air travel would eliminate about 20% of its Heathrow's runway capacity.

The third important benefit of HST is the safety record of these train systems. In most markets, these trains offer substantially greater safety records than any alternative mode of transportation. Japan's Shinkansen HST, for example, has not had a fatality over the 45 years of operation.⁶⁰ Although Japan is noted for the high incidence of earthquakes, these catastrophes have infrequently lead to derailments and never resulted in fatalities.

Although there are substantial benefits to HST, there are some notable environmental outcomes.⁶¹ Because HSTs are predominantly electric powered, emissions are related to sources used to generate the electricity. HST operations increase local air pollution, climate change, noise, and land conversion. The most harmful pollutants related are sulfur dioxide (SO₂) and nitrogen oxides (NO_x). Although evidence suggests that HST operations have a smaller influence on environment than the aircraft and the car, because the environmental influence of HST and other modes depends on infrastructure and interface to other transportation modes and services, the environmental trade-offs between HST and other modes remain unclear. The merits of HST depend on balance between the amount of travelers that substitute HST for air or auto travel versus the amount of new traffic generated by HST.

Rapid Transit

Since 1995, public transit use has increased by 20%, yet it still only accounts for about 1% of total passenger miles. One technology that has drawn substantial recent attention is **bus rapid transit (BRT)**. BRT is a rubber-tired rapid transit mode that combines stations, vehicles, services, running ways, and intelligent transportation system (ITS) elements into an integrated system.⁶² BRT systems and features have been implemented in South America, Europe, and Australia, and BRT systems are integrated into urban planning programs in more than 20 cities in the United States and Canada.⁶³

BRT offers a number of benefits. First, these bus-based systems can be flexibly integrated into existing transportation routes. In congested areas, rapid bus lines can be integrated at relatively lower cost than alternative transit systems such as light rail. Second, digital operating systems used in BRT systems provide increased service quality in terms of on-time performance and speed. For example, the BRT line on Wilshire Boulevard in Los Angeles operates at speeds that are 75% faster than local service.⁶⁴ The introduction of BRT systems also has been associated with increased patronage. In Brisbane, Australia, for instance, bus ridership was up 40% in the six months after the introduction of a BRT system.⁶⁵

Rapid transit system designers have also benefitted by using some of the attractive components of light rail systems throughout bus routes. Thus, BRT systems emphasize simple and direct routes. In addition, they emphasize the permanency of routing and ease of use. Not surprisingly, these features, along with speed of transportation, increase the attractiveness of BRT to consumers.⁶⁶

Together, these benefits yield lower carbon footprints for communities. The carbon footprint per capita for the bus is substantially lower than the footprint for auto travel. Each time someone elects to ride rather than drive, the footprint is lowered.

Due to the popularity of BRT, a number of applications with varying benefits have adopted this term.⁶⁷ The Orange Line in Los Angeles is a full-scale BRT because it incorporates all facets of BRT systems—including dedicated bus lanes with intelligent transportation systems, full-scale stations, low floor/level boarding, branded vehicles, and off-vehicle ticket vending. In contrast, partial BRT systems run part of their routes in city streets and part of their routes in dedicated transit lanes. They offer most of the other amenities and efficiencies of full BRT systems. For example, the Euclid Busway in Cleveland combines in-traffic operations with single bidirectional dedicated lanes. Other rapid bus systems do not employ most BRT benefits but are primarily express buses. Although they may employ intelligent transportation systems, they do not operate via dedicated traffic lanes.

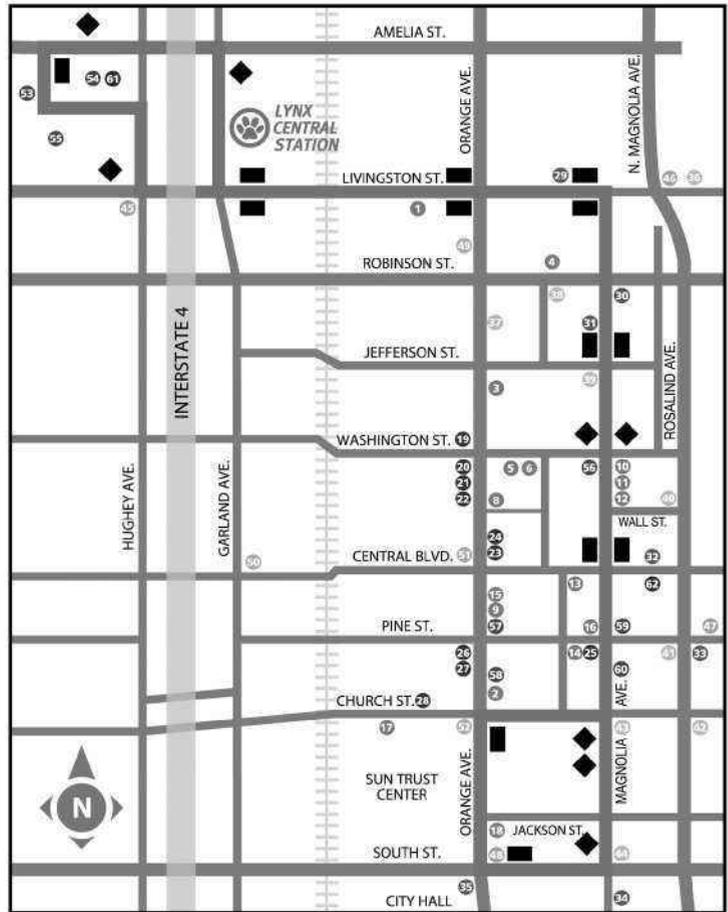
FIG. 13-7 Los Angeles MTA Valley College Stop



Source: © *Jeremy Oberstein*

FIG. 13-8 Orlando's Lymmo Bus Rapid Transit

- RESTAURANTS**
- 1 East Side Cafe
- 2 Urban Flats
- 3 Annie's Cafe
- 4 Java Lava Coffee Shop
- 5 Season's Harvest
- 6 Sushi Hatsuz
- 7 Subway
- 8 Koho
- 9 Thai Cafe
- 10 Philly Steak and Hoagies
- 11 Daily News Cafe
- 12 Crooked Bayou
- 13 Napsorn Thai Restaurant
- 14 The Pita Pit
- 15 Breakfast Club of Orlando
- 16 Amura
- 17 Starbucks
- NIGHTLIFE**
- 18 Bar 8 Que Bar
- 19 Independent Bar
- 20 The Social
- 21 Tabu
- 22 One-Eyed Jack's
- 23 Wall Street Cantina
- 24 Pine Street Bar & Grill
- 25 Tanqueray's
- 26 Vintage
- 27 Chiller's
- GOVERNMENT**
- 28 Orange County Courthouse
- 29 Legal Aid Society
- 30 US Post Office
- 31 Orange County Library
- 32 Orange County Administration Bldg.
- 33 Fire Station No. 1
- 34 Orlando City Hall
- CHURCHES**
- 35 Trinity Lutheran
- 36 St. James Catholic Cathedral
- 37 Catholic Diocese Offices
- 38 St. Luke's Episcopal
- 39 St. George Orthodox
- 40 Downtown Baptist Church
- 41 St. Paul's Lutheran
- 42 First Presbyterian
- 43 First United Methodist
- HOTELS**
- 44 Marriott Downtown
- 45 Travelodge
- 46 Embassy Suites
- 47 The Grand Bohemian
- BANKS**
- 48 Bank of America
- 49 Fairwinds Credit Union
- 50 Wachovia Bank
- 51 Sun Trust
- ARTS/MUSEUMS**
- 52 Amway Arena
- 53 SAK Comedy
- 54 Bob Carr Auditorium
- 55 Orange County History Center
- 56 City Arts Factory
- 57 Plaza Cinemas
- 58 Gallery at Avalon Island
- 59 Mad Cow Theatre
- PARKING GARAGES**
- 60 Centroplex Garage
- 61 Library Garage



■ LYMMO Station ◆ LYMMO Stop ♿ All LYMMO buses are wheelchair accessible.

Source: Courtesy of LYNX (www.golynx.com)

The introduction of BRT must be accompanied by appropriate marketing efforts to ensure patronage.⁶⁸ These BRT systems should have a unique and consistent brand image. For example, the Lymmo system operated in downtown Orlando is a BRT system that operates within the city's Linx transit program. The Lymmo signs use attractive and distinct lettering that distinguish the Lymmo system from the rest of transit operations. BRT systems should also promote rider awareness and usage via logos, color combinations, and graphics that are applied consistently to vehicles, stations, and printed materials. Thus, the Orlando Lymmo buses use distinctive colors and the Lymmo logo consistently throughout their routes. Promotional programs also should include public information, service innovation, and pricing incentives. As Figure 13-7 illustrates, Orlando's Lymmo provides information that links the BRT system to points of interest as well as to other modes of transportation. In addition, the free cost of this system to consumers is emphasized throughout promotional materials.

The introduction of BRT to Orlando has reaped many benefits. The city enjoys reduced congestion and reduced parking demand in the downtown area. Lymmo has also encouraged more transit use and increased mobility and accessibility to major downtown destinations. Moreover, BRT has enhanced public perceptions of downtown Orlando and allowed for additional downtown development capacity.⁶⁹

D. Freight Transportation

Within the transportation sector, freight accounts for 30% of energy consumption among the International Energy Agency's 18 countries. Freight transport energy use was 18 exajoules, and this consumption level was 27% greater than the level in 1990.⁷⁰ Freight includes the transport of products by highway, air, rail, sea, and pipeline. At 99% of total final energy consumption, oil is far and away the fuel of choice for moving freight. Most of this fuel is some form of diesel. Diesel fuel represents 87% of trucking and 88% of rail transport. Ships use fuel oil (59%) and diesel fuel (41%) to move products across waterways. Because the movement of freight via rail, water, and pipeline is relatively energy efficient, our analysis focuses on the highway sector.⁷¹

Movement of freight via highways occurs via light, medium, and heavy-duty trucks.⁷² Light trucks include utility vans and step vans, whereas medium-sized trucks include walk-in trucks, city delivery trucks, school buses, and beverage delivery vehicles. Between 1990 and 2000, light truck energy use grew at a faster rate than for any other mode.⁷³ Together, light and medium-sized trucks use about 26.8 billion gallons of fuel per year. Heavy-duty vehicles include refuse trucks, dump trucks, cement trucks, and conventional semi-trailers. These trucks use about 10.6 billion gallons of fuel per year.

Since 1975, the amount of energy required to move a ton of freight has been cut in half.⁷⁴ Enhancements in the efficiency of freight transportation are associated with engine systems, heavy-duty hybrids, parasitic losses, idle reductions, and safety considerations.⁷⁵ Consider first technological enhancements to engine systems.

Engine systems are inextricably related to pollution, emissions, oil dependency, and safety. Twin goals of engine systems are to lower emissions and improve thermal efficiency of engine operations. Over the past two decades, NO_x and particulate matter have been decreased 85% and 95%, respectively. Today's state-of-the-art highway trucks achieve 42% thermal efficiency—thus 58% of the energy is not converted to mechanical work. In the United States, the goal is to achieve another 83% reduction in NO_x and particulate matter while simultaneously increasing thermal efficiency another 20% (resulting in thermal efficiency of 50%) by 2010.

A second initiative associated with engine operations is **hybrid electric vehicles (HEV)**. In heavy-duty hybrid trucks, two power sources are combined to obtain the required power to propel the vehicle. HEVs combine advantages of the electric motor drive and an internal combustion engine to propel the vehicle. The electric traction motor is powered from a battery pack that serves as a secondary energy storage device. The HEV also has the ability to absorb energy from the operation of the brakes and store this energy in the fuel cells. In a conventional vehicle, only 10 to 15% of the energy contained in gasoline is converted to traction, but the hybrid can potentially be improved to 30 to 40%. This increase in efficiency reduces emissions and increases fuel economy.⁷⁶ Regrettably, the development of heavy hybrid technology has not kept pace with advancements in passenger vehicles (e.g., Prius) and demands more research before commercialization.

The operations activities associated with a truck influence the potential to reduce energy consumption. Large trucks are not only the means of transportation for drivers, but they are also the homes for drivers on the road. **Parasitic energy losses** are energy losses incurred due to a number of factors that include aerodynamics, auxiliary operations, and other operations. Together, these constraints account for 40% of the energy used by heavy trucks. Improved technologies that limit energy use contribute to reductions in parasitic energy loss. The aerodynamics and rolling resistance of trucks can be enhanced somewhat, but the rectangular shape of the cargo area is a significant constraint. Auxiliary operations include heating, lighting, and on-board amenities (e.g., computers, entertainment systems, appliances). These ancillary activities also contribute to efforts to minimize idling. In many cases, the long-haul trucks stand in the idle position for more than six hours per day. This inactive time produces particulate matter, raises the level of noise, and consumes fuel. The energy cost of auxiliary functions can be reduced via technologies that reduce the power requirements associated with these operations. In addition, the time spent idling can be reduced by enhanced freight scheduling, new idling technologies, and turning trucks off.

In order to attract and retain competent drivers, it is essential that safety improvements accompany other efforts to enhance energy efficiency. Crash avoidance and survival are enhanced via advanced braking technologies, stability controls, lane-tracking systems, and video-based visibility systems. The introduction of these technologies can be incompatible with other efficiency goals given that many safety features increase the weight and reduce the aerodynamics of trucks. Therefore, strong coordination between safety and energy efficiency is critical to long-term sustainability concerns.

Summary

A. Introduction: Transportation Sector Contributors to Carbon Emissions

The purpose of this chapter has been to provide an overview of the role of transportation in energy consumption. Given that the transportation sector accounts for 26% of worldwide energy consumption, no review of energy is complete without analysis of transportation. We provided a summary of the energy use associated with passenger and freight transportation. In the process, we discussed efforts to enhance the fuel efficiency of alternative modes of transportation. Importantly, we highlighted opportunities to engage in green marketing action that contributes to energy conservation in transportation.

B. Personal Modes of Transportation

Passenger travel energy use has increased by 24% since 1990, and this increase has prompted substantial effort to reduce energy consumption associated

with personal transportation devices. Personal, motorized modes include diesels, hybrids, and enhanced gasoline technologies. Each of these innovations has benefits and limitations. Furthermore, the market share of each technology varies considerably across national and international market regions. The fuel efficiency of auto transportation can also be enhanced via increased educational efforts for drivers, new traffic plans (e.g., HOV), and improved energy utilization technologies.

C. Mass Transit

Mass transit includes travel via air, bus, and rail. The net result of burning fossil fuels in the air is double that of burning the same fuels at ground level. Reductions in climate effects for air travel require consideration of the technological performance of aircraft as well as the operational activities. New technologies from manufacturers have reduced emissions and achieved the largest re-

ductions in energy intensity of any transportation system. High-speed trains reduce travel time relative to other rail systems, are extremely safe, and use electricity that can be derived from replenishable sources. Bus rapid transit is a rubber-tired rapid transit mode that combines stations, vehicles, services, running ways, and intelligent transportation system elements into an integrated system. These buses can be flexibly integrated into existing transportation routes and provide increased service quality in terms of on-time performance and speed. Rapid transit system designers have also benefitted by using some of the attractive components of light rail systems throughout bus routes.

D. Freight Transportation

Enhancements in the efficiency of freight transportation are associated with engine systems, heavy-duty hybrids, parasitic losses, idle reductions, and safety considerations. Engine system enhancements seek to lower emissions and improve thermal efficiency of motor operations. Hybrid electric vehicles combine the advantages of the electric motor drive and an internal combustion engine to propel the vehicle. *Parasitic energy losses* are inefficiencies due to aerodynamics, auxiliary operations, and other operations. Idling can occur for many hours a day, and efforts are being made to reduce the particulate matter, noise, and fuel use created while idling. Safety considerations include crash avoidance technologies such as advanced braking and stability controls.

Keywords

bus rapid transit (BRT), 271	gas engine, 265	hybrid engine, 265
corporate average fuel economy (CAFE), 261	high-occupancy vehicle (HOV), 268	parasitic energy losses, 275
diesel engine, 262	high-Speed Trains (HSTs), 270	particulate matter, 262
	hybrid electric vehicle (HEV), 274	

Questions

1. The Siemens Sapsan example illustrates how new technologies can be applied to reduce carbon emissions. What is the influence of low oil prices on such efforts?
2. The Siemens example mentions 11 corridors that could use high-speed rail. Name three routes between major cities that would be candidates, and name one route that would not be a candidate. Explain your answers.
3. How have diesel technologies changed over the past few years?
4. What factors account for the poor acceptance of hybrid automobiles for personal travel?
5. What are the limitations associated with using corn as a fuel for automobiles?
6. Table 13–1 outlines a number of mechanisms designed to increase fuel efficiency of personal vehicles. How can these ideas be communicated to the public more effectively?
7. From a carbon footprint standpoint, what are the merits of jet travel versus high-speed train travel between Los Angeles and San Francisco?
8. Why is it necessary to examine the links between transportation systems to gain an understanding of usage and fuel efficiency?
9. To what extent has your community promoted use of mass transit systems? What could be done to enhance this effort?
10. About 40% of the energy consumed by a semi-tractor trailer is consumed when the vehicle is not moving. What contributes to this overhead cost, and what can be done to reduce this cost?

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- ⁷⁴ See Note 72 above.
- ⁷⁵ See Note 72 above.
- ⁷⁶ Ali Emadi and others, "Topological Overview of Hybrid Electric and Fuel Cell Vehicular Power System Architectures and Configurations," *IEEE Transactions on Vehicular Technology* 54, no. 3 (2005): 763–770.