INFORM
Strategies for a Better Tomorrow

Bus Futures 2006

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INFORM, Inc., is a national nonprofit environmental research and outreach organization that solves complex environmental and health problems through independent research aimed at practical solutions. Our goal is to identify ways of doing business that ensure environmentally sustainable practices and economic growth.

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Foreword

Between 2000 and 2006, the world changed in many fundamental ways, and during that time, public concern has focused on several major issues.

In 2000, environmental emissions were the primary concern; in 2006, imported oil was a key issue. The threat posed by dependence on petroleum-derived fuels became an immediate concern as oil prices rose to nominal record highs. Strong economic development in Asia, particularly in China and India, has increased competition for the world's limited oil supplies, placing the US in a precarious situation because of its heavy oil consumption. Greenhouse gases and global warming also became concerns as the record-setting hurricane season of 2005 drew attention to the potentially devastating consequences of climate change.

During this six-year period, the transit bus sector has encountered its own challenges because of intensifying competition in the market. Diesel buses have sought to retain their market share even as natural gas buses, hybrid buses and buses that run on biodiesel command an increasing percentage of the transit market. Ultimately, these changes in the bus sector can be seen in the context of achieving a long-term goal: developing transportation powered by pollution-free and renewable fuel sources.

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Preface

In 2000, INFORM released *Bus Futures: New Technologies for Cleaner Cities*, an in-depth analysis of available commercial bus technologies (compressed natural gas and diesel), developing bus technologies (hybrid-electric and fuel cells), and the emissions that they produce.

In *Bus Futures 2006*, INFORM first reviews the latest information about health, environmental, and energy security issues—information that provides a compelling case for transit agencies to use cleaner buses and fuels. Then we focus on the current state of the clean bus market, using statistics from the American Public Transit Association (APTA), the transit bus industry, and government sources to examine the progress that has been made in the development and commercialization of clean bus technologies. Looking to the future, we assess how these technologies can lead to the transportation sector's eventual embrace of hydrogen and fuel cell propulsion, which may one day constitute a truly sustainable form of transportation.

Specifically, chapter 1 analyzes the effects of diesel exhaust on human health and the environment, energy security issues, and regulatory action. Chapter 2 examines new diesel technologies, alternative fuels, advanced technologies, and government programs that offer financial incentives to encourage the use of alternative fuels and technologies.

The following four chapters provide detailed analyses of the mechanics, emission levels, performance levels, infrastructure requirements, and overall program costs associated with four types of alternative transit buses. Chapter 3 looks at compressed natural gas (CNG) and liquefied natural gas (LNG) buses. Chapter 4 examines transit buses powered by hybrid-electric technologies. Chapter 5 discusses transit buses that run on biodiesel or blends of diesel and biodiesel. Chapter 6 explores transit buses that run on hydrogen-powered fuel cells.

This report is written to help transit agencies, policymakers, municipal planners, and environmental leaders evaluate each of these bus options so they can make strategically sound, forward-thinking decisions and investments that achieve local transit service goals while meeting the interests of the public and the environment.

Introduction

Public transportation plays a vital role in urban life, each day carrying millions of people safely, efficiently, and reliably in metropolitan areas. It allows the public to travel from point to point without private automobiles. It alleviates congestion in increasingly crowded streets and provides on-demand mobility while stimulating community development and economic growth.

At this early point in the 21st century, the public's need for mobility has pushed mass transit ridership to its highest levels in 40 years. In 2004, according to the American Public Transportation Association (APTA), Americans took 9.6 billion trips using all forms of public transportation, including light and heavy rail, transit buses, and para-transit vehicles. This number is an increase of more than 2.1 percent over 2003 and an increase of approximately 23 percent since 1995.[1] In comparison, highway vehicles trips grew by only 1.1 percent.[2]

In the transit bus sector in 2004, ridership rose to 5.8 billion trips, a 1.7-percent increase over 2003. In general, bus travel remains the most popular form of public transit, representing more than 60 percent of passenger trips in the US.[3] Buses give transit agencies the capacity to carry millions of people from place to place with an over-the-road service that is versatile, flexible, accessible, and cost efficient. They serve a variety of access needs and travel along routes throughout metropolitan areas. In addition, buses travel on existing roadways and reach riders who may be beyond the range of other forms of mass transport.

But what will transit fleets look like in five years with regard to the kinds of buses and fuels they use? In 15 years? In 50? Can a single type of bus dominate the transit market as the conventional diesel bus has for most of the 20th century? Or will multiple fuels and technologies rise to prominence?

Before answering these questions, another question must first be considered: What is the ideal urban bus for transit agencies? It must be operationally capable, with the durability, reliability, and capacity to meet the demands of daily transit routes. It must be affordable to purchase and operate, and it must be supported by a strong fueling infrastructure. It must also offer the lowest possible emissions to address growing concerns about air pollution. Furthermore, it must be more fuel-efficient or, ideally, use a non-petroleum-derived fuel given the threat posed by our dependence on foreign oil.

Diesel fuel has been the preferred choice for bus service: it delivers power, reliability, fuel efficiency, and people-moving capacity at a relatively low capital cost and a reasonable per-gallon price. However, even though the performance of diesel buses has contributed to the success of urban transit systems, these buses have contributed to some of the most serious problems confronting urban areas—air pollution, respiratory ailments, and traffic noise. Moreover, because they travel long distances and have low fuel economies, buses contribute significantly to our dependence on imported oil and to climate change. For these reasons, the public and policymakers are putting increasing pressure on transit agencies to replace noisy, high-polluting, aging diesel buses with cleaner, quieter, more fuel-efficient models.

The evidence supporting the need to significantly reduce emissions from diesel buses—or to switch to cleaner technologies and fuels—is compelling. In 2002, a US Environmental Protection Agency (EPA) report concluded that long-term exposure to diesel engine exhaust likely poses a cancer hazard to humans and can damage the lungs in other ways, depending on level of exposure. In addition, the EPA found clear evidence that short-term exposure to diesel exhaust can irritate the eyes and respiratory tract, cause neuro-physiological symptoms, and possibly exacerbate allergies and asthma symptoms. This report marked the first time that the EPA had explicitly linked diesel exhaust to lung cancer and other pulmonary problems.[4] In 2005, following EPA's methodology, the nonprofit Clean Air Task Force conducted a study to assess the health impacts of diesel particle pollution. This study found that particulate matter from diesel exhaust was responsible for 410,000 asthma attacks, 27,000 non-fatal heart attacks, and 21,000 premature deaths, including 3,000 deaths from lung cancer, in the US every year.[5]

With the health of millions of Americans at stake, urban transit agencies have been replacing their older diesel buses with newer, lower emission models at a faster pace. Likewise, government entities at the federal, state, and local levels have shown a greater commitment to developing programs that encourage transit operators to accelerate the retirement of their dirtiest diesel buses. In 2006, 18 percent of transit buses ran on alternative fuels or advanced technologies, compared to only 3.4 percent in 1995.[6]

Transit agencies seeking to invest in cleaner bus technologies can now choose from a greater selection of alternative fuel and advanced technology models. Most major transit bus manufacturers offer models equipped to run on either compressed natural gas (CNG) or liquefied natural gas (LNG) (chapter 3). The engines in many of these buses can meet or exceed the strictest federal and state emission standards for their class. Also, transit buses powered by hybrid-electric technologies (chapter 4)—which combine an electric motor with an engine powered by another fuel such as diesel, gasoline, or natural gas—have reached the commercial market and are in revenue service in more than two dozen fleets across the country.

However, diesel transit buses are changing to keep pace with the emerging competition and emissions regulations. Manufacturers are building increasingly cleaner diesel engines, while refineries are producing cleaner formulations of diesel fuel. Also, a growing number of transit agencies are testing blends of diesel and biodiesel (chapter 5), which is produced from renewable sources and can provide modestly fewer emissions and reductions in petroleum consumption.

Beyond these commercially available options—beyond even the conventional internal-combustion engine (ICE)—looms a technology that many automotive and transportation market observers believe could be the future not only of transit bus service but of vehicular propulsion: the hydrogen fuel cell (chapter 6). Although the full commercialization of fuel cell technology is at least a decade away, several fuel cell bus demonstration projects are already underway in various parts of the world. Some significant technological obstacles that must be overcome before hydrogen fuel cells can become a practical and commercially viable technology.

Summary of Findings

1. The vision of what constitutes an ideal urban bus for transit agencies has changed dramatically since 1995. Buses must be more than merely capable, reliable, and economical to purchase and operate. Given growing concerns about climate change, the impact of poor air quality on public health, the economic threats posed by the rising costs of petroleum-based fuels, and the national security threats posed by US reliance on imported oil, today's ideal bus must offer lower emissions while using less, or no, petroleum.

• After more than 50 years of dominance, conventional diesel buses are no longer the only option available to transit agencies. According to the American Public Transit Association's (APTA's) 2006 survey, which gathered data from nearly 70 percent of all transit buses in the US, 81.4 percent of the nation's 57,616 buses were powered by diesel, down from 90.1 percent in 2001 and 98.0 percent in 1993.

• Transit agencies are facing increased pressure to reduce their dependence on petroleum-based fuels and to address the air pollution, public health, and traffic noise issues that affect cities across the country. In response, they are investing in cleaner, quieter, more fuel-efficient buses and alternative-fueled buses. In the US, the population of alternative fuel/advanced technology (AF/AT) buses—which includes buses that use natural gas, hybrid-electric diesel, biodiesel, and other technologies—has grown, rising from 6,718 in 2002 to 10,396 in 2006. Likewise, their share of the overall transit bus market has increased from 3.4 percent in 1995 to 7.5 percent in 2000 to 18 percent in 2006.

• The diesel bus industry has sought to retain its market share and has developed cleaner buses. This promise of near-term reductions in diesel emissions has slowed the market share expansion of AF/AT buses. As of January 2006, AF/AT buses constituted only 13.4 percent of the 2,399 orders placed for the year, dropping from a peak of 40.9 percent in 2004 and registering the lowest percentage of orders since 2000.

2. Municipalities and transit agencies that are looking to purchase alternatives to conventional diesel buses continue to purchase natural gas buses.

• Since 2000, the number of natural gas buses more than doubled, increasing from 3,844 to 8,749. Their share of the overall bus market in the US also doubled, rising from 7 to 15 percent.

• Nearly 85 percent of all AF/AT buses are fueled by natural gas.

• At the beginning of 2006, 86 transit fleets in the US operated natural gas buses, up from 65 in 1999, and the number of fleets operating more than 100 natural gas buses more than doubled, rising from 10 to 22. The Los Angeles County MTA operates the nation's largest AF/AT fleet, which contains 2,168 natural gas buses.

• The use of biogas-based fuel in Europe suggests its potential as an important renewable source. Sweden has 2,300 buses that run on bio-methane generated from 20 plants, which reduces greenhouse gas emissions and pollution while strengthening the rural economy. Lille Metropole (France) powers 128 of its 311 buses with bio-methane, which was generated from wastewater treatment plants in the early 1990s but will be derived from fermenting organic household wastes in the future.

3. Several commercial technologies, such as hybrid-electric technologies and biodiesel fuel blends, allow transit agencies to continue using petroleum-based fuels while addressing concerns about air quality, climate change, fuel cost, and oil dependency.

• Hybrid-electric diesel buses have become a fully commercial technology since 2000, increasing in number from 50 in 2000 to 115 in 2003. Since 2003, their number has quintupled to 611. Hybrid-electric diesel buses are operating in 10 fleets in the US, with the largest fleet (214) in Seattle. A small number of hybrid-electric gasoline buses are also in operation.

• At least two bus fleets contain hybrid-electric natural gas buses—one in Denver (CO) and another in Seattle (WA)—taking advantage of an alternative fuel and the more efficient hybrid-electric technology.

• Biodiesel buses have recently entered into service in the US. Most of these buses use B20, a fuel blend that is 20 percent biodiesel (primarily derived from domestic renewable resources) blended with 80 percent diesel. The number of buses powered by biodiesel, in the form of either B20 or pure biodiesel, rose from four in 2003 to 118 in 2005. According to APTA, these buses are operating in six fleets, including Intercity Transit (Olympia, Lacey, Tumwater, and Yelm, WA), King County Metro (Seattle, WA), and Knoxville Area Transit (Knoxville, TN).

• Interest in biodiesel is also growing in other parts of the world, such as Canada, Europe, and India, because it can be made from various local renewable resources: for example, fish oil in Nova Scotia, rapeseed in Europe, and the jatropha tree in India.

4. The economics of purchasing and operating AF/AT buses are becoming increasingly favorable for municipalities, and when a cost gap exists between AF/AT and diesel buses, government funding or tax credits can largely bridge that gap.

• Clean diesel buses retain a distinct price advantage over alternatives. On average, a 40-foot diesel bus costs $23,000 less than a natural gas transit bus and $100,000 less than a diesel-hybrid. Transit agencies that operate natural gas buses must also invest in refueling facilities, whose cost can range from several hundred thousand to millions of dollars.

• The costs associated with buying and operating diesel-powered vehicles are expected to rise in the next few years for two reasons. (1) Manufacturers will have to add equipment to meet the 2007 federal emissions standards (and aftermarket treatment costs to meet the stricter 2010 standards will be greater). (2) The per-gallon price of diesel fuel, already at (nominal) all-time highs in the US during part of 2005, will likely continue to rise in 2006.[7]

• AF/AT buses are expected to become less costly relative to their diesel counterparts. According to a 2005 report that the research and development group TIAX prepared for the California Natural Gas Vehicle Partnership, the costs of buying and operating a natural gas bus will drop below those for a comparable diesel bus if crude oil remains above $31 a barrel in 2005 dollars.[8] In addition to having lower fuel costs, natural gas buses, which use a cleaner fuel, will need less costly emissions controls to meet the 2007 and 2010 federal emissions standards.

• Under a program of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act (SAFETEA), signed into law in July 2005, sellers and transit users could be eligible for tax credits of up to $0.50 per gasoline gallon equivalent of CNG (compressed natural gas) or per liquid gallon of LNG (liquefied natural gas). Also, under the 2005 Energy Policy Act, tax credits can cover from 50 to 80 percent (up to $32,000) of the incremental costs of purchasing an AF/AT bus and 30 percent (up to $30,000) of the costs of natural gas refueling infrastructure. These credits will further reduce the costs of operating natural gas buses.

• The US government, the major source of funding and economic incentives, offers support through three programs administered by the Federal Transit Administration (FTA): the Congestion Mitigation and Air Quality Improvement (CMAQ) Program, the Urbanized Area Formula Program, and the Clean Fuels Formula Grant Program.

• California, Texas, and New York offer substantial funds for transit projects that involve AF/AT buses and fueling stations.

5. Most major transit bus manufacturers, whose products have proven track records in the transit market, build and sell fully commercial, fully warranted AF/AT buses and the engines/powertrains that propel them.

• Ten manufacturers build natural gas buses, including the largest in the North American market (New Flyer, North American Bus Industries [NABI], and Orion Bus). Three produce commercially available, fully warranted engines: Cummins Westport, Clean Air Power/Caterpillar, and John Deere.

• Seven manufacturers produce hybrid-electric diesel buses: Ebus, Electric Vehicles International, GM/Allison, ISE Research-ThunderVolt, New Flyer of America, Orion Bus Industries, and TransTeq.

6. Recent one-to-one test data that compare the emissions of similarly equipped, current-generation commercial natural gas, diesel-hybrid, and “clean diesel” buses are not sufficient enough to draw definitive conclusions about which technology generates the fewest emissions.

• Hybrid-electric, natural gas, and biodiesel transit buses create fewer emissions than conventional diesel buses. However, the difference in emissions vary significantly depending on the aftertreatment pollution control technology used, the age of the transit bus and engine tested, the fuel formulations used in the tests, and other factors.

• Natural gas buses will likely maintain an advantage over clean diesel buses because natural gas is an inherently cleaner, more carbon-free fuel and because, when comparable aftermarket treatment technology is used, natural gas has a better chance of meeting more stringent standards. Also, two engine manufacturers have announced that, beginning in 2007, they will offer natural gas engines that already meet the 2010 EPA heavy-duty engine standard.

• Electric-hybrid diesel buses operate with greater fuel efficiency and lower emissions than conventional diesel buses. However, results from recent emissions tests conducted on hybrid-electric diesel buses cast doubt on the scale of these benefits. For example, a comparison of two diesel and two hybrid buses operated by Conn Transit found the hybrid buses to be only 10 to 15 percent more fuel efficient and to provide marginal differences in emissions.

• Biodiesel buses produce lower NO_x and particulate emissions than diesel buses, although diesel blended with more than 20 percent biodiesel produces NO_x emissions at levels greater than the EPA 2007 standards.

7. Noise pollution is becoming an important quality of life issue in the US, and natural gas buses generate less noise.

• The Natural Gas Bus Project Berlin, a project co-financed with the European Commission, found that CNG buses were quieter than diesel buses under certain driving conditions, for example, while accelerating during passing.

• Although hybrid-electric diesel buses have yet to be comprehensively tested for noise levels, their operators report that they are quieter than conventional diesel buses because of their operating conditions and smaller combustion engines.

8. Of all AF/AT buses, natural gas and biogas technologies provide transit agencies with the most immediate means of addressing rising diesel fuel costs and national security concerns related to US dependence on imported oil because these fuels can replace the use of petroleum-based fuel.

• A transit agency’s ability to displace petroleum fuel consumption depends on the type of AF/AT buses that it invests in. Natural gas, hybrid-electric, biodiesel, biogas, and other advanced technologies offer some petroleum-displacement benefits.

• Dedicated natural gas buses or buses that combine natural gas with bio-methane offer the greatest petroleum-displacement and energy security benefits because they use no petroleum-based fuel and because these gaseous fuels can be procured primarily from the US and Canada.

• Although pressure on the domestic natural gas supply is increasing and driving up its prices, North American natural gas reserves are significantly greater than US oil reserves. Also, natural gas reserves in other parts of the world are available and more secure than oil reserves.

Approximately 96 percent of the natural gas used in the US is produced in North America. The Energy Information Administration forecasts that natural gas imports will increase by 4.1 percent per year and that, by 2025, 31 percent of natural gas will be imported, compared to 77 percent of crude oil.[9]

• Most commercial hybrid-electric buses are powered by diesel fuel, while a few fleets, such as one in Denver (CO), operate buses that combine hybrid technology with natural gas fuel.

• If biodiesel is used in its pure form (B100), instead of B20, and if biogas is extracted from landfills, wastewater treatment plants, and agricultural operations, these low emission, renewable, domestically produced fuels could play an important role in displacing petroleum.

9. Even though hydrogen fuel cells promise to fulfill the vision of the ideal 21st century transit bus, they remain at least a decade or more from commercialization.

• By the end of 2005, 50 hydrogen fuel cell buses were operating in demonstration projects in North America, Europe, and Asia. The California Fuel Cell Partnership and the Georgetown University Fuel Cell Bus Development Program are operating programs in the US. The CUTE program in Europe is demonstrating 33 buses (3 bus in 11 cities). In 2001, the Global Development Fund announced a program to demonstrate 46 buses in São Paolo (Brazil), Cairo (Egypt), Mexico City (Mexico), New Delhi (India), Shanghai (China), and Beijing (China) during a five-year period; however, none of these buses are on the road.

• Twelve manufacturers are involved in these projects, including New Flyer, NABI, and MAN.

• Significant technological obstacles, such as systems for refueling and maintaining these vehicles, must be overcome before hydrogen fuel cells can become a practical, economic technology. California is already tackling the challenge of creating a refueling infrastructure through its Hydrogen Highway Initiative, which plans to build 250 stations to support 20,000 fuel cell vehicles. The plan for its first phase includes building 50 to 100 of stations by 2010. As of May 2006, 39 stations have been built; some derive hydrogen from natural gas, while others derive hydrogen from water using electricity or renewable energy.

10. The vision of the ideal transit bus for the 21st century has led to the development of the bus rapid transit (BRT) concept. An integrated approach to improving transit service, the BRT concept is modeled on modern light-rail service.

• Several international transit bus systems have implemented the BRT concept, including Brisbane (Australia), Curitiba (Brazil), Bogota (Colombia), and Kunming (China).

• Spurred by programs such as the Federal Transit Administration's BRT Initiative, dozens of US BRT projects are in operation, in development, or under consideration.

• The advantages of BRT over light rail and other transit initiatives include cost, flexibility, and performance.

11. Given the severity of the environmental, health, climate change, and national security issues facing the US, choosing AF/AT buses for new purchases is preferable to any investments in the status quo.

• Where natural gas is readily accessible or where bio-methane resources exist, investments made in new transit buses that use these technologies (in combination with hybrid propulsion systems, if possible) offer the greatest near-term benefits for the environment, public health, noise reduction, and fuel security. Choosing these technologies also requires transit agencies and municipalities to make a larger new investment; however, government grants and private partnerships can potentially cover some or all of the incremental costs.

• Where no ready access to natural gas or bio-methane exists, hybrid-electric diesel buses can reduce emissions and displace petroleum consumption, which makes them an important alternative. Biodiesel extends the efficiency of petroleum use and helps reduce emissions.

• Transit agencies that serve areas where biodiesel is available, where the use of fuel derived from locally grown feedstocks is appealing, and where NO_x emissions are not a significant issue may find biodiesel the most appealing option in the near term.

12. Since 2000, the US, Europe, and Asia have changed their views of the paradigm for transit buses.

• Rather than commit to a single type of AF/AT bus, some of America's largest transit agencies are adopting a flexible approach by simultaneously operating hybrid, natural gas, and clean diesel buses, while others are integrating hydrogen-natural gas blends (HCNG) or hydrogen fuel cell buses into their operations.

• During the past six years, the various merits of the available technologies and fuels have become much clearer.

13. When evaluating fuels and technologies or when choosing which ones to invest in, municipalities and transit agencies should consider a wide range of factors, all crucial for making the best local decisions. These factors include

• Bus purchase and operating costs

• Access to fuel

• Costs for refueling infrastructure, depot modification, or land acquisition

• Costs for training workers

• Costs of bus lifecycle maintenance

• Emissions reduction goals (government mandates)

• Costs and reliability of aftermarket pollution control devices (depending on the fuel)

• Goals for reducing greenhouse gas emissions (in some cases, government policy or mandates) and costs of greenhouse gas emission controls

• Noise reduction goals

• Petroleum displacement goals

• Engine retrofit cost (if necessary)

• Availability of outside funding from public and private sources

• Ability to leverage current capital investments against future investments

Chapter 1
The Need for Change

Transit agencies and government policymakers are under increasing pressure to move beyond the conventional diesel technologies that have dominated urban transit for decades. Factors motivating this change include safeguarding human health and the environment, mitigating energy security concerns, and meeting stringent government emissions standards.

HUMAN HEALTH EFFECTS OF DIESEL BUSES

For more than 30 years, various programs mandated by the 1970 federal Clean Air Act and its 1990 amendments have sought to reduce tailpipe emissions from gasoline- and diesel-burning vehicles. Despite these efforts, automotive air pollution remains one of the most intractable environmental problems facing the US. Although many improvements have been made, nearly 170 million people nationwide still live in places that the US Environmental Protection Agency (EPA) has designated as “nonattainment” areas. These areas persistently exceed health-based air pollution standards for one of the six “criteria pollutants” cited in the original Clean Air Act (lead, carbon monoxide, ground level ozone, particulate matter, sulfur dioxide, and nitrogen oxides).[10] Of these people, 158 million (56 percent of the total US population) live in areas that have been cited for nonattainment for ground-level ozone, and 88 million (31.4 percent of the population) live in areas that have been cited nonattainment for fine particulates. (Ground-level ozone and fine particulates are the primary targets of emissions regulations.) Fewer people live in areas that have been cited for nonattainment for the other criteria pollutants.[11]

Vehicle emissions are responsible, at least in part, for five of these criteria pollutants (lead is the only exception). Conventional diesel vehicle engines also emit various air toxics that can cause cancer and other serious health problems in humans. Table 1.1 lists the components of diesel exhaust and their effects.

In discussing specific pollutants, separating statistics for diesel-fueled buses from those for all heavy-duty diesel vehicles and trucks is not generally possible. In general, buses constitute only 8.7 percent of the total number of all heavy-duty vehicles,[12] and they travel only 3.1 percent of

Table 1.1. Major Components of Conventional Diesel Engine Emissions, Known Products of Atmospheric Reaction, and Effects on Human Health and the Environment

Emission Component	Products of Atmospheric Reaction	Impacts
	Gases	
Carbon dioxide	N/A	Major contributor to global warming
Carbon monoxide	N/A	Highly toxic to humans; inhibitor of oxygen uptake
Nitrogen oxides (NO_x)	Nitric acid, ozone	Nitrogen dioxide: respiratory tract irritant and major ozone precursor; nitric acid: contributor to acid rain
Sulfur dioxide	Sulfuric acid	Respiratory tract irritant; contributor to acid rain
	Particulates	
Elemental carbon	N/A	Nuclei: absorption of organic compounds; transported deep into the lungs
Inorganic sulfate and nitrate	N/A	Respiratory tract irritant
Hydrocarbons (C_{14}–C_{35})	Little information available: possibly aldehydes, ketones, and alkyl nitrates	Unknown
Polycyclic aromatic hydrocarbons (PAHs) (≥ 4 rings, such as pyrene)	Nitro-PAHs (≥ 4 rings), nitro-PAH lactones	Larger nitro-PAHs: major contributors of carcinogens in combustion emissions; many nitro-PAHs: potent mutagens and carcinogens
Nitro-PAHs (≥ 3 rings, such as nitropyrenes)	Hydroxylated-nitro derivatives	Many nitro-PAHs: potent mutagens and carcinogens; some reaction products: mutagenic in bacteria
	Hydrocarbons (Gases)	
Alkenes (≤ C_{18})	Aldehydes, alkyl nitrates, ketones	Respiratory tract irritant; reaction products: ozone precursors (in the presence of NO_x)
Alkenes (≤ C_4)	Aldehydes, ketones	Respiratory tract irritant; some alkenes: mutagenic and carcinogenic; reaction products: ozone precursors (in the presence of NO_x)
	Aldehydes (Gases)	
Formaldehyde	Carbon monoxide, hydroperoxyl radicals	Probable human carcinogen and ozone precursor (in the presence of NO_x)
Higher aldehydes (acetaldehyde, etc.)	Peroxyacyl nitrates	Respiratory tract and eye irritant; plant damage
Monocyclic aromatic compounds (benzene, etc.)	Hydroxylated and hydroxylated-nitro derivatives	Benzene: toxic and carcinogenic in humans; some reaction products: mutagenic in bacteria
PAHs (≤ 4 rings)	Nitro-PAHs (4 rings)	Some of PAHs and nitro-PAHs: known mutagens and carcinogens
Nitro-PAHs (2 and 3 rings)	Quinones and hydroxylated-nitro derivatives	Some reaction products: mutagenic in bacteria

Source: US Environmental Protection Agency, Office of Research and Development, *Health Assessment Document for Diesel Engine Exhaust*, EPA-600-8-90-057F, Washington, DC: National Center for Environmental Assessment, May 2002, pp. 2-87 and 2-91, available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060.

the miles traveled by these vehicles.[13] However, their use and emissions are concentrated in urban areas, which face particular burdens caused by air pollution.

Nitrogen Oxides

Internal combustion engines operate by igniting a mixture of air and some fuel. In the high-pressure and high-temperature conditions of an engine, nitrogen and oxygen atoms react to form nitrogen oxides, generically referred to as NO_x. Although various natural processes form NO_x, human activity accounts for the majority of nitrogen emitted into the earth's atmosphere. The majority of the anthropogenic (human-generated) emissions result from high-temperature combustion processes, such as those occurring in automobiles and power plants. Nitric oxide (NO) constitutes approximately 95 percent of these NO_x emissions, and it readily converts to nitrogen dioxide (NO_2) in the atmosphere. Nitrous oxide (N_2O), a potent greenhouse gas, is another form of NO_x, although it is emitted in much smaller quantities.[14]

Health Effects of NO_x

NO_x have been shown to cause a variety of health effects. When NO_x reacts with compounds in the air, it can form small particles that can penetrate deeply into sensitive parts of the lungs and cause or worsen respiratory diseases such as emphysema and bronchitis.[15] These particles can also aggravate existing heart disease.[16] However, the most significant health threat posed by NO_x lies in their ability to form ground level ozone, which forms when NO_x reacts in sunlight with volatile organic compounds (VOCs), another product of fuel combustion.[17]

Health Effects of Ground Level Ozone

Although ozone naturally produced in the earth's atmosphere helps shield the planet from the sun's harmful ultraviolet (UV) rays, ozone formed when NO_x reacts in sunlight with VOCs can harm human health when it occurs close to the earth's surface.[18] Ground level ozone is associated with many health problems: respiratory system irritation, chest pain, coughing, inflammation and damage to the lining of the lungs, decreased lung (pulmonary) function (especially in children), and possibly permanently reduced lung capacity.[19] Asthmatics are particularly affected by ozone; when ozone levels are high, a larger number of asthmatics experience attacks that require medical attention.[20] Ozone aggravates chronic lung diseases such as emphysema, and emerging evidence suggests that exposure to ozone may limit the immune system's ability to fight bacterial infections.[21] Children, the elderly, people with existing respiratory problems (such as asthma and emphysema), and adults who are active outdoors are particularly vulnerable to the effects of ozone and face a greater risk for these health problems.[22]

A long-term study conducted by the University of Southern California showed that ozone affects children more adversely than it does adults. This study indicated that, in communities with high ozone levels, children's lungs develop more slowly, and it suggested that these deficits probably have long-term health and social consequences.[23] Children who live in urban areas or engage in significant outdoor activity develop asthma more often than children who live in less polluted communities or who stay primarily indoors. Children's respiratory problems become more acute when ozone levels rise, causing increased absenteeism, which in turn places a socio-economic burden on children, parents, and school districts.[24]

Additional research indicates a link between ozone and adult mortality levels. A 2004 study conducted by researchers at John Hopkins and Yale Universities compared short-term peaks in air ozone levels to short-term peaks in premature death rates in 95 urban areas in the US between 1987 and 2000. (These areas are home to nearly 40 percent of the US population.) The study found that an increase of 10 parts per billion (ppb) from the previous week's ozone level was associated with a 0.52-percent increase in the overall daily death rate and a 0.64-percent increase in cardiovascular and respiratory-related deaths. These figures imply that, in 2000, a 10 ppb increase in the ozone level would have been responsible for 319 extra deaths in New York City and nearly 4,000 extra deaths across the 95 areas studied.[25]

Particulate Matter

Diesel particulate matter (PM) is composed of a core of elemental carbon surrounded by organic compounds, sulfate, nitrate, metals, and other trace elements. PM encompasses fine particles (those smaller than 2.5 microns in diameter, referred to as $PM_{2.5}$) and coarse particles (those larger than 2.5 microns in diameter). Coarse particles that measure less than 10 microns in diameter are referred to as PM_{10}.[26]

$PM_{2.5}$ and PM_{10} are the main targets of pollution reduction efforts because they are small enough to inhale deeply into the lungs, where they can endanger the lower respiratory tract and occasionally enter the bloodstream. Although particles larger than 10 microns appear as soot and are the most visible, they pose less risk to human health than $PM_{2.5}$ and PM_{10}.[27]

Health Effects

EPA considers diesel PM, long used as a measure of diesel exhaust levels, to be the most hazardous air pollutants.[28] Numerous studies have found a causal relationship between fine particulates and serious health effects such as increased hospital admissions and emergency room visits for heart and lung diseases, aggravated respiratory conditions (particularly asthma and bronchitis), cardiac arrhythmias, and heart attacks.[29]

Other research has linked PM to developmental problems and infant mortality. A study conducted by a team from the Harvard School of Public Health and Switzerland's University of Basel predict that as many as 11 percent of infant deaths in the US (up to 3,000 per year) may be caused by microscopic particles in the air. The study concluded that, as levels of PM in the air increase, infant mortality rates rise between 10 and 40 percent.[30]

EPA has identified PM as one of the 21 mobile source air toxics because numerous health problems are linked to it and because it is a suspected carcinogen. Animal studies have shown that PM causes lung tumors,[31] and the Multiple Air Toxics Exposure Study II (MATES II), a study of air pollution in Los Angeles, found that diesel soot accounted for 71 percent of the region's cancer risk associated with ambient air pollution.[32] According to EPA's reference concentration (RfC, a toxic substance's maximum exposure level that is considered safe for humans), daily exposure to more than 5 micrograms of diesel exhaust per cubic meter may have harmful health effects on humans.[33]

Carbon Monoxide

A colorless, odorless gas, carbon monoxide (CO) is a byproduct formed during the incomplete combustion of fossil fuels. It typically disperses quickly and has the greatest impact near its source.

Health Effects

Localized exposure to CO reduces the amount of oxygen in the bloodstream, can impair mental function, and can affect visual perception.[34] At low concentrations, CO exposure can cause fatigue in healthy individuals and chest pains in those with heart disease. Exposure to higher concentrations can result in impaired vision, impaired coordination, headaches, dizziness, confusion, nausea, and flu-like symptoms.[35] Exposure to very high concentrations of CO can be fatal.[36]

Pregnant women and their unborn children are especially vulnerable to the adverse effects of CO. Exposure during pregnancy can cut off the supply of oxygen to the fetus, resulting in its death. Researchers have found evidence of CO in the umbilical cords of nonsmoking mothers.[37] Other studies indicate that pregnant women exposed to high levels of CO are three times more likely to have underweight babies and babies with cleft lips, cleft palates, and defective heart valves.[38]

Air Toxics

Mobile source air toxics (MSATs) are air pollutants emitted from highway vehicles and non-road equipment. Known to cause cancer, they produce serious health effects and environmental impacts.[39] In March 2001, EPA identified 21 MSATs[40] (see Table 1.2).

EPA believes that dioxins and the metals identified as MSATs (arsenic, chromium, lead, manganese, mercury, and nickel) are produced primarily by engine wear and fuel additives. However, it considers diesel PM and the gaseous compounds (particularly acetaldehyde, benzene, 1,3-butadiene, formaldehyde, and methyl tertiary butyl ether) to be generated from fuel, either through volatilization or incomplete combustion.[41]

Even though EPA does not regulate air toxics as criteria pollutants, various federal programs designed to reduce emissions of ozone precursors and PM have been effective in reducing emissions of air toxics. These initiatives include heavy-duty engine and vehicle emission standards, on-highway diesel fuel sulfur control requirements, and inspection and maintenance programs. EPA projects that, between 1990 and 2020, these efforts will reduce on-highway emissions of benzene, formaldehyde, 1,3-butadiene, and acetaldehyde between 67 and 76 percent.[42]

Table 1.2. Mobile Source Air Toxics (MSATs)

Acetaldehyde	DPM/DEOG	Methyl tertiary butyl ether (MTBE)
Acrolein	Ethylbenzene	Naphthalene
Arsenic compounds	Formaldehyde	Nickel compounds
Benzene	n-Hexane	Polycyclic organic matter
1,3-Butadiene	Lead compounds	Styrene
Chromium compounds	Manganese compounds	Toluene
Dioxin/Furans	Mercury compounds	Xylene

Source: US Environmental Protection Agency, “List of Mobile Source Air Toxics (MSATs),” May 27, 2004, available at http://www.epa.gov/otaq/regs/toxics/msatlist.pdf (accessed March 28, 2006).

Health Effects

In addition to increasing the risk of cancer, air toxics can cause a host of health problems. For example, studies have shown that chronic exposure to benzene can adversely affect hematopoetic function (the ability to form blood cells) and cause neurotoxic effects[43]; 1,3-butadiene can cause reproductive and developmental problems[44]; naphthalene can cause hemolytic anemia, cataracts, and respiratory toxicity[45]; and xylenes can cause neurological impairment and irritate the eyes and throat.[46]

Noise

The Noise Control Act of 1972 identified noise as an environmental concern that posed a threat to "the health and welfare of the Nation's population."[47] Research shows that noise continues to interfere with the health and quality of life for many. In its 1999 survey of New York City community boards, the New York City Council on the Environment found that New Yorkers rated noise pollution as one of their top three environmental concerns.[48]

In 2000, the nonprofit League of Hard of Hearing conducted a survey of 647 individuals in the US and abroad. Respondents identified vehicles and urban traffic among four of the top five sources of specific noises that were most bothersome.[49] Conventional diesel buses generate noise when they idle, when they accelerate, when they brake, and when they operate during normal driving conditions. Noise from buses can affect drivers, passengers, and the communities served by bus routes.

ENVIRONMENTAL EFFECTS OF DIESEL EXHAUST

Acid Rain and Eutrophication

NO_x and sulfur dioxide (SO_2), both components of diesel exhaust, are the two biggest contributors to acid rain. Once emitted into the atmosphere, they react with water, oxygen, and sunlight to form nitric and sulfuric acid, which can return to the earth's surface in gases, particles, or water droplets.[50]

Acid rain can harm the environment in numerous ways. It can enter watersheds. When it falls on open bodies of water and soil, it can dissolve aluminum deposits in the soil and flow into freshwater lakes or streams. The acid and aluminum are toxic to fish and other parts of aquatic ecosystems. Nitric and sulfuric acid can weaken trees by stripping forest soil of nutrients. They can also degrade metal, stone, and some paints on buildings, monuments, or other outdoor structures.[51]

In addition to being a precursor of acid rain, NO_x can severely disrupt aquatic ecosystems through a process called eutrophication. When atmospheric NO_x is deposited in water bodies, it accelerates the growth of plants and algae, which can choke off a lake or estuary's oxygen supply as dead plant matter decomposes. Without oxygen, fish and other aquatic animals die, and the ecosystem is essentially destroyed.[52]

Climate Change

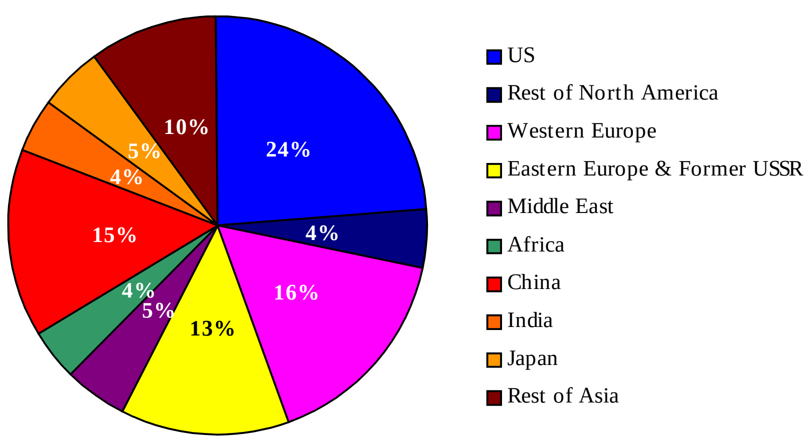
During the past 20 years, climate scientists worldwide have arrived at the consensus that anthropogenic increases in atmospheric concentrations of greenhouse gases—gases that trap the earth's heat—could lead to long-term regional and global changes in temperature, precipitation, wind, climate variability, and other elements of the earth's climate system.[53] The combustion of fossil fuels generates carbon dioxide (CO_2), methane (CH_4), and N_2O,[54] three of the most significant greenhouse gases.

CO_2 is the greenhouse gas primarily released by the burning of fossil fuels, and the majority of increases in US and global greenhouse gas emissions that result from industrialization are attributed to CO_2.[55] For these reasons, CO_2 is generally the focus of climate change policies. Even though burning fossil fuels generates smaller quantities of CH_4 and N_2O, these greenhouse gases have a relatively more powerful warming effect: one molecule of CH_4 traps 21 times more heat per molecule than CO_2, while one molecule of N_2O traps 270 million times more heat per molecule than CO_2.[56]

The most current scientific consensus, represented by the UN's Intergovernmental Panel on Climate Change (IPCC), is based on a wide variety of evidence, most notably that global temperatures likely rose more in the 20th century than in any other century for the past 1,000 years and that the 1990s was the warmest decade on record. The IPCC asserts that most of the observed warming is likely attributable to anthropogenic increases in greenhouse gas concentrations.[57]

The US is the world's largest emitter of CO_2, generating 24 percent of the world's total in 2003, followed by Western Europe at 16 percent, China at 15 percent, and Eastern Europe and the former Soviet Union at 13 percent (see Figure 1.1).[58] Transportation is a major contributor to greenhouse gas production: between 1990 and 2002, US greenhouse gas emissions rose by 13 percent overall, while those generated by transportation rose by 24 percent. In 2003, transportation accounted for 27 percent of all US greenhouse gas emissions.[59]

Figure 1.1. World Carbon Dioxide Emissions, 2003



Source: US Department of Energy, Energy Information Administration, "International Energy-Related Environmental Information," July 27, 2004, available at http://www.eia.doe.gov/env/intlenv.htm (accessed March 30, 2006).

Even though the extent and likely effects of continued warming remain uncertain, transit operators will increasingly have to factor CO_2 emissions into their fleet management plans as governments on the international, national, state, and local levels seek to bring greenhouse gas emissions under control.

International Agreements

The Kyoto Protocol, the UN's first global warming treaty, came into force on February 16, 2005. Under Kyoto, the industrialized signatory countries have agreed to reduce their combined greenhouse gas emissions during a five-year period (from 2008 to 2012) to levels that are 5.2 percent below their 1990 levels. The US and Australia did not ratify the treaty; however, on July 28, 2005, they joined China, India, South Korea, and Japan to form the Asia-Pacific Partnership for Clean Development and Climate. Unlike Kyoto, this pact does not impose mandatory emissions caps on its participants. Instead, it focuses on developing and sharing technologies (including advanced transportation) to combat climate change.[60] Although some critics are skeptical about the effectiveness of this nonbinding treaty, it signals US willingness to finally acknowledge climate change and engage in international action to combat it.[61]

National Legislation

Although the US government has been slow to address climate change on the national level, congressional actions have acknowledged the problem. The Energy Policy Act of 2005 and the Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2005 (SAFETEA), both passed in August 2005, include measures that will reduce greenhouse gas emissions and that specifically target the transportation sector.[62]

State Regulations

Many state governments have enacted efforts to reduce greenhouse gas emissions. On June 2, 2005, California Governor Arnold Schwarzenegger announced plans to reduce the state's emissions to levels that would be 80 percent below its 1990 levels by 2050.[63] (California is the tenth largest emitter of greenhouse gases in the world.) On September 24, 2004, California also became the first state to pass legislation regulating CO_2 emissions from vehicles.[64]

Local Initiatives

On the day the Kyoto Protocol went into effect, Seattle Mayor Greg Nickels made climate change a municipal challenge by launching the US Mayors Climate Protection Agreement.[65] The agreement identifies municipal fleets as a sector that needs to be reformed to reduce greenhouse gas emissions.[66] As of August 10, 2005, 175 mayors representing nearly 39 million people have signed the agreement.[67]

THREAT TO ENERGY SECURITY

The transportation sector's reliance on oil-derived fuels poses a threat to US energy security. According to the US Department of Energy's (DOE's) *Annual Energy Review 2004,* US oil consumption reached an all-time high of 20.5 million barrels per day in 2004 (see Figure 1.2). Of that total, more than 66 percent went to transportation.[68] Meanwhile, the price of oil reached a (nominal) record of $69.82 per barrel on August 30, 2005.[69]

Throughout most of the 20th century, this country's access to the world's oil remained secure, but three factors are changing this situation. The first factor is the reliability of supplies from the Persian Gulf region, the source of 19.3 percent of US oil imports. (Overall, 43.6 percent of US oil imports come from OPEC [Organization of Petroleum Exporting Countries] member nations, which includes Venezuela, the source of 12 percent of our imports.[70])

In 1973, the Arab OPEC (AOPEC) oil embargo wreaked havoc with the US economy and led to extensive national efforts to reduce energy consumption. Despite these efforts, US oil consumption remains at an all-time high, and the country imports a greater percentage of its oil than ever before. In 1992, the year Congress passed the Energy Policy Act (EPACT) to reduce American dependence on foreign oil, the US imported 46 percent of its oil; in 2004, it imported 63 percent of its oil.[71]

In recent years, the US has been importing substantially more oil from more reliable countries such as Canada (up 93 percent since 1992) and Mexico (up 97 percent). However, increased oil production in other parts of the world could not replace the oil supplies that would be lost during a disruption in output or sales from the Middle East, which produces approximately 28 percent of the world's oil.[72] Such a disruption would almost certainly result in significant price spikes and global shortages.

Each year, the US sends more than $100 billion abroad to foreign energy suppliers and spends tens of billions of dollars on military involvement in the Persian Gulf. The political situation in the Middle East further raises the risk, financially and militarily, of this country's heavy dependence on imported oil.

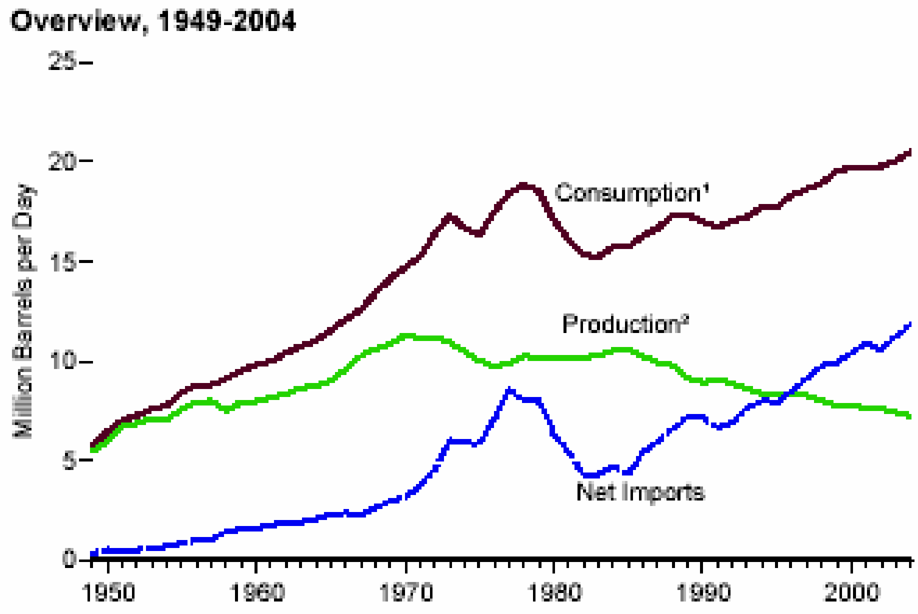
The second factor threatening the security of the US's access to oil is increasing competition for oil from modernizing Asia. China and India—home to 2.3 billion people, more than one-third of the world's population—import oil to feed their expanding economies. INFORM's 2005 report *The Transportation Boom in Asia: Crisis and Opportunity for the United States* reports that, through 2015, China's and India's oil consumption rates are projected to increase at an annual rate of 4.0 and 3.9 percent, respectively, the fastest rates in the world. As these and other industrializing countries continue to develop, the competition for oil is expected to intensify.[73] However, having recognized the pressures on the world's oil supply, China and India are diversifying their fuel use by investing heavily in natural gas vehicles, while this country's failure to take similar measures has accelerated its dependence on oil.[74]

The third factor is the dearth of oil remaining in this country. The US has approximately 2 percent of the world's estimated crude oil reserves[75]; thus, pumping more money into domestic oil production will not provide a long-term solution to the problems of energy supply and security. If the US relied solely on its domestic oil supply, it would run out in less than 3 years.[76]

EMISSIONS REGULATIONS

The federal government began regulating emissions from bus engines in 1976. Since then, it has repeatedly tightened these standards (see Table 1.3), playing an important role in influencing the types of buses and engines that transit fleets purchase.

Figure 1.2. US Petroleum Overview, 1950–2004



Source: US Department of Energy, Energy Information Administration, *Annual Energy Review 2004*, DOE-EIA-0384(2004), August 2005, Fig. 5.1, p. 126, available at http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf.

In 2004, EPA tightened nationwide engine emissions standards on all diesel vehicles that weighed more than 8,500 pounds, including transit buses. These vehicles are now required to meet a standard of 0.5 grams per brake horsepower hour (g/bhp-hr) for PM and 2.4 g/bhp-hr combined for NO_x and hydrocarbons. By 2007, EPA standards for all heavy-duty vehicles will further tighten to 0.01 g/bhp-hr for PM, 0.2 g/bhp-hr for NO_x, and 0.14 g/bhp-hr for hydrocarbons.[77] The PM standard is fully effective in 2007, but the NO_x standard will be phased in based on engine production. Between 2007 and 2009, 50 percent of the engines sold must meet the NO_x standard; the number rises to 100 percent of those sold beginning in 2010.

In an analysis of the projected costs and benefits of the 2007 heavy-duty vehicle standards, EPA estimates that, annually, the standards will eventually prevent approximately 8,300 premature deaths, nearly 5,500 cases of chronic bronchitis, roughly 361,400 asthma attacks, and significant numbers of hospital visits, lost work days, and multiple respiratory ailments caused by air pollution. EPA estimates that the overall net benefits in health and general welfare improvements will amount to $66.2 billion in 2030.[78]

However, rather than adopting EPA's emissions standards, many states have voluntarily adopted the more stringent emissions standards set by the California Air Resources Board (CARB), a state agency that addresses air quality issues associated with air pollution.[79] California adopted the nation's first automobile tailpipe emissions standards in 1966.[80] As a result, the Clean Air Act of 1970 (under section 209) granted California the right to set more stringent emissions standards than those required by the federal government.[81] For example, the heavy-duty engine standards that CARB adopted in October 2001 for model years 2005 and 2006 effectively implemented the federal government's 2007 Heavy-Duty Engine and Vehicle Standards. Other states have the choice of adopting the California or federal standards.

Table 1.3. Federal (EPA) and California (CARB) Emission Standards for Transit Buses (g/bhp-hr)

Effective Model Year	Applicable Vehicle/ Engine Type	Particulate Matter	Nitrogen Oxides	Carbon Monoxide	Non-Methane Hydrocarbons
		US Environmental Protection Agency (EPA)			
Pre-1976	Heavy-duty engines	None	None	None	None
1984–1987	Heavy-duty engines	None	10.7	15.5	None
1988–1989	Heavy-duty engines	0.6	10.7	15.5	None
1991–1993	Heavy-duty engines	0.25	5	15.5	None
1994–1995	Heavy-duty engines	0.07	5	15.5	1.2
1996–1997	Heavy-duty engines	0.05	5	15.5	1.2
1998–2003[1]	Heavy-duty engines	0.05	4	15.5	1.2
2004–2006	Heavy-duty engines for vehicles over 8,500 lbs.	0.1/0.05[2]	2.4 HC + NO_x[3]	15.5	2.4 HC + NO_x
2007 and later	Heavy-duty engines/vehicles	0.01	0.2	15.5	0.14
		California Air Resources Board (CARB)			
1991–1993	Heavy-duty diesel engines	0.25	5	15.5	1.2
1994–1995	Heavy-duty diesel engines	0.07	5	15.5	1.2
1996 and later	Heavy-duty diesel engines	0.05	4	15.5	1.2
2002 and later	Urban transit vehicles (fleets choosing diesel path)	0.05	2.5 NO_x + NMHC	15.5	2.5 NO_x + NMHC
			4.8 NO_x fleet avg.		4.8 NO_x fleet avg.
2002 and later	Urban transit vehicles (fleets choosing alternative fuels path)	0.03	1.8 NO_x + NMHC (optional)	15.5	1.8 NO_x + NMHC (optional)
			4.8 NO_x fleet avg.		4.8 NO_x fleet avg.
2004–2006	Urban transit buses (fleets choosing diesel path)	0.01	0.5	15.5	NA
2004–2006	New diesel-fueled, dual-fuel or bifuel heavy-duty engines in urban transit buses	0.01	0.5	5.0/7.0	0.05
2007 and later	Urban transit buses (fleets choosing diesel path)	0.01	0.2	NA	NA
2007 and later	Urban transit vehicles (fleets choosing alternative fuels path)	0.01	0.2	NA	NA

1. EPA also has optional Clean Fuel Fleet emissions standards for model years 1998–2003 engines for vehicles over 8,500 lbs. GVWR.

2. The standard applies to urban buses from model years 1996 and later.

3. For vehicles from model years 2004–2006 (EPA) and 2002–2004 (CARB), the emission standards for NO_x and non-methane hydrocarbons (HCs) are combined. For these same years, CARB also specifies a fleet average for NO_x emissions that applies to all vehicles in an agency's fleet, not just the new purchases.

Sources: US Department of Energy, Office of Transportation Technologies, *Heavy Vehicle and Engine Resource Guide 2001*; and James S. Cannon and Chyi Sun, *Bus Futures: New Technologies for Cleaner Cities*, New York: INFORM, 2000, p. 17.

In addition to emissions standards, California has set special mandates for transit fleets. In 2000, CARB passed the Diesel Risk Reduction Plan, a set of rules designed to make diesel engines cleaner by requiring technology improvements or emissions reductions.[82] One rule requires transit buses to comply with PM and NO_x emissions standards that are more stringent than those set by EPA. Under the plan, public transit fleets have two options for reducing their emissions: (1) replacing their diesel-reliant buses with vehicles powered by certain alternative fuels and power sources, including natural gas, electricity, and fuel cells, or (2) using diesel-fueled buses but phasing in significantly cleaner diesel fuel formulations and diesel engines.[83] Both options specify deadlines for reducing N_2O emissions and describe the requirements for retrofitting older buses to reduce emissions of PM.

Under the plan, transit agencies that operate 200 or more buses were required to begin investing in zero-emission bus demonstration projects (hydrogen fuel cell or battery electric) in 2003. They will also be required to make 15 percent of their new bus purchases zero-emission buses by either 2008 or 2010, depending on which option they chose for reducing their emissions. Agencies that chose the diesel option must meet this requirement in 2008, while those that chose the alternative fuels option must meet it in 2010.[84] By June 2003 (the date for the most recent data available), 43 agencies chose the diesel option and 26 the alternative fuels option.[85]

In June 2000, the South Coast Air Quality Management District (SCAQMD)—the agency that oversees mobile source pollution policy in a four-county region in Southern California—adopted rules that are more ambitious than the CARB bus requirements. (The four countries under SCAQMD's jurisdiction are Orange, Riverside, San Bernardino, and Los Angeles, whose air quality is consistently among the worst metropolitan air quality in the nation.[86]) Under SCAQMD's Rule 1192, all new buses (except articulated buses) operated in the district must run on alternative fuels. This rules applies to transit fleets that contain 15 or more buses, and alternative fuels include natural gas (liquefied or compressed), propane, methanol, electric batteries, or fuel cells. Hybrid-electric and dual-fuel buses that use diesel fuel do not meet the requirements, nor do buses that use "clean diesel" technology.[87]

An 8–1 US Supreme Court decision in the case *Engine Manufacturers Association v. South Coast Air Quality Management District* (April 27, 2004) found that section 209 of the federal Clean Air Act preempted Rule 1192's regulation of private fleets. However, US District Judge Florence-Marie Cooper upheld SCAQMD's clean fleet rules on May 6, 2005. Judge Cooper decided that the rules pertained to vehicle procurement, not production, which made SCAQMD a market "participant," not a "regulator"; therefore, SCAQMD's fleet rules do not fall under section 209's scope of preemption.[88]

In September 2004, CARB imposed limits on greenhouse gas emissions from new passenger cars and light-duty vehicles starting with model year 2009, which made California the first state to enact such legislation.[89] Although the Alliance of Automobile Manufacturers and a group of automotive dealers from California's Central Valley are challenging these regulations,[90] at least seven other states—Connecticut, Maine, Massachusetts, New Jersey, New York, Rhode Island, and Vermont—and Canada are expected to consider adopting similar measures.

Chapter 2
New Approaches to Diesel and Alternatives to It

NEW DIESEL TECHNOLOGIES, FUEL VARIATIONS, AND SERVICE CONCEPTS

Diesel remains the fuel predominantly used in the US transit sector. According to the American Public Transportation Association's (APTA's) 2006 survey, diesel fuel powered 81.4 percent of the 57,616 transit buses operated in the US, down from 90.1 percent in 2001 and 98.0 percent in 1993.[91] Also, of the 2,399 buses that agencies had on order as of January 1, 2006, only 71.1 percent were diesel units.[92] (APTA's survey represents an estimated 70 percent of all transit bus fleet operators in the US. Small-city and rural agencies operate most of the vehicles that were not included in the survey, and these buses would be 30 feet or less in length. APTA's survey includes an estimated 90 percent of buses between 35 and 45 feet in length and 99 percent of articulated buses.)

In response to increasingly stringent emissions requirements (imposed by EPA at the federal level and by CARB in California at the state level), diesel engine manufacturers are developing new emission control technologies and designing engines to run on cleaner burning fuel variations such as ultra low-sulfur diesel and biodiesel.

Emission Control Technologies[93]

Diesel oxidation catalysts (DOCs) reduce particulate emissions by oxidizing CO, gaseous hydrocarbons, and liquid hydrocarbons that adhere to carbon particles in diesel exhaust. DOCs have proven to be effective in reducing particulate emissions from older buses. EPA has certified several brands of DOCs that can reduce particulate emissions by 20 to 50 percent.[94] However, DOCs will not meet EPA's 2007 particulate emissions standards without the additional use of particulate filters.

Diesel particulate filters (DPFs) reduce the emissions of PM by filtering it from the exhaust stream. To work effectively, DPFs must undergo "regeneration," a process that cleans the filter using oxidation catalysts. The oxidation catalysts convert N_2O to NO_2, which destroys soot trapped on the walls of the filter and thereby avoids the clogging problems that plagued earlier particulate traps. EPA has certified several brands of DPFs that can reduce PM emissions by up to 90 percent.[95] However, for DPFs to function properly, engines must burn low-sulfur fuel.

Exhaust gas recirculation (EGR) systems reintroduce exhaust gas into the engine, decreasing peak combustion temperature and thereby reducing NO_x emissions. If gas recirculation and temperatures are not balanced properly, EGR systems can increase the emissions of PM. However, increased PM emissions should not be a significant problem because manufacturers plan to integrate DPFs into their new engines, which would greatly reduce PM emissions.

Selective catalytic reduction (SCR) systems use ammonia or urea to convert NO_x into harmless nitrogen and oxygen. SCR systems are commonly used to reduce NO_x emissions from stationary sources, such as power plants, and manufacturers in Europe and Japan are developing this technology for heavy-duty vehicles.[96] However, SCR systems are expected to be more difficult to integrate into vehicles than EGR systems because SCR systems require precise control systems to ensure that the proper amount of ammonia or urea is injected into the engine. Also, an infrastructure that distributes ammonia or urea would be needed before SCR systems can be widely adopted.

Ultra-Low Sulfur Diesel

Because the sulfur present in diesel fuel can damage PM and NO_x aftertreatment systems,[97] EPA mandated that the sulfur content of diesel fuel intended for highway use be reduced by 97 percent. (This mandate became effective October 15, 2006.) Although this new diesel formulation, called ultra-low sulfur diesel (ULSD), is expected to cost more than conventional petroleum diesel and to slightly lower fuel economy, EPA calculates that its use will reduce NO_x emissions by 2.6 million tons/year and PM emissions by 110,000 tons/year.[98]

Meeting the expected demand for ULSD could present some challenges. A report by the US General Accounting Office (GAO) says fuel suppliers must resolve two key issues related to ULSD supply. First, ULSD must be made available on time in sufficient volumes and at enough locations. Second, fuel distributors must be able to avoid contaminating ULSD with higher sulfur fuel that uses the same distribution systems.[99] However, US refineries are already beginning to produce ULSD, and an EPA analysis indicates that it will be available in quantities sufficient enough to meet demand when the 2007 heavy-duty standards come into force.[100]

The Appeal of “Clean Diesel”

Shifting to ULSD and new aftertreatment systems will allow transit fleets to reduce their emissions while retaining their existing buses and refueling infrastructure. Some transit fleet operators find this prospect appealing, and it has already influenced their purchasing decisions. In January 2005, the Cleveland (OH) Regional Transit Agency (RTA) voted to phase out its 160 compressed natural gas (CNG) buses in favor of new clean diesel buses.

In December 2004, the board of the Denver (CO) Regional Transportation District (RTD) decided to continue deploying diesel buses rather than switch to CNG buses, a move advocated in a public campaign mounted by Clean Energy, a CNG fuel provider. The RTD board voted to buy 183 new diesel units built by the Gillig Corporation. The buses, which can run on ULSD, will cost $53.6 million, nearly $13 million less than a comparable order of natural gas buses.[101]

Clean Diesel and Energy Security Goals

Although clean diesel will enable transit agencies to meet EPA's requirements of improving the air quality in their regions of operation, it does not reduce their use of oil-derived fuel. Agencies that rely on diesel could face unexpected fuel price spikes caused by instability in key oil-producing regions such as the Middle East. Also, in the event of a future transition to hydrogen fuel cell vehicles, fleet operators that retain diesel-powered fleets will face larger transition costs than those faced by operators that switch to CNG buses because these operators will already have an infrastructure designed to distribute gaseous fuels and have the personnel trained to use them.

Bus Rapid Transit Concept

An increasingly popular model of transit service, called bus rapid transit (BRT), seeks to make traditional bus service more suitable to the contemporary urban environment. The Federal Transit Administration's (FTA's) BRT slogan "Think rail, use buses"[102] describes the BRT concept. This type of bus service integrates coordinated improvements and strategies to create a faster, more well-defined bus system that is modeled on the light rail concept. BRT systems may include the following components[103]:

- Special roadways or lanes (busways) dedicated exclusively to buses or high-occupancy vehicles
- Traffic engineering enhancements, such as giving buses priority at traffic signals, that reduce congestion and save time
- Intelligent transportation system (ITS) technologies, such as vehicle-location systems and onboard passenger information systems
- Prepaid fare options, electronic fare-collection systems, more modern stops or stations, and service strategies that improve boarding times and rider comfort
- Transit-friendly land use development and other urban design enhancements
- Bus designs with low floors, wide doors, and greater maneuverability

Curitiba (Brazil), a city of 2.2 million people, is recognized as the BRT pioneer. Although the city's per capita income and automobile ownership rates are higher than Brazil's national averages, nearly 70 percent of Curitiba's daily commuters use bus transit. Because of this high ridership figure, the total number of automobile trips in the city has been reduced by approximately 27 million per year. Likewise, fuel consumption has been reduced by 30 percent per capita—equivalent to an annual savings of 27 million liters (7.1 million gallons) of fuel.[104] The BRT concept has also played a role in making Curitiba one of the cleanest cities in Brazil in terms of air pollution.[105]

Other transit agencies across the globe have embraced the BRT concept, including those in Bogotá (Colombia), Brisbane (Australia), Kunming (China), and Ottawa (Canada). In the US, BRT is attracting interest in Albuquerque (NM), Boston (MA), Charlotte (NC), Cleveland (OH), the Dulles Corridor (VA), Eugene (OR), Hartford (CT), Honolulu (HI), Los Angeles (CA), Miami (FL), San Jose (CA), and San Juan (PR).

Transit agencies and governments consider BRT to be an attractive alternative to light rail. Even though it is designed to travel routes and carry a passenger volume comparable to those of a light rail system, BRT offers the advantages of cost, flexibility, and performance. A US General Accounting Office (GAO) study, *Bus Rapid Transit Shows Promise*, concluded that BRT systems generally have lower capital costs per mile than light rail systems. According to GAO's study, BRT projects that run buses on city streets cost an average of $680,000 per mile and those that use dedicated busways cost an average of $13.5 million per mile, while light rail projects cost an average of $34.8 million per mile (all totals in 2000 dollars).[106]

An FTA report, prepared by CALSTART, estimated that the number of communities implementing new BRT service corridors is increasing by four to six per year. If this pace of growth continues, the demand for BRT buses between 2004 and 2013 is projected to be 5,210 vehicles.[107]

ALTERNATIVES TO DIESEL

A new generation of alternative fuel and advanced technology (AF/AT) buses—including CNG, LNG, hybrid, and biodiesel buses—offers an array of commercially available options. These buses have proven to be reliable, economically viable (given the range of government economic incentives), and beneficial for the urban environment and its inhabitants. They are also capturing a growing portion of transit bus market.

According to APTA's 2006 survey, 10,396 buses (18.0 percent of the US bus population) are running on alternative fuels or using advanced technologies, slightly more than two and a half times the number in 2000.[108] Table 2.1 shows the numbers of AF/AT buses on the road between 1996 and 2006.

The Future of Heavy-Duty Vehicles

The increased use of alternative fuels and advanced technologies in the transit bus sector seems to be the start of a growing trend in the heavy-duty vehicle market. At least that is the opinion of the participants who responded to WestStart-CALSTART's annual Clean Fuels and Technologies Market Forecast Survey 2005.[111] The 125 respondents included stakeholders from various sectors: truck and engine manufacturers, component suppliers, fleet operators, fuel providers, government regulators, environmentalists, and academics.

When asked for their views about future fuels for the heavy-duty vehicle market, respondents replied that, in 2010, they expected diesel to hold 80.7 percent of the market share, with natural gas at 7.7 percent, hybrids at 8.9 percent, and fuel cell/hydrogen at 3.2 percent. By 2020, they anticipated that traditional diesel fuel (in a low-sulfur blend) would account for the 65 percent of the market share, while alternative fuels and advanced technologies would make up approximately 35 percent. In a breakdown of this 35 percent, hybrids represented 18.4 percent, natural gas 10.6 percent, and fuel cell/hydrogen 8.6 percent.

In discussing future challenges, respondents cited oil supply and cost as the second and third most crucial issues facing the heavy-duty vehicle sector between 2005 and 2020. (Meeting EPA's 2010 emission requirements was the top-ranked issue.) The survey found that 69 percent of respondents believed oil supply challenges will have a "significant" or "very significant" impact on US businesses by 2015.[112]

Table 2.1. Alternative Fuel and Advanced Technology Buses, 1996–2006

	CNG/LNG			Biofuels			Hybrid-Electric					
Year	No.	% of AF/AT	% of All Buses	No.	% of AF/AT	% of All Buses	No.	% of AF/AT	% of All Buses	Total AF/AT	AF/AT as % of Total	Total Buses
1996	1,421	69.00	2.82	569	27.62	1.13	—	—	—	2,060	4.09	50,344
1997	1,909	78.43	3.83	476	19.56	0.96	—	—	—	2,434	4.88	49,841
1998	2,494	82.50	4.94	484	16.01	0.96	—	—	—	3,023	5.99	50,447
1999	3,201	87.24	6.20	418	11.39	0.81	—	—	—	3,669	7.11	51,608
2000	3,844	95.67	7.19	81	2.02	0.15	68	1.69	0.13	4,018	7.52	53,464
2001	4,979	94.96	9.02	127	2.42	0.23	80	1.52	0.14	5,243	9.50	55,190
2002	6,376	94.91	11.03	142	2.11	0.25	113	1.68	0.20	6,718	11.62	57,815
2003	7,106	95.19	12.36	123	1.65	0.21	146	1.96	0.25	7,465	12.99	57,461
2004	7,009	93.89	12.46	174	2.33	0.31	181	2.42	0.32	7,465	13.27	56,241
2005	7,917	87.71	13.98	208	2.30	0.37	606	6.71	1.07	9,026	15.93	56,650
2006	8,749	84.61	15.19	376	3.62	0.65	961	9.24	1.67	10,396	18.04	57,616

Source: American Public Transportation Association, "Mode Data: Bus and Trolleys," in *2006 Fact Book*, 57th ed., Washington, DC; American Public Transportation Association, April 2006, table 57, p. 46, available at http://www.apta.com/research/stats/factbook/documents/bustb.pdf.

Pending transit agency bus orders show that fleet operators continue to purchase AF/AT buses. Of the 2,399 transit buses on order as of January 2006, 13.4 percent were AF/AT models, down from a peak of 40.9 percent in 2004 and the smallest percentage ordered since 2000.[109] One possible explanation for the decrease in pending orders for AF/AT buses is that fleet operators are seeking to meet emissions reduction requirements by purchasing conventional buses that run on low-sulfur diesel fuel.

A look at potential transit bus orders—orders planned but not actually placed as of January 2006—indicates that fleet operators plan to purchase additional AF/AT buses, but not as aggressively as they have in the past. Of 7,143 total potential orders, 1,121 (15.7 percent) were for AF/AT models, the lowest level since 2001. One possible explanation for the declining number of potential AF/AT bus orders is that fleet operators have not decided on the power source for potential bus orders; in 2006, 23.6 percent of potential orders did not specify a power source, compared to 7.4 percent and 8.9 percent undecided potential orders in 2003 and 2004, respectively.[110]

Government Financial Incentives for Alternatives to Diesel

Federal Programs

At the federal level, three programs administered by FTA provide transit agencies with grants that can help them switch to AF/AT buses (see Table 2.2). In addition to these programs, federal tax credits are available to assist with the purchase of AF/AT buses, alternative fuels, and required infrastructure improvements.

Table 2.2. Federal Sources for Transit Bus Funding

Program	Administering Agency	Program Purpose	Program Funding
Congestion Mitigation and Air Quality Improvement (CMAQ) Program	Federal Highway Administration and Federal Transit Administration	To fund highway, transit, and environmental programs in nonattainment areas of the US	$8.9 billion in matching funds available for fiscal years 2005–2009
Urbanized Area Formula Program	Federal Transit Administration	To fund transit improvement projects in urban areas	$22.2 billion appropriated for fiscal years 2005–2009
Clean Fuels Formula Grant Program	Federal Transit Administration	To fund transit agency capital improvement projects related to buses	$238.1 million appropriated for fiscal years 2005–2009

Sources: US Department of Transportation, "The Safe, Accountable, Flexible and Efficient Transportation Equity Act of 2003: Title I—Federal-Aid Highways," available at http://www.fhwa.dot.gov/reauthorization/safetea_bill_t1.htm#sec1101, and American Public Transportation Association, "TEA 21 Reauthorization Bill Passed and Sent to President!" *Washington Report*, August 3, 2005, available at http://www.apta.com/government_affairs/washrep/2005august03.cfm.

Congestion Mitigation and Air Quality Improvement (CMAQ) Program. The Federal Highway Administration (FHWA) and FTA administer the Congestion Mitigation and Air Quality Improvement (CMAQ) Program, which provides funds for AF/AT transit bus and fueling infrastructure projects. Congress funded CMAQ through the Safe, Accountable, Flexible and Efficient Transportation Equity Act of 2005 (SAFETEA), making nearly $8.9 billion available between fiscal years 2005 and 2009.[113]

CMAQ funds are intended for projects in areas that have the most severe air pollution problems—places that EPA has designated as "nonattainment areas" because they fail to meet national ambient air quality standards for ozone, CO, NO_2, sulfur dioxide, PM, and lead. However, local transit agencies and those seeking CMAQ grants do not have direct access to program funds. Each year, FHWA and FTA provide the funds to state transportation agencies, which can distribute funds to grant-seekers or to local metropolitan planning organizations (MPOs). If the latter option is taken, the local MPOs distribute the moneys.

Transit agencies are the primary beneficiaries of CMAQ, having received 44 percent of the $6.3 billion distributed during its first eight years (1992 through 1999). Of this funding, only $193 million (3.1 percent) went to alternative fuel vehicle projects.[114] Alternative fuel vehicle projects funded by CMAQ must use at least one qualifying alternative fuel, such as natural gas, ethanol, methanol, electricity, or propane.[115]

Urbanized Area Formula Program. As part of the 2005 transportation bill, Congress renewed the Urbanized Area Formula Program, which is designed to fund transit improvement projects in urbanized areas (defined by the US Census Bureau as an incorporated area with a population greater than 50,000).[116] In 2004, $560 million in grants went to bus purchases, including nearly $113 million for 320 natural gas transit vehicles[117] and more than $46 million for other AF/AT transit vehicles.[118] Congress has authorized approximately $22.2 billion for the program between fiscal years 2005 and 2009.[119]

Clean Fuels Formula Grant Program. The Bus Capital Investments Program administers FTA's Clean Fuels Formula Grant Program, which assists transit agencies in purchasing or leasing clean fuel buses, retrofitting or repowering buses with cleaner engines, constructing alternative fuel fueling outlets, and modifying garage facilities to accommodate alternative fuel buses. The program covers up to 80 percent of the costs of these activities.[120] Previously, only alternative fuels were eligible for this program; however, under changes implemented in SAFETEA, clean diesel projects are eligible for grants that equal up to 25 percent of a program's total funding.[121] The Clean Fuels Formula Grant Program can provide $288 million in grants between fiscal years 2005 and 2009.[122]

Tax Credits. SAFETEA included important tax credits for the sale of alternative fuels. Section 11113, the Volumetric Excise Tax Credit for Alternative Fuels, provides sellers of alternative fuels with a tax credit of 50 cents per gallon for every gallon or gallon equivalent of natural gas, hydrogen, or propane or 50 cents per gallon of ethanol or biodiesel used in a fuel blend.[123]

State Programs

Because clean transit projects are typically used to address air quality problems, states with established, well-funded alternative fuel vehicle grant programs are often those with serious air quality problems, such as California, Texas, and New York.

California. In California, state agencies such as the California Energy Commission and local air quality groups such as the South Coast Air Quality Management District (SCAQMD) regularly provide grants for alternative fuel projects. Funding criteria and available amounts vary from program to program.

California Assembly Bill 2776, signed into law in 1990, offers the most consistent source of funding. It established a $4 surcharge on annual vehicle registration fees, and the money collected through this program is used to fund projects that reduce air pollution from motor vehicles in compliance with the California Clean Air Act. Of the collected funds, 30 percent are allocated for air quality management district projects needed to comply with the state's Clean Air Act, 40 percent are distributed to cities and counties to reduce air pollution from motor vehicles, and 30 percent are deposited in a discretionary fund for air pollution reduction projects.[125]

Launched in 1998, California's Carl Moyer Clean Engine Incentive Program (Moyer Program) provides private companies and public agencies with money to cover the incremental costs of purchasing engines and equipment that are cleaner than those required by air pollution regulations.[126] Administered by CARB, the Moyer Program distributes funds to local air quality management districts, which provide the money to grantees via a competitive grant process.[127] During its first four years, the program provided $11.3 million for 778 alternative fuel engines for transit buses.[128]

Texas. The Texas Emission Reduction Program (TERP) offered approximately $40 million in grants in 2002, with similar amounts allocated for each year until 2006. TERP is designed to help fleets acquire cleaner heavy-duty vehicles, retrofit or repower existing vehicles with cleaner engines, and build alternative fuel fueling stations. Like the Moyer Program, it provides funds to cover the incremental costs of a heavy-duty alternative fuel vehicle and the full cost of alternative fueling installations. TERP reserves money for heavy-duty fleets in the Houston-Galveston and Dallas-Fort Worth non-attainment areas.[129]

New York. New York's budget for alternative fuel vehicle projects supports various grant programs that fund the purchase of cleaner burning transit buses and alternative fueling stations. Some of these programs use CMAQ dollars; others receive funding through the state's Clean Water/Clean Air Bond Act, which was adopted in 1996.

New York's $55 million Clean Fueled Bus Program—funded by the Clean Water/Clean Air Bond Act and administered by the New York State Energy Research and Development Authority—provides transit agencies, municipalities, and schools with funds to cover the incremental costs of a clean-fueled bus. As of spring 2005, the program had awarded fleets $28 million to pay for the acquisition of 435 CNG buses and 102 diesel hybrid-electric buses.[130]

Energy Policy Act of 2005

The Energy Policy Act of 2005 provides incentives and federal funding for clean transit projects.[124]

Tax Credit Incentives

Sec. 1341: the Alternative Motor Vehicle Credit provides a tax credit for purchases of new, dedicated alternative fuel vehicles, covering 50 percent of the incremental cost of the vehicle, plus an additional 30 percent if the vehicle meets certain tighter emission standards. The credit can be as much as $32,000, depending on the price of the vehicle. To be eligible, the vehicle must be fueled by natural gas, methanol blends of 85 percent or higher, or hydrogen. For non-tax-paying entities, the seller of the vehicle can take the credit and pass it on.

Sec. 1342: the Credit for Installation of Alternative Fueling Stations provides a tax credit equal to 30 percent of the cost of refueling equipment for stations that dispense natural gas, biodiesel blends of 20 percent or greater, or hydrogen. The credit can be as much as $30,000 for large stations and $1,000 for home refueling appliances. For non-tax-paying entities, the seller of the fueling equipment can take the credit.

Grants for Demonstration Projects

Sec. 721–723: the Advanced Vehicles Pilot Demonstration Program offers competitive grants of up to $15 million each to fund up to 30 advanced vehicle demonstrations geographically dispersed locations. Eligible projects must involve the deployment of alternative fuel, hybrid, or fuel cell vehicles, which may include transit buses.

Sec. 731: the Fuel Cell Transit Bus Demonstration Program provides $10 million per year for five years (2006 to 2010). These funds will be distributed to five projects that demonstrate up to 25 fuel cell transit buses each in five geographically dispersed locations.

Chapter 3
Natural Gas Buses

Of all available alternative fuels and advanced technologies, natural gas is the most established commercially and the most popular: in its 2006 survey of US transit fleets, the American Public Transportation Association (APTA) identified 7,856 natural gas-fueled buses, which represent 15.2 percent of all buses and 84.2 percent of all alternative fuel/advanced technology (AF/AT) buses on US roads.[131]

Natural gas transit buses have a record of reliability, backed by industry support and more than a decade of on-road experience. They offer lower nitrogen oxide (NO_x) and particulate matter (PM) emissions than diesel buses. Government financial incentives at the state and federal levels can also make natural gas an economical choice. Some analysts believe that, as new US Environmental Protection Agency (EPA) heavy-duty emission regulations come into effect in 2007 and 2010, the rising costs for diesel emissions controls and improving economies of scale for natural gas vehicles will make the lifecycle costs of a natural gas bus lower than those of a diesel bus.

In relative terms, natural gas is more plentiful domestically than oil: of the 22.5 quads (quadrillion BTUs) of natural gas consumed by all sectors in the US in 2003, only 4 quads (18 percent) were imported.[132] Although the percentage of imported natural gas is expected to rise over time, increased use of natural gas offers more energy security than the use of diesel.

NATURAL GAS BUS TECHNOLOGY

A naturally occurring fossil fuel, natural gas is often found in underground reservoirs in conjunction with oil, but it is sometimes found in separate deposits. Like oil, it is extracted through wells drilled from the surface; however, unlike oil, natural gas does not require extensive refining prior to use because it contains few contaminants.

By composition, natural gas is approximately 90 percent methane (CH_4), a simple, clean-burning molecule that contains one atom of carbon and four atoms of hydrogen. This low carbon content allows natural gas to burn more cleanly. It produces lower emissions of key criteria pollutants such as NO_x and PM than diesel fuel, although it can generate higher emissions of carbon monoxide (CO) and certain air toxics if aftertreatment technology is not used.

As a fuel, natural gas can be carried in gaseous form, called “compressed natural gas” (CNG), or liquid form, called “liquefied natural gas” (LNG). Both forms are used in the transit market. In a CNG storage system, cylinder tanks are typically filled to a pressure between 3,000 and 3,600 pounds per square inch (psi). Even when natural gas is compressed at these high pressures, the storage system takes up three to four times more space than a conventional gasoline fuel tank, and the cylinder tanks weigh two to three times more (although tanks made of composite carbon fiber are lighter than metal tanks).[133]

In an LNG system, the natural gas is stored at a temperature of approximately –250° Fahrenheit to liquefy it. LNG must be stored in specially designed insulated containers so that it does not warm and shift to its gaseous phase. LNG contains much more energy per pound or per unit of space than CNG, which gives LNG-fueled buses a greater traveling range than CNG buses. However, handling super-cold LNG requires special procedures and training.

EMISSIONS

CARB Study

Comparative emissions data compiled by CARB (in collaboration with the University of California, Davis and the University of Connecticut) demonstrate that, when outfitted with similar emissions control technologies, the current generation of natural gas buses generates fewer emissions than diesel buses.[134] In tests conducted in 2002, CARB monitored emissions from three CNG buses and two diesel buses. Two CNG buses were equipped with oxidation catalysts, while the other used no aftertreatment technology. The diesel buses were fitted with catalysts and ran on low-sulfur diesel fuel, although one of them was retrofitted with a diesel particulate filter (DPF).

NO_x emissions from the CNG buses were approximately 50 percent lower than those from either configuration of the diesel buses. The difference in PM emissions depended on aftertreatment technology. The CNG bus without aftertreatment produced 70 percent less PM and the catalyst-equipped buses produced 84 percent less PM than the non-DPF-equipped diesel bus. The catalyst-equipped CNG buses generated approximately the same PM emissions as the diesel bus equipped with a DPF, but the CNG bus without aftertreatment generated nearly double the PM emissions.

The study also compared carbon monoxide (CO) and air toxics emissions. The CNG bus without aftertreatment emitted higher levels of CO than the diesel buses, although the two CNG buses equipped with oxidation catalysts emitted nearly the same levels of CO as the diesel buses.[135] Regarding air toxics emissions, the CNG bus without aftertreatment produced greater levels of formaldehyde and benzene than the diesel buses. However, the CNG buses equipped with catalysts generated formaldehyde emissions that were 95 percent lower than those from the other CNG bus (the diesel buses produced negligible amounts of formaldehyde), and their benzene emissions were approximately 70 percent lower than those of the other CNG bus, 66 percent lower than those of the non-DPF-equipped diesel bus, and nearly identical to those of the DPF-equipped diesel bus. Only the CNG bus without aftertreatment emitted 1,3-butadiene.[136]

VTT Processes Study

A 2004 study by the Finland-based consulting company VTT Processes provided information about the comparative emissions performance of CNG and ultra-low sulfur diesel fuel.[137] Seven European buses—four running on CNG and three on ultra-low sulfur diesel, from model years 2002 to 2004, each with various exhaust aftertreatment configurations—were tested. The four CNG buses were equipped with catalysts, one diesel bus had no aftertreatment controls, one used an oxidation catalyst, and the other was fitted with a continuously regenerating trap particulate filter. The CNG buses emitted less PM than the diesel bus with no aftertreatment controls and the diesel equipped with the catalyst, while they emitted approximately the same amount of PM as the diesel bus that used the particulate filter. However, NO_x emissions from the CNG buses were between 13 and 78 percent lower than those from the diesel buses.[138]

NOISE

Under certain driving conditions, CNG buses are quieter than their diesel counterparts. The Natural Gas Bus Project Berlin, a project co-financed with the European Commission, examined external decibel (dB) levels for natural gas and diesel buses during the following driving conditions: constant driving at 30 and 50 kilometers per hour [km/hr], acceleration while passing, and acceleration while pulling from a bus stop. Although CNG buses were only slightly quieter than diesel buses at constant driving speeds, CNG buses were 3.3 dB quieter during acceleration to pass, which is equivalent to a 50-percent decrease in noise effect. However, CNG buses were 1 dB louder when pulling from a bus stop.[139]

PERFORMANCE

Range

Natural gas buses can travel nearly 300 miles between fuel stops, which is approximately 100 miles less than comparable diesel models but which is sufficient enough to cover most daily transit routes.[140] They have also proven to be as reliable as their diesel counterparts in transit service. A 2000 study by the Natural Gas Transit Users Group (TUG)—a group of transit agencies whose fleets include natural gas buses and which is sponsored by the US Department of Energy (DOE), the National Renewable Energy Laboratory (NREL), and the Clean Vehicle Education Foundation—tracked the reliability of diesel and natural gas buses. It found that road call rates were approximately 2.14 per 100,000 miles for diesel buses and 2.15 per 100,000 miles for natural gas buses.[141]

Maintenance

The maintenance rate for engines depends on several factors and varies from agency to agency. INFORM could not find statistics that compared overall natural gas and diesel bus maintenance rates, but anecdotal information is available. For example, in the TUG study, Pierce Transit of Tacoma (WA) reported that its CNG buses accumulated 260,000 miles without requiring engine rebuilding. Sacramento (CA) Regional Transit estimated that CNG engines can accumulate as many as 300,000 miles between engine overhauls. These rates for miles between engine rebuilds are comparable to those for diesel engines. Regarding LNG, maintenance staff at Sun Metro in El Paso (TX) examined two bus engines after 100,000 miles and found each to be in excellent condition.[142]

COSTS

Costs for natural gas bus programs fall into three general categories: procurement; development of the necessary refueling, maintenance, and storage infrastructure; and operations and maintenance.

Procurement

New natural gas buses typically cost between $15,000 and $60,000 more than comparable diesel models. For example, APTA bus purchase figures for 2004 show that a 40-foot low-floor CNG transit bus costs approximately $324,000, nearly $23,000 more than a comparable diesel bus but $90,000 less than a comparable diesel hybrid-electric bus.[143] This incremental cost between a CNG and conventional diesel bus is related to the extra equipment, design, and production costs associated with natural gas models.

As the economies of manufacturing natural gas buses improve with increased demand and as emissions standards require additional aftertreatment equipment for diesel buses, the cost differences may decrease or even disappear. A July 2005 report by TIAX, a research and development group, projected and compared the future lifecycle costs of model year 2010 diesel and natural gas transit buses, refuse haulers, and short-haul trucks. The study, prepared for the California Natural Gas Vehicle Partnership, estimated that after 2010, lifecycle costs for natural gas buses will be lower than those for diesel buses if crude oil remains above $31/barrel in 2005 dollars.[144] The TIAX projections for future diesel vehicle costs are connected to uncertainty in diesel engine technology and the emissions control equipment needed to meet the 2010 EPA heavy-duty vehicle regulations. In the meantime, government funds and tax incentives are available to help offset the incremental acquisition costs of natural gas buses.

Fueling Infrastructure

The total cost of a natural gas fueling installation depends on many factors, such as the location, land costs, number of buses to be refueled, type of fuel (CNG or LNG), accessibility of a gas line, availability of adequate pressure, type of drying or filtering equipment, type and amount of compression, and amount of on-site storage required.[145] In 2001, NREL conducted a survey of natural gas bus users in the transit sector, and it found that the costs of natural gas fueling facilities varied widely—from $60,000 for a 10-year-old facility serving 11 buses to $16 million for a state-of-the-art facility serving 80 buses.[146]

Some extra capital costs can often be partly offset with government funds. For example, when Sun Metro of El Paso (TX) spent nearly $1.4 million (for construction and equipment) to build a state-of-the-art fueling facility that dispensed CNG and LNG, federal Congestion Mitigation and Air Quality Improvement (CMAQ) Program grants covered the entire amount.[147]

Public-private partnerships between infrastructure developers and fleets can also assist in developing natural gas fueling infrastructure. In 1999, the Los Angeles County Metropolitan Transport Authority and Trillium, USA (a company that specializes in designing and installing CNG fueling stations) formed the first public transit agency-private contractor partnership to finance and build a CNG refueling station.[148] Clean Energy (another CNG infrastructure provider) has began to offer capital for financing new fueling stations or upgrading existing stations in return for long-term maintenance and fuel contracts. For instance, Clean Energy financed the construction of the Foothill Transit's Pomona and Irwindale (CA) CNG fueling stations by providing more than $3 million in up-front capital for each station; Foothill Transit will repay over a period of several years.[149]

In these public-private partnerships, the infrastructure developer contributes funding and technical expertise at every stage from design to maintenance, while the transit agency provides the ridership and vehicles that make the fueling station economically viable. Such partnerships help mitigate many of the risks that surround the construction of natural gas fueling stations—risks that many transit agencies are reluctant to take. These partnerships work by shifting the burden of heavy up-front construction investment from the transit agency to the private company, by providing monitors and technicians during the fuelling station's operation, and providing the security of a national support network.

The costs of a natural gas fueling station can be recouped in other ways. For instance, a transit agency that installs a natural gas fuel outlet could make it accessible to other fleets in the community. At its Clean Fuels Mall, SunLine Transit of Thousand Palms (CA) sells CNG, LNG, and other fuels to the public.[150] Also, smaller fleets could share infrastructure, which would allow them to more easily meet the minimum fuel usage requirements made by some turnkey station developers.

Facilities

In addition to developing fueling infrastructure, transit agencies need to modify their existing storage and maintenance facilities to accommodate natural gas vehicles. They need to ensure ventilation, install leak detection systems, and implement monitoring systems. Again, costs vary from location to location because many factors must be considered, including location, availability of land, number of buses being accommodated, local fire safety and building construction codes, labor costs, whether buses are being stored indoors or outdoors, and whether old structures are being modified or new ones built. Costs for facilities can range from $320,000 to $15 million.[151]

Operations and Maintenance

Fuel costs for natural gas buses depend on several factors, such as the age of the buses in a fleet, the routes on which buses operate, and the price an agency pays for fuel.

Fuel prices compiled by DOE show that even though the costs of natural gas and diesel vary around the country, CNG is typically less expensive than diesel fuel (see Table 3.1).

Table 3.1. Regional Diesel and CNG Fuel Prices, June 2006

US Region	Diesel ($ / gallon)	CNG ($ / gallon equivalent)
New England	3.04	No information
Central Atlantic	3.01	2.56
Lower Atlantic	2.93	No information
Midwest	2.88	1.21
Gulf Coast	2.89	2.28
Rocky Mountain	3.03	2.16
West Coast	3.25	2.30

Source: US Department of Energy, *The Alternative Fuel Price Report*, June 1, 2006, available at http://www.eere.energy.gov/afdc/resources/pricereport/pdfs/afpr_jun_06.pdf (accessed August 9, 2006).

Note: Heating values were used to convert gallons of gasoline equivalent to gallons of diesel equivalent: one cubic foot of CNG contains 1,000 BTU of energy, while one gallon of diesel contains 130,000 BTU.

Transit agencies can employ innovative strategies for regulating the price that they pay for natural gas. As a report published by NREL explains,

> Fuel-purchasing savvy can also result in significant [fuel] cost savings. Recent deregulation within the natural gas industry now makes it possible for most transit properties to negotiate for long term prices and seasonal bulk purchases at prices well below what they would pay by simply purchasing [natural gas] direct from a local utility. Most transits have been following a similar practice with diesel fuel for years, but only a small number are now doing this with natural gas. Those that do report not only significant savings but pricing stability that doesn't fluctuate with closely linked, weather-sensitive commodities like fuel oil for home heating.[152]

An informal survey conducted by TUG in August 2004 shows that some natural gas transit fleets have locked in long-term natural gas prices that are lower than prevailing diesel prices. For example, SunLine Transit of Palm Desert (CA) signed a multiyear fixed-price contract that includes natural gas and full operating and maintenance services for its stations. The price amounted to $0.93/diesel gallon equivalent (dge), with a fully loaded cost of $1.40/dge.[153] Phoenix (AZ) had a two-year fixed-price gas contract at approximately $0.84/dge, and the Washington Metropolitan Area Transit Authority (WMATA) had a two-year fixed-price contract for $0.79/dge.[154]

Maintenance costs for natural gas buses vary from agency to agency.

COMMERCIAL AVAILABILITY

Engines

In North America, three manufacturers produce commercially available, fully warranted natural gas engines suitable for buses: Clean Air Power/Caterpillar, Cummins Westport, and John Deere. Their product lines offer models that can use CNG or LNG, operate at various horsepower ratings, and meet several emission standards (see tables 3.2).

Table 3.2. Commercially Available Heavy-Duty Natural Gas Engines, Model Year 2005

Manufacturer	Model	Description	Fuel	Emissions Standards
Clean Air Partners/ Caterpillar	C10, C12, 3126B dual-fuel engines	Engines available in hp ratings of 250, 315, and 410	Diesel + CNG, Diesel + LNG	CARB optional low-NO_x levels; EPA LEV*
Cummins Westport	B Gas Plus and C Gas Plus	C Series available in hp ratings of 250, 275, and 280 B Series available in hp ratings of 195, 200, and 230 Lean-burn, spark ignition	Dedicated CNG or LNG	C8.3: CARB LEV; CARB low-NO_x, CARB ULEV, and EPA '04 heavy-duty engine standards when outfitted with advanced catalyst
	L Gas Plus	Six-cylinder, 8.9 liter, ultra-low-emission engine with a hp rating of 320	CNG or LNG	US EPA 2004 standard; US EPA 2004 transit bus standard; CARB optional Low-NO_x and Low-PM; Euro V/EEV capable
John Deere Power Systems	6081 HFN	8.1-liter engine, available in hp ratings of 250, 275, and 280 at 2,200 rpm Lean-burn, closed-loop	CNG or LNG	EPA ULEV* and CARB emission certified for use in 50 states; California optional low 1.5 gr NO_x + NMHC and 1.8 gr NO_x + NMHC

Source: "The 2005 Natural Gas Vehicle Shopping Guide," *Natural Gas Fuels,* July 2004, p. 32. Additional information was gathered from manufacturer websites.

* US EPA has established low-emission vehicle (LEV) and ultra-low-emission vehicle (ULEV) standards.

Buses

A diverse selection of natural gas transit buses are readily available from virtually all North American bus manufacturers (see Table 3.3).

NATURAL GAS SUPPLIES

In recent years, a combination of declining production from old wells, delays in bringing new domestic production online, and steadily rising demand (mostly for heating and electricity generation) have resulted in tightening natural gas supplies and record prices in the US.[155]

In 2003, of the 22.5 quads (quadrillion BTUs) of natural gas consumed by all sectors in the US, only 4 quads (18 percent) were imported.[156] EIA expects imports to grow at an annual rate of 4.1 percent between 2003 and 2025, rising from 4 to 9.7 quads.[157] Currently, the majority of natural gas imports comes from Canada via pipelines.[158] Future new imports are expected to come via tankers carrying super-cooled LNG because natural gas cannot be shipped overseas in its gaseous form. (LNG must be received at marine terminals equipped with infrastructure for re-gasifying, storing, and delivering the gas.)

EIA projects that total natural gas consumption by the transportation sector will increase 42 percent between 2003 and 2025, rising from 0.67 quads to 0.95 quads. However, other sectors will continue to consume the majority of natural gas: industry, 48 percent; residential, 28 percent; and commercial, 19 percent. The transportation sector will account for only 4 percent of total gas consumption.[159] EIA also projects that, by 2025, only 31 percent of US natural gas demand will be met by imports, 66 percent of which will come from overseas.[160]

Table 3.3. Commercially Available Natural Gas Buses, Model Year 2005

Manufacturer	Model	Model Description	Length	Fuel	Engine
Blue Bird Corporation	All American RE	Rear-engine school bus Available in 66- or 84-passenger	33 to 40 feet	CNG	Deere
	CSFE Commercial Series	Front-engine transit or shuttle bus			Cummins
	CS Series	Rear-engine transit or shuttle bus	32 to 39 feet	CNG	Cummins or Deere
	Ultra LF Series	Low-floor commercial transit or shuttle bus	30 and 35 feet		Cummins
	Xcel 102	Transit or shuttle bus.	30, 35, or 40 feet	CNG	Deere
Champion Bus	CTS	Transit or shuttle bus Available to meet all ADA requirements	25.5, 26, 29 feet	CNG or LNG	Cummins
	Defender	Medium-duty transit or shuttle bus Available to meet all ADA requirements	27 and 29.3 feet	CNG	
El Dorado National	Axess	Low-floor transit bus with roof-mounted natural gas tanks	35 and 40 feet	CNG or LNG	Cummins
	EZ-Rider II	Low-floor, rear-engine transit bus	30 and 35 feet	CNG or LNG	Cummins or Deere
	MST II	Front-engine transit bus	26 to 30 feet	CNG	Cummins
	Transmark and XHF	Transit bus	30 to 40 feet	CNG or LNG	
Goshen Coach	Euroshuttle	Front-engine, rear-drive, medium-duty transit or shuttle bus built on Freightliner MB-55 chassis.		CNG	Cummins
Neoplan USA Corporation	AN 440	Heavy-duty bus	40 feet	CNG	Cummins
	AN 460	Heavy-duty articulated bus	60 feet	CNG or LNG	
New Flyer of America	C30LF, 35LF, C40LF, L40LF	Low-floor, heavy-duty transit buses	30, 35, and 40 feet	CNG or LNG (L40LF only)	Cummins
North American Bus Industries (NABI)	35-LFW, 40-LFW	Low-floor transit bus	35 and 40 feet	CNG or LNG	Cummins
	CompoBus	Heavy-duty, advanced-composite transit bus	40 and 45 feet	CNG or LNG	
	60-BRT	Low-floor, advanced-design, articulated city transit bus	60 feet	CNG or LNG	
Orion Bus Industries	Orion V	High-floor transit bus	32 and 35 feet	CNG	Cummins
	Orion VII	Low-floor transit bus	30, 35, and 40 feet	CNG	
Thomas Built Buses	Saf-T-Liner HDX	Rear-engine school bus		CNG	Deere
	TransitLiner HDX	Rear-engine commercial bus		CNG	
TransTeq	Ecomark II	Natural gas-electric hybrid shuttle bus	45 feet	CNG	

Source: "The 2005 Natural Gas Vehicle Shopping Guide," *Natural Gas Fuels*, July 2004, p. 32. Additional information was gathered from official websites and through personal communications with bus manufacturers.

MAJOR FLEET USERS

The natural gas transit bus population and the number of transit agencies using them has grown considerably in since 1995. In 1995, 1,035 natural gas transit buses traveled US roads. By the beginning of 2006, the number rose to 8,749, an eightfold increase, according to APTA figures.[161]

The increased numbers of natural gas buses being used corresponds with their expanded share of the overall transit bus market. At the beginning of 2006, natural gas buses held a 15 percent market share, up from 2.0 percent in 1995 and 6.2 percent in 1999. Although their share of the AF/AT market rose from 58.0 percent in 1995 to 95.0 percent in 2001, that share decreased to 84.6 percent in 2006 because other AF/AT buses, particularly hybrid-electric buses, gained commercial viability and popularity.[162]

At the beginning of 2006, 86 US transit agencies that provided data to the APTA survey operated natural gas buses, up from 65 in 1999. Of these, 22 agencies have fleets that contain more than 100 natural gas buses, up from 10 in 1999 (see Table 3.4).

Los Angeles County (CA)

For more than a decade, the Los Angeles County Metropolitan Transit Authority (LA MTA) has led the transit sector in terms of the overall number of natural gas buses in use, operating 2,168

Table 3.4. Transit Agencies with 100 or More Natural Gas Buses

City	Transit Agency	Number of Buses
Atlanta, GA	Metro Atlanta Rapid Transit Authority	324 CNG
Boston, MA	Massachusetts Bay Transportation Authority	360 CNG
Cleveland, OH	Greater Cleveland Regional Transit Authority	165 CNG
Dallas, TX	Dallas Area Rapid Transit	15 CNG, 183 LNG
El Paso, TX	El Paso Mass Transit Department	70 CNG, 35 LNG
Fort Worth	Fort Worth Transportation Authority	123 CNG
Los Angeles, CA	Los Angeles County MTA	2,168 CNG
New York, NY	MTA New York City Transit	480 CNG
New York, NY	New York City Dept of Transportation	356 CNG
Orange County, CA	Orange County Transportation Authority	232 LNG
Phoenix, AZ	City of Phoenix PTD	320 LNG
Riverside, CA	Riverside Transit Agency	129 CNG
Sacramento, CA	Sacramento Regional Transit District	258 CNG
San Bernardino, CA	OMNITRANS	150 CNG, 3 CNG/electric battery
San Diego, CA	San Diego Metro Transit Development Board	113 CNG
San Diego, CA	San Diego Transit Corporation	157 CNG
Syracuse, NY	CNY Centro	124 CNG
Tacoma	Pierce Transit	169 CNG
Tempe, AZ	City of Tempe Transportation Division	20 LNG/electric battery, 104 LNG
Tucson, AZ	City of Tucson MTS	89 CNG, 47 CNG/diesel
Washington, DC	Washington Metro Area Transit Authority	164 CNG
West Covina, CA	Foothill Transit	192 CNG

Source: American Public Transit Association, *2005 Transit Vehicle Database*, Washington, DC: American Public Transit Association, 2005.

CNG buses as of January 2006. In 1993, LA MTA decided that all of the buses that it purchased would run on alternative fuels. Since then, its AF fleet has logged more than 450 million service miles, reducing NO_x and PM emissions by an estimated 6,400 tons and 50 tons, respectively.[163]

In 2005, LA MTA began phasing in the first of its 200 high-capacity North American Bus Industries (NABI) CNG articulated buses, which will be used on some of the city's busiest bus routes, including a new Metro Orange bus rapid transit (BRT) line. These buses, referred to as "Metroliners," are powered by a 360-hp Cummins engine designed specifically for natural gas.[164] Each of these buses costs $633,000 and carries up to 57 passengers, approximately 45 percent more than a standard bus.

A Formula for Success

In 2001, NREL surveyed 42 transit agencies that operated natural gas buses to examine their experiences. Using this information, NREL identified seven basic steps for building a successful CNG or LNG fleet.[168]

1. Research the fuel and maintenance options; seek advice from others with experience
2. Involve partners at an early stage, including state and local politicians, regulators, and safety officials
3. Build commitment from all staff, from upper management to drivers and mechanics
4. Clearly understand and budget for all costs
5. Institute a comprehensive training program that builds a comfort level for drivers, technicians, maintenance workers, and others
6. Install an adequate, expandable fueling infrastructure; work with experienced consultants to determine station sizing, equipment specifications, and design; and work with a fuel supplier to determine fuel sourcing and pricing
7. Increase ridership and revenue by promoting the program, giving emphasis to reducing pollution

California

California has six other bus fleets that contain 100 or more natural gas buses: Orange County, Riverside, Sacramento, San Bernardino, San Diego, and West Covina. California is home to many natural gas bus fleets because of the state's progressive transportation policies and the South Coast Air Quality Management District's (SCAQMD's) transit bus rule.

Phoenix (AZ)

The Phoenix Public Transportation Department (PTD) has the largest fleet of LNG-fueled transit buses in the US (and the world), operating 320 LNG buses. After analyzing various fuels in 1995, Phoenix PTD selected LNG as the best alternative to diesel for heavy-duty vehicles in fixed route service, partly because projected fuel station building costs and maintenance costs were lower for LNG than for CNG.[165] In 1997, Phoenix PTD ordered 156 40-foot, low-floor buses from NABI at a cost of approximately $325,000 per bus (nearly $50,000 more than a comparable diesel bus).[166]

Phoenix PTD's current LNG buses get 1.7 mi/gallon, have a range of 300 mi, and travel nearly 220 mi/day. They require an average of 264 mechanic hours per year, compared to 318 mechanic hours for the agency's diesel buses. To fuel its LNG fleet, Phoenix PTD built two LNG fueling stations: the first cost $3.6 million, and the second, completed in May 2002, cost $2.5 million.[167]

Chapter 4
Hybrid-Electric Buses

Since the publication of *Bus Futures* in 2000, hybrid-electric buses—buses with advanced engines that rely on a battery pack to maximize fuel efficiency—have become fully commercial. Although several transit agencies in the US have added hybrids to their bus fleets, hybrid-electrics account for less than 2 percent of the overall US bus population and only 9 percent of all alternative fuel/alternative technology (AF/AT) buses.

At the beginning of 2005, transit fleets that provided data to the American Public Transportation Association (APTA) reported using 611 hybrid-electric buses, up from the 184 hybrids in service one year earlier (see Table 4.1).[169]

Most hybrid-electric buses run on diesel, but hybrid-electric buses can also run on compressed natural gas (CNG), liquefied natural gas (LNG), gasoline, and propane.[170] Although hybrid-electrics offer lower emission levels and fuel costs compared to buses powered by other fuels, these reductions are primarily the result of using less fuel.

Because most hybrid-electric buses run on diesel, they do not require the installation of new fueling infrastructure—which makes hybrid-electric technology an attractive alternative for heavy-duty fleet operators.[171] In a study released in March 2005, the research and development group TIAX and Global Insight, an industry forecasting firm, predicted that, by 2020, 15 to 25 percent of the heavy-duty vehicles worldwide will incorporate some form of hybrid technology, partly because heavy-duty vehicle operators follow regularly scheduled routes and can accurately calculate how much they will save on fuel and brake maintenance by switching to hybrids.[172]

Table 4.1. Existing Fleets of Hybrid-Electric Buses in the US

Year	Number of Buses	Percentage of AF/AT Buses	Percentage of All Buses
2005	611	6.8	1.1
2004	184	2.5	0.3
2003	115	0.2	0.2

Source: American Public Transit Association, *2005 Transit Vehicle Database*, Washington, DC: American Public Transit Association, 2005.

Although the current generation of diesel hybrid-electric buses can provide reduced emission levels, they cost more to purchase than conventional diesel and natural gas buses. However, fuel savings can offset this incremental initial cost over time.

HYBRID-ELECTRIC BUS TECHNOLOGY

Hybrid-Electric Drives

For propulsion, hybrid-electric vehicles rely on a combination of a fuel-fed internal combustion engine (ICE) and an energy storage system (usually a battery pack). A hybrid-electric drive has four main components:

- The *auxiliary power unit* (APU) is generally an ICE/generator combination, but it could be a fuel cell or turbine. The APU converts the fuel's chemical energy into electrical energy.
- The *energy storage device*, usually a battery pack but possibly a flywheel or ultracapacitor, is the centerpiece of hybrid-electric technology.
- The *electric drive motor* typically draws power from the energy storage device, but it could draw power from the APU if the drive is a parallel configuration. The electric motor drives the vehicle's wheels.
- The *electronic controller* regulates the energy flow from the energy storage device or APU to the motor. The controller also monitors the energy storage device and automatically directs the engine to recharge it when its charge becomes low.[173]

Using the energy storage device to provide direct power to the electric motor allows the engine to operate at a constant speed.[174]

Electric-Hybrid Drive Configurations

The engine and battery can operate in one of two configurations: parallel or series. In a *parallel configuration*, both power sources (the APU and the energy storage device) connect to the vehicle's wheels, and either can propel the vehicle. Because the parallel configuration has two separate energy paths, the vehicle's wheels can be driven mechanically by the ICE, electrically by the batteries, or by a combination of both.[175]

In a *series configuration*, the ICE feeds energy exclusively to an electric generator that supplies electricity to the traction motor that powers the wheels. Excess power is stored in the battery pack, which is larger, heavier, and more expensive than that used in a parallel configuration. When the vehicle requires more energy than the battery pack can supply, the engine and battery can both power the motor.[176]

Because hybrids in parallel configurations typically have larger engines and smaller, lighter, and cheaper batteries than those in series configurations and because they can draw full power from the APU and ICE simultaneously, hybrids with parallel configurations are better equipped for applications that require sustained operation at high speeds.

However, the series configuration offers more torque for improved acceleration at low speeds, and the engine operates independently from the vehicle, theoretically allowing the engine/

generator to run at peak efficiency all the time, which produces lower emissions and increased fuel economy in stop-and-go traffic.[177] For this reason, the series configuration is used more predominantly in hybrid buses.

Regenerative Braking

Regenerative braking is an important feature of hybrid-electric technology. In conventional vehicles, energy generated during braking is lost to the environment in the form of heat or noise. During regenerative braking, the motor captures this kinetic energy and, acting as a generator, feeds it to the battery or other onboard systems such as air conditioning and lighting. In addition to using energy more efficiently, this regenerative system reduces brake maintenance costs because the electronically actuated brakes are more efficient than conventional mechanical brakes, whose linings wear down more quickly.[178] Because transit buses often operate in stop-and-go traffic conditions, they can effectively take advantage of regenerative braking.[179]

Energy Storage

Even though the current generation of lead-acid batteries used on most hybrid-electric buses have proven to be cost efficient and reliable, different kinds of batteries with greater energy efficiency, higher density, and longer life spans are becoming available. The most popular alternatives are nickel-metal hydride (Ni-MH), nickel-cadmium (Ni-Cd), and lithium (Li) batteries.[180] Compared to lead-acid batteries, Ni-MH and Ni-Cd batteries offer shorter recharge times and higher energy density, which allows them to be lighter in weight, while Li batteries are more energy efficient and have longer life spans. Each type of battery has its own safety concerns; for instance, lead, cadmium, and acid are highly toxic and must be disposed of carefully. Although none of these alternative batteries can compete with the low cost of lead-acid batteries, some bus manufacturers feel that higher initial investments can offset frequent and expensive replacements in the future, while other manufacturers consider the operational advantages of Ni-MH, Ni-Cd, and Li batteries to be worth the higher price.[181]

Researchers are investigating energy storage devices that may be more efficient than batteries. A gasoline hybrid-electric ISE-ThunderVolt transit bus that uses an energy storage system based on ultracapacitors recently completed Federal Transit Administration durability testing. Ultracapacitors store energy electrostatically, which reduces charging and discharging times. They are also more durable than batteries, store energy from regenerative braking more efficiently, and could reduce the maintenance and replacement costs associated with battery packs.[182]

Emissions Controls

The diesel-powered ICEs used in electric-hybrids are compatible with cleaner diesel formulations and much of the aftertreatment technology developed for conventional diesel engines. New York City Transit’s hybrid fleet uses exhaust gas recirculation, particulate filters, and ultra-low sulfur diesel to further reduce emissions from its hybrid-electric buses.[183]

Table 4.2. Fuel Economy and Emissions Comparison by Bus Type

Bus Type	Fuel Economy (mi / gallon)	Carbon Monoxide (g / mile)	Carbon Dioxide (g / mile)	Nitrogen Oxide (g / mile)	Particulate Matter (g / mile)
Conventional Diesel	3.5–4.7	1–3	2,200–2,600	15–30	0.05–0.25
CNG	2.5–3.2	1–10	2,300–2,800	9–25	0.02
Diesel Hybrid-Electric	6.0–6.8	0.1–0.2	1,400–1,600	9–15	0.02–0.03

Source: Environment Canada, *Orion VII Transit Bus Equipped with BAE SYSTEMS HybriDrive Propulsion System (MY2004): Emissions and Fuel Economy Test Report*, Table 8, ERMD Final Report 04-18, September 2004.

EMISSIONS

Because of their greater fuel efficiency, diesel hybrid-electric buses generate emissions at levels below those of conventional diesel buses. For this same reason, diesel hybrid-electrics that use aftertreatment technology produce emissions at levels comparable to or lower than those of natural gas buses.

In April 2004, Environment Canada (the Canadian counterpart of the US Environmental Protection Agency), in collaboration with Orion Bus and BAE Systems, tested the emissions and fuel economy of a diesel hybrid-electric bus. They then made a head-to-head comparison to results gathered from previous tests of conventional diesel and CNG buses. The hybrid-electric was a 2004 Orion VII transit bus equipped with a BAE HybriDrive Propulsion System (a series configuration), an exhaust gas recirculation- (EGR-) equipped Cummins ISB02 diesel engine, and a Johnson Matthey CRT diesel particulate filter. The bus was fueled with ultra-low sulfur diesel.[184]

The Orion VII compared favorably to the conventional diesel bus and was similar or superior to the CNG bus in several respects (see Table 4.2). Compared to a conventional diesel bus, the Orion VII's fuel economy was 20 to 40 percent better, while its emission levels of nitrogen oxide (NO_x) were 30 to 40 percent lower, and those of particulate matter (PM) were 30 to 50 percent lower. Compared to a CNG bus, the Orion VII's fuel economy was doubled, while its carbon monoxide (CO) emissions were dramatically lower, and its NO_x and PM emissions were similar.[185]

NOISE

Although diesel hybrid-electric buses have yet to be evaluated for their noise levels, anecdotal reports from fleet operators[186] and assertions made by transit agencies and vehicle manufacturers[187] suggest that these vehicles generate less noise because of their operating characteristics. For example, the mechanical technology of hybrid-electric buses allows them to accelerate and climb hills without revving their engines, eliminating one of the main sources of noise associated with conventional diesel buses. Also, the diesel engines used in diesel hybrid-electric buses are much smaller than those of conventional buses, thereby producing less engine noise.[188]

The most advanced hybrid-electric buses have an all-electric operation feature that reduces idling-related noise (and emissions) by automatically turning off the engine when the vehicle stops for more than a few seconds. New Jersey Transit reports that this feature will allow its Thundervolt hybrid buses to operate with the engine off as much as 30 percent of the time and will enable them to operate in "ultra-quiet, zero emission" mode for up to 10 miles at a time in environmentally or noise-sensitive areas such as tunnels or residential neighborhoods.[189]

PERFORMANCE

Although the first generation of hybrid-electric buses was not expected to meet the same reliability standards as conventional diesel or natural gas buses, the second generation of hybrid-electrics is proving to be reliable. Since February 2004, New York City Transit's fleet of Orion VII hybrid-electric buses has accumulated more than 2 million revenue service miles, with an availability rate at or above 85 percent (which meets the agency's standard requirement for conventional diesel and CNG buses).[190]

The evaluation of hybrid-electric transit buses is ongoing. For example, four transit agencies are testing hybrid-electric buses as part of the US Department of Energy's Advanced Vehicle Testing Activity Program: IndyGo (Indianapolis, IN), King County Metro (Seattle, WA), Knoxville Area Transit (TN), and New York City Transit (NY). Operational, maintenance, and performance data that compare hybrid-electrics to similar diesel buses in those fleets are being collected.[191]

COSTS

The cost of a new hybrid-electric bus has dropped considerably in the past few years, decreasing from nearly $840,000 to approximately $415,000.[192] However, a hybrid-electric bus costs more than a conventional diesel and natural gas model. Also, battery replacement can add between $10,000 and $35,000 to the cost of operating a hybrid-electric bus over its lifetime.[193]

Manufacturers of hybrid-electrics have predicted fuel efficiency improvements ranging from 20 to 40 percent over conventional buses, which would offer substantial fuel savings over time.[194] Also, anecdotal evidence from New York City Transit indicates that hybrid-electrics have nearly double the brake life and fewer particulate filter problems than conventional buses, which reduces operating and maintenance costs.[195]

In addition, the savings from improved fuel economy may offset the higher purchase price of a hybrid-electric. Assuming a 30-percent average increase in fuel economy in its hybrid-electric buses, New York City Transit expects to save nearly 50,000 gallons of fuel per bus throughout a 12-year service life. The agency calculates that, if fuel prices double from what they were in May 2005, this fuel savings will enable it to recoup the incremental initial costs of its Orion VII buses.[196]

COMMERCIAL AVAILABILITY

Transit agencies considering hybrid-electrics can choose from a variety of commercially available bus models designed in series or parallel configurations and using ICEs fueled by diesel, natural gas, or other fuels (see Table 4.3). The latest generation of hybrid-electric buses also features improved components and better system integration.

Table 4.3. Commercially Available Hybrid-Electric Buses

Manufacturer	Model	Model Description	Type	APU Fuel
Ebus	Hybrid-Electric Transit Bus	22-foot, low-floor transit bus	Series	CNG, LNG, diesel, propane
Electric Vehicles International	EL-25	27.5-foot, low-floor shuttle bus	Series	Propane
GM/Allison	EV40, EV50	40-foot transit bus, 50-foot articulated bus	Parallel	Diesel
ISE Research–ThunderVolt	TB30HG, TB40HD, and TB40HG	transit buses/shuttle buses	Series	Diesel, gasoline
New Flyer of America	DE40LF, DE60LF	40-foot transit bus, 60-foot articulated bus	Parallel	Diesel
Orion Bus Industries	Orion VII	transit bus	Series	Diesel
TransTeq	EcoMark	45-foot, low-floor transit bus	Series	CNG

Source: US Department of Energy, Clean Cities Program, available at http://www.eere.energy.gov/cleancities/progs/afdc/hsearch_hybrid.cgi (accessed July 29, 2005).

MAJOR FLEET USERS

Hybrid-electric buses are operating in more than one dozen transit fleets across the US, as of January 1, 2005 (see Table 4.4 for the 11 largest fleets).

New York City Transit (NY)

In 1998, the Metropolitan Transportation Authority's New York City Transit (NYCT) became the first transit agency in North America to demonstrate a pilot fleet of diesel hybrid-electric buses in revenue service. NYCT purchased 10 40-ft BAE/Orion VI buses, at a cost of approximately $465,000 each.[197] Between 1998 and May 2005, the buses collectively logged approximately 700,000 miles in normal revenue service. NYCT reported that the experience was generally "very positive,"[198] even though the hybrid-electrics were somewhat less reliable and significantly more costly to maintain than the rest of its fleet. However, these issues were expected for a small, pre-commercial fleet, and NYCT indicated that bus performance exceeded expectations for a new technology.[199]

Table 4.4. Largest Hybrid-Electric Bus Fleets in the US

City	Transit Agency	Type of Fuel
Seattle, WA	King County Dept of Transportation	214 Diesel Hybrids
New York City, NY	MTA New York City Transit	128 Diesel Hybrids
Denver, CO	Regional Transportation District	38 CNG Hybrids
Philadelphia, PA	Southeastern Pennsylvania TA	32 Diesel Hybrids
Las Vegas, NV	Regional Transportation Comm of South NV	30 Diesel Hybrids
Seattle, WA	Central Puget Sound RTA	20 CNG Hybrids
Tempe, AZ	City of Tempe Transportation Div	20 LNG Hybrids
Syracuse, NY	CNY Centro	19 Diesel Hybrids
Lancaster, PA	Red Rose Transit Authority	16 Diesel Hybrids
Tampa, FL	Hillsborough Area Regional Transit Authority	11 Diesel Hybrids
Honolulu, HI	City & County of Honolulu DTS	10 Diesel Hybrids

Source: American Public Transit Association, *2005 Transit Vehicle Database*, Washington, DC: American Public Transit Association, 2005.

After its experience with the pilot fleet, NYCT purchased 325 BAE/Orion VII hybrid-electric buses, the world's largest fleet of hybrid-electric transit buses in service. Each bus cost $385,500.[200] Since February 2004, this fleet has logged more than 2 million miles in revenue service.

NYCT reported that NO_x emission levels for these buses are approximately one-third those of buses equipped with particulate filters and fueled with ultra-low sulfur diesel and that they are one-half the levels of CNG buses. Also, CO emission levels are one-fourth those of ultra-low sulfur diesel and one-tenth those of CNG buses.[201]

King County Metro, Seattle (WA)

In May 2004, Seattle's King County Metro received an order of 213 diesel hybrid-electric buses—New Flyer 60-ft articulated hybrid buses equipped with General Motors hybrid drivetrains. Each bus cost $645,000 ($152 million total),[202] and this fleet replaced the agency's dual-mode Bredas on service routes that traveled through a long bus tunnel in downtown Seattle. King County Metro purchased the hybrid-electrics because the length of the tunnel required buses with a quieter, lower emissions operation than conventional diesel buses could deliver.[203]

King County Metro reported that emissions have been reduced more than expected and that it is saving $3 million per year in maintenance costs.[204] The agency also noted that it is pleased with the reliability of the hybrid-electrics; after 1.5 million miles of road service (as of October 2004), the buses averaged more than 6,000 miles between road calls.[205]

CTTransit, Hartford (CT)

CCTransit—the agency that provides transit service for Hartford, New Haven, and Stamford—operated two New Flyer diesel hybrid-electrics during an 18-month demonstration project. Preliminary results suggest that the hybrid-electrics delivered a fuel economy 10 percent better than that of new diesel buses and 30 to 35 percent better than that of older diesel buses in the fleet. Maintenance costs for the hybrid-electrics were also lower. Although official data have not been released, CTTransit expects emission levels to be reduced by approximately 20 percent. Each bus cost nearly $500,000.[206]

Denver Regional Transportation District (CO)

The Denver Regional Transportation District operates 38 hybrid-electric shuttle buses built by TransTeq and fueled by natural gas.[207] The agency was the first to purchase these shuttle buses and use them in daily service.[208]

Chapter 5
Biodiesel and Biodiesel Blend Buses

According to the American Public Transportation Association (APTA) survey, the number of buses fueled by biodiesel increased from four in 2003 to 118 in 2005. Produced from renewable sources—either first-use oils (e.g., soybean oil, rapeseed oil, or animal tallow) or second-use oils (e.g., recycled cooking oil)—biodiesel can be used alone or in blends with conventional diesel. Conventional diesel engines require minimal or no modifications to run on biodiesel, making this alternative fuel an attractive choice for transit agencies unable to afford the initial infrastructure or vehicle investments associated with switching to natural gas or hybrid-electric buses.

Made primarily from agricultural products, biodiesel can reduce emission levels and even offer some performance improvements. The US Department of Agriculture (USDA) estimates that, because of the biodiesel tax incentive included in the American JOBS Creation Act of 2004 and extended by the Energy Policy Act of 2005, annual biodiesel consumption in the US will increase from 30 million gallons in 2004 to 124 million gallons by the end of 2006.[209] The USDA believes that biodiesel and ethanol (a similar renewable fuel made from corn and used in light-duty vehicles) could provide at least 20 percent of the nation's transportation fuel needs.[210]

Biodiesel is usually blended with conventional diesel or ultra-low sulfur diesel (ULSD) in ratios of 2, 5, or 20 percent—blends called B2, B5, and B20, respectively.[211] Integrating biodiesel or biodiesel blends into a fleet operation can be a relatively easy and cost-effective transition compared to that for other alternative fuels or advanced technologies.

BIODIESEL TECHNOLOGY

Fuel Characteristics

Biodiesel is a fuel produced from organically derived fats or oils, and its combustion properties are so similar to those of diesel that it can be used as a diesel substitute of additive in conventional diesel engines. Biodiesel is created through a chemical process called transesterification in which a feedstock, such as soybean oil, is reacted with alcohol to produce biodiesel and glycerin.[212]

Although biodiesel can be used in its pure ("neat") form, it is more typically blended with diesel in varying percentages. These blends are designated by the name BXX, where XX represents the percentage of biodiesel in the blend. For example, B20, the most common blend of biodiesel used in the US, is a mix containing 20 percent biodiesel and 80 percent conventional diesel. (Low blends such as B5 and B2 are available on a more limited basis.) The US Environmental Protection Agency (EPA) has registered pure biodiesel (B100) as a fuel, and the US Departments of Energy and Transportation consider B100 to be an alternative fuel.[213] Blends of diesel are considered to be fuel additives.[214]

Potential Fuel Sources

A joint study conducted by the US Departments of Energy and Agriculture examined the potential for creating energy from biomass. The study estimated that, with improvements in agricultural processes and land management practices, the US could annually harness 1.3 billion tons of biomass from agricultural products and forests to create biofuels in an environmentally sustainable manner.[215] The study projected that, in the early twenty-first century, fuels made from biomass (including biodiesel and ethanol) could account for an increasing portion of the fuel used in the transportation sector, rising from 0.5 percent in 2001 to 4 percent by 2010, to 10 percent by 2020, to 20 percent by 2030. The study also estimated that if all soybeans not used for food, feed, or export were used to create biodiesel, up to 415 million gallons of biodiesel could be produced annually in the US.[216]

EMISSIONS

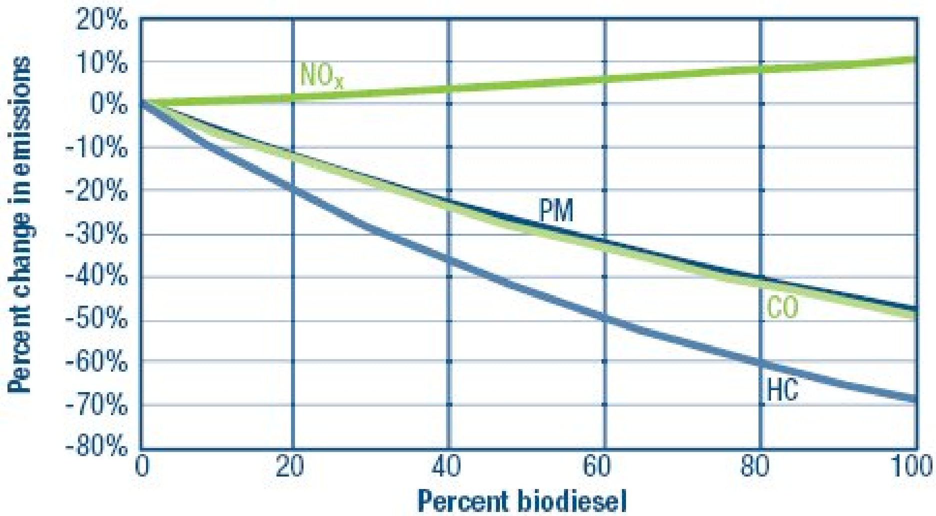
By nature of their composition, biodiesel and biodiesel blends offer reductions in emission levels of most pollutants, including particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons.[217] Because biodiesel contains virtually no sulfur, it emits practically no sulfate when burned.[218] It also has a high oxygen content (approximately 11 percent by weight),[219] which reduces the byproducts generated during incomplete combustion, notably CO, unburned hydrocarbons, and several air toxics. In addition, DOE's Office of Energy Efficiency and Renewable Energy estimated that B100 reduces CO_2 emissions by more than 75 percent.[220]

However, the amount by which emissions levels are reduced depends on the biodiesel content; the higher the percentage of biodiesel in the blend, the greater the reduction in emission levels (see Figure 5.1). For example, using B20 does lower emission levels as much as using B100.

A 2002 study conducted by EPA found that the feedstock used to make biodiesel also affects the levels of emissions that were generated. For example, the emission levels of NO_x, CO, and PM were relatively higher for soybean-derived biodiesel than for rapeseed-derived biodiesel (the dominant variety used in Europe). Likewise, the emission levels of these three pollutants were relatively higher for rapeseed-derived biodiesel than for animal-derived biodiesel.[221]

Some studies indicate that using blends with a high biodiesel content may increase NO_x emission levels, ranging from a 2-percent increase with B20 to a 10-percent increase with B100.[222] However, laboratory tests being conducted by the National Renewable Energy

Figure 5.1. Emissions Comparison of Biodiesel and Biodiesel Blends in Heavy-Duty Engines



Source: US Environmental Protection Agency, "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions," draft technical report, EPA-420-P-02-001, October 2002, available at http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf (accessed August 4, 2006).

Laboratory (NREL) show that bus engines running on B20 achieve NO_x emissions reductions of 4 percent over engines running on conventional diesel.[223] Another study conducted by NREL indicates that increases in NO_x emissions found in other studies may be partly attributable to problems with the emissions testing process.[224]

NOISE

Because biodiesel can run in a conventional diesel engine without any additional modifications, engines running of biodiesel or biodiesel blends can be expected to generate the same levels of noise as an engine using conventional diesel.

PERFORMANCE

Advantages

Although similar to conventional diesel in many respects, biodiesel has a number of physical and chemical properties that offer the following performance advantages:

- *High lubricity*. Although diesel's lubricity is generally sufficient to prevent wear on fuel-injection equipment and other metal surfaces that regularly come in contact with fuel, low-sulfur formulations have a lower lubricity than conventional diesel. Adding biodiesel to ultra-low sulfur diesel can restore lubricity without increasing sulfur content. Blends as low as B2 can meet manufacturer lubricity requirements for fuel injection equipment.[225]
- *High cetane number.* The cetane number (comparable to the octane number of gasoline) measures how easily diesel fuel auto-ignites in a diesel engine; the higher the cetane number, the quicker the fuel ignites in the engine. Biodiesel's relatively high cetane number (between 48 and 65 compared to a cetane number between 40 and 55 for petroleum-based diesel[226]) means that it has a relatively short ignition delay time, thereby reducing the formation of engine deposits that can cause engine wear and increase emissions.[227]

- *High flash point.* The flash point is the lowest temperature at which a flammable liquid, such as fuel, can mix with air and ignite. Biodiesel's relatively high flash point (between 212º and 338º F[228]) is nearly double that of conventional diesel, thereby making it safer to handle and transport and less likely to combust during vehicle collisions.[229]

Disadvantages

Biodiesel also has a number of physical and chemical properties that create the following performance disadvantages:

- *High cloud and pour points.* Cold weather affects the performance of pure biodiesel. The pour point is the temperature below which fuel will not flow, and the cloud point is the temperature below which it begins to form wax crystals. Biodiesel's relatively high pour point (between 5º and 50º F) and cloud point (between 26.6º and 53.6º F) can cause fuel to gel and can affect performance in cold temperatures.[230] The solutions to these problems are similar to those for conventional diesel: blending the fuel with kerosene, using fuel heaters, or storing the vehicle indoors. Blends of up to B20 perform similarly to conventional diesel in cold weather.[231]
- *Reduced fuel economy*. Biodiesel's energy content is approximately 11 percent lower than that of conventional diesel. Thus, reductions in fuel economy can be estimated using the following formula: percentage of fuel economy reduction = percentage of biodiesel x 11 percent. For example, the fuel economy derived from B20 can be expected to be 2.2 percent lower than that of conventional diesel.[232]
- *Strong solvency.* Biodiesel is a strong solvent and may degrade natural or butyl rubbers over time. These materials were often used in the hoses and gaskets of vehicles built before 1994. Therefore, using pure biodiesel in an older engine may require a modest investment in new components; however, blends of B20 or less are not potent enough to affect these materials.[233]

COSTS

Biodiesel and biodiesel blends can be integrated into a fleet without major investments in fueling infrastructure or complex engine technologies, which are required with natural gas or hybrid-electric buses. In terms of fuel costs, biodiesel prices vary according to the feedstock used to produce it and shipping costs. Typically, biodiesel costs more than conventional diesel or natural gas. As of October 2006, B20 cost between $2.04 and $2.20 per gallon, compared to $1.71 to $1.93 per gallon for conventional diesel.[234] However, higher costs for biodiesel can be partly offset by maintenance costs savings derived from its high lubricity.

ISSUES SPECIFIC TO BIODIESEL

Availability

Produced at refineries located throughout the US, biodiesel is available in all 50 states, and it can be purchased in several ways. Fleet operators typically purchase it directly from a biodiesel supplier, which may deliver it in pure form (for onsite blending) or pre-blended; however, smaller fleets may choose to rely on a petroleum distributor.

B100 and B20 are also available at a growing number of retail fueling stations and fuel docks. The National Biodiesel Board (NBB) maintains an online list of retail fueling sites that offer biodiesel or biodiesel blends.[235] (As of August 2006, this list contained more than 900 entries.) Although fueling stations that carry biodiesel are more heavily concentrated in agricultural regions such as Minnesota, Indiana, and Missouri, such a station can be found in a majority of states. NBB also offers contact information for producers and marketers that will supply biodiesel to nearly any location in the US.[236]

Engine Warranties

According to NBB, "most major engine companies have stated formally that the use of blends up to B20 will not void their parts and workmanship warranties."[237] However, even though many engine manufacturers build units using biodiesel-compatible components, biodiesel advocates recommend contacting engine manufacturers for specific information. Table 5.1 shows the biodiesel and biodiesel blend standards that some manufacturers have established for their engines.

FEDERAL GOVERNMENT INCENTIVES

American JOBS Creation Act

A federal tax incentive included in the American JOBS Creation Act of 2004 reduced the cost of biodiesel fuels. This tax incentive works like a federal excise tax credit, and the amount is calculated as follows: for biodiesel made from first-use oils, the rate is 1 cent per gallon per percentage point of biodiesel blended with conventional diesel (e.g., 20 cents per gallon of B20), and for biodiesel made from secondary sources, it is 0.5 cent per percentage point of biodiesel blended with conventional diesel (e.g., 10 cents per gallon of B20). The USDA projects that this incentive will increase biodiesel demand in the US from an estimated 30 million gallons in 2004 to 124 million gallons annually starting in 2006.[238] The incentive went into effect on January 1, 2005, and was scheduled to expire December 31, 2006,[239] before it was extended by the Energy Policy Act of 2005.

Table 5.1. Recommended Biodiesel and Biodiesel Blend Standards

Manufacturer	Recommended Standard
EMA	Approved for up to 5 percent biodiesel; must meet ASTM D6751[a]
Caterpillar	Many engines approved for B100, others limited to B5; must meet ASTM D6751
Cummins	All engines approved for up to 5 percent biodiesel; must meet ASTM D6751
Detroit Diesel	Approved for up to 20 percent biodiesel; must meet DDC specific diesel fuel specification
Ford	Approved for up to 5 percent biodiesel; must meet ASTM D6751 and EN 14214
General Motors	All engines approved for up to 5 percent biodiesel; must meet ASTM D6751
International	Approve for up to 20 percent biodiesel; must meet ASTM D6751
John Deere	All engines approved for 5 percent biodiesel; must meet ASTM D6751

[a] To be a legal motor fuel, biodiesel must meet ASTM D6751 specifications. These specifications are available from American Society for Testing and Materials, available at http://www.astm.org/cgi-bin/SoftCart.exe/STORE/filtrexx40.cgi?U+mystore+odfz5276+-L+D6751+/usr6/htdocs/astm.org/DATABASE.CART/REDLINE_PAGES/D6751.htm.

Source: Bob McCormick, "Effects of Biodiesel on Pollutant Emissions," National Renewable Energy Laboratory, presentation for Clean Cities Informational Webcast on Fuel Blends, March 16, 2005, available at www.eere.energy.gov/cleancities/toolbox/pdfs/mccormick_webcast.pdf (accessed August 4, 2006).

Energy Policy Act of 2005

By extending the biodiesel tax incentive established in the American JOBS Creation Act, the Energy Policy Act of 2005 ensures that this incentive will remain in effect until the end of 2008.[240] The Energy Policy Act also authorized $5 million per year between 2006 and 2010 for a biodiesel engine testing program. If funded, this program will research the effects of current and future emissions control technologies on engines that run on biodiesel and biodiesel-ULSD blends.[241]

MAJOR FLEET USERS

A small but growing number of transit bus fleets in the US use biodiesel. APTA survey figures indicate that, in 2005, six fleets were using biodiesel or biodiesel blends in a total of 118 buses—nearly double the 63 buses that operated in four fleets at the beginning of 2004.[242] Worldwide, biodiesel is used in the transit sectors of several countries. Europe has been using rapeseed-derived biodiesel for years, and Canada and India are launching programs to use biodiesel in some of their transit fleets.

Intercity Transit, Olympia (WA)

Intercity Transit—which serves the cities of Olympia, Lacey, Tumwater, and Yelm in Washington[243]—uses B20 in its entire fleet of 66 transit buses.[244] In 2003, the Washington Department of Ecology gave Intercity Transit the state's top environmental award for its leadership role in using alternative fuels.[245]

King County Metro, Seattle (WA)

To complement its large fleet of diesel hybrid-electric buses, Seattle's King County Metro intends to increase its use of biodiesel. In 2005, King County Metro began running its diesel buses on a blend of 5 percent biodiesel and 95 percent ULSD; the agency plans to fuel its entire fleet of more than 1,200 buses with this B5 blend by the end of 2006. King County Metro expects to purchase 500,000 gallons of biodiesel each year, and it hopes that its commitment will help expand the market for biodiesel in the state, which is beginning to develop a biodiesel production industry.[246]

Knoxville Area Transit, Knoxville (TN)

Knoxville Area Transit (KAT) is one of several fleets that uses biodiesel but was not included in APTA's 2005 survey. In 2004, after experimenting with B5, KAT began using B20 in its fleet of more than 100 diesel buses and other vehicles. Barry Greenberg, KAT's director of maintenance, viewed biodiesel as a smart economic choice for Tennessee: "We're hopeful that production of biodiesel in Tennessee will come to fruition so that we'll know that more of our money is helping the Tennessee economy. That helps us help Tennessee grow its renewable and cleaner fuels future."[247]

Europe

In May 2003, the European Parliament passed a directive that required biofuels to replace 2 percent of all petroleum-derived fuels brought to market by the end of 2005; the required replacement rate will increase to 5.75 percent in 2010.[248] In addition, two German transit agencies operate exclusively biodiesel-fueled buses,[249] and a French government mandate requires all diesel sold to be blended with biodiesel in a B5 ratio to restore the lubricity lost when the country converted to low-sulfur fuels.[250]

Canada

In September 2004, the Toronto Transit Commission launched a 9-month project to test a biodiesel blend in 180 of its buses. The project will determine whether the agency uses biodiesel in its entire fleet of 1,500 buses.[251] Then, in October 2004, after several months of testing, the Halifax Regional Municipality (Nova Scotia) announced plans to switch its entire transit bus fleet to a B20 blend. Halifax Regional intends to derive its biodiesel from a byproduct generated during the production of Omega-3 oil, which is refined from fish oil. The agency expected that the switch to B20 would create a cost increase of less than 1 percent.[252]

India

Gujarat (a state in western India) and Gurgaon (a suburb of New Delhi) have introduced B5 into their bus fleets,[253] and biodiesel is fueling some express trains in commercial service.[254] Also, the jatropha tree provides India with an indigenous biodiesel feedstock that can be cultivated on an estimated 17.4 million hectares of land within the country.[255]

Chapter 6
Hydrogen Fuel Cell Buses

In recent years, hydrogen fuel cell vehicles have garnered substantial attention because, unlike other transportation technologies, they do not generate harmful emissions or greenhouse gases. Fuel cells provide energy via chemical reaction rather than fuel combustion, and they run on hydrogen, a carbon-free energy source. As a result, hydrogen fuel cells emit only water vapor and heat as byproducts. Also, even though hydrogen does not exist in its pure, gaseous form on Earth, it can be extracted from various sources, including fossil fuels, biomass, and water. Thus, hydrogen fuel cell vehicles could be a pollution-free, fully sustainable transportation solution.

Hydrogen fuel cell technology is already being demonstrated in more than a dozen transit bus fleets around the world. However, because of the significant technological obstacles that must be overcome before hydrogen fuel cell vehicles can match the cost and performance of conventional vehicles, many analysts believe that they will not become a fully commercial transportation option for at least ten years, perhaps several decades.[256] Despite this forecast, the US Department of Energy (DOE) has initiated an extensive research program designed to meet certain performance and cost targets that DOE hopes will help commercialize fuel cell technologies by 2015.[257]

HYDROGEN FUEL CELL TECHNOLOGY

Fuel Cells

A fuel cell is an electrochemical device that produces energy through a chemical reaction between a fuel (typically hydrogen) and an oxidant present within the cell (typically oxygen); the fuel does not combust, as happens in an internal combustion engine. In vehicles, layers of fuel cells are combined in a “stack” that converts the chemical energy produced inside the fuel cells into electricity to power an electric motor. A fuel cell stack converts hydrogen directly to electricity, without moving parts or combustion; thus, it produces only water vapor and heat as emissions, operates almost silently, and can potentially operate at double the efficiency of an internal combustion engine.[258]

Several types of fuel cells are being developed for various applications, ranging from personal electronic devices to large stationary power generators. The polymer electrolyte membrane (PEM) fuel cell is the fuel cell design currently favored for vehicle applications for two reasons: (1) it has a high power density, which allows the onboard fuel cell stack to be more compact, and (2) it can produce electricity at low temperatures, which is a necessity for vehicle start-up.[295] PEM fuel cells also promise low-cost manufacture.

Fuel Storage

In its pure, gaseous form, hydrogen has an even lower energy density than natural gas and must be stored in large, pressurized tanks. Current research is exploring various gaseous storage systems, including lightweight carbon fiber tanks, cryo-compression techniques that cool the hydrogen so more of it can be stored in the same amount of space, and "conformable" tanks that can use available space within a vehicle's internal structure more effectively.[260] Non-gaseous approaches are also being studied, such as storing hydrogen in super-cooled liquid form (similar to liquefied natural gas) and storing it in solid form in metal hydrides or carbon-based materials that can release hydrogen as needed.[261]

Another strategy is to extract (or "re-form") hydrogen onboard the vehicle from more energy-dense fuels such as gasoline, methanol, or natural gas. Not only would this approach allow hydrogen to be stored in a denser form, but it would eliminate the need for hydrogen production because it would use a readily available fuel and use existing infrastructure, thereby avoiding the cost associated with developing new refueling infrastructure. However, this approach still relies on using fossil fuels, which would not be a fully sustainable solution.

Hydrogen Production Systems

As a transportation fuel, hydrogen can be produced from various feedstocks, including water. Thus, it can be produced in potentially limitless quantities, and researchers are developing a range of technologies for producing hydrogen in economically and environmentally sustainable ways. The two most viable near-term technologies are (1) the re-formation of hydrogen from natural gas and (2) the production of hydrogen via the electrolysis of water.

Steam Re-formation

Of the 9 million tons of hydrogen annually produced in the US, 95 percent is created by the steam re-formation of natural gas—the most energy-efficient and cost-effective technology currently available. In steam re-formation, a gas (primarily methane) is reacted with steam to produce hydrogen, which can be used for fuel, and carbon dioxide, which can be sequestered or sold for other uses.

Electrolysis

Hydrogen can also be produced via electrolysis, which uses electricity to extract hydrogen from water. The electrical charge breaks the chemical bond that holds a water molecule together, releasing its constituent hydrogen and oxygen ions.

Electrolysis remains less efficient and more expensive than steam re-formation. However, electrolysis can enable hydrogen to be produced cleanly and sustainably if renewable sources of electricity, such as wind or solar power, are used.[262]

To improve efficiency and reduce the costs of conventional electrolysis, DOE is developing high-temperature electrolysis (HTE) production methods. HTE is also known as “steam electrolysis” because the electrolytic reaction occurs at a temperature high enough for the water to become steam, which reduces the amount of electricity needed to break the molecule into hydrogen and oxygen. DOE’s research is focused on developing HTE systems integrated into advanced nuclear reactor designs, which operate with enough excess heat to generate hydrogen via the HTE process.[263]

In late 2004, researchers at the Idaho National Engineering and Environmental Laboratory used an advanced nuclear reactor with an HTE system to achieve conversion efficiencies of 45 to 50 percent (i.e., the hydrogen produced contained 45 to 50 percent of the energy consumed during the process) versus efficiencies of approximately 30 percent from conventional electrolysis methods.[264] The Energy Policy Act of 2005 has facilitated the further development of the HTE concept. The act guaranteed $1.25 billion in funding to construct an experimental nuclear reactor in Idaho to produce electricity and hydrogen.[265]

EMISSIONS

Because fuel cells generate energy via a chemical reaction and because they run on hydrogen, a carbon-free energy source, the only emissions that they create are water vapor and heat.

NOISE

Fuel cell buses offer the quietest operating levels of any transportation technology. A study conducted for DOE’s Hydrogen, Fuel Cells & Infrastructure Technologies program compared the performance of a SunLine ThunderPower fuel cell bus to that of a conventional diesel bus. In terms of noise levels, the fuel cell bus generated the following noise levels: 57 decibels (dB) when stopped, 65 dB when traveling at 30 mph, and 75.9 dB when traveling at 55 mph, compared to 71 dB (stopped), 73 dB (30 mph), and 77 dB (55 mph) for the diesel bus.[266] However, because the decibel scale is logarithmic (i.e., increases are exponential), a reduction of only a few decibels can translate into a halving of noise levels.

Other data suggest that these noise reductions are typical. Scania, a large Swedish manufacturer of heavy-duty vehicles, reports that its fuel cell buses are approximately 7 dB quieter than diesel buses,[267] while Georgetown University found that the Generation I and Generation II buses used in its fuel cell bus demonstration program are 10 dB quieter than conventional buses.[268]

PERFORMANCE

Because hydrogen fuel cell buses are being used primarily in demonstration projects, analytical data related to their performance is limited. However, some anecdotal evidence is available. For example, between mid-2000 and September 2001, SunLine Transit in Thousand Palms (CA) tested a demonstration ZEbus hydrogen fuel cell bus.[269] The 40-foot, 70-passenger Zebus was propelled by a 205-kW (275-horsepower) Ballard fuel cell stack. According to the California Fuel Cell Partnership (CaFCP), the ZEBus performed reliably, "with excellent hill climbing ability, strong and smooth acceleration and high road speed."[270]

Between summer 2002 and 2003, SunLine also tested a 30-foot ThunderPower hybrid fuel cell bus developed by ISE Research and Thor Industries.[271] Powered by a 60 kW UTC PEM fuel cell and a hybrid-electric drive with advanced lead-acid batteries, the bus had a fuel economy of 7 to 11 miles per gallon (mpg), nearly double the fuel efficiency of a conventional bus.[272]

COMMERCIAL AVAILABILITY

Although some pilot projects are demonstrating hydrogen fuel cell buses, the technology is still not commercially available because of various technological obstacles. However, to help overcome these obstacles, DOE has initiated an extensive research program designed to meet certain performance and cost targets that it hopes will make fuel cell technologies commercially viable by 2015.[273] Part of this program focuses on developing new materials and novel fabrication methods.[274]

In terms of fuel cell technology, DOE has set a target cost goal of $30 to $45 per kilowatt for PEM stacks; current PEM stacks cost approximately $2,000 per kilowatt. DOE has also established a goal for driving time: 5,000 hours (equivalent to approximately 150,000 miles, the expected service life of a vehicle), compared to only 1,000 hours of driving time provided by current PEM stacks.[275]

Regarding fuel storage technology, DOE's commercialization goal is 2.7 kilowatt hours per liter volume (kWh/L) of storage space at a cost of $2/kWh by 2015. Current 10,000 pound per square inch (psi) gas tanks are capable of only 0.8 kWh/L at a cost of $18/kWh.[276]

Aside from these gaps between DOE's 2015 goals and actual performance, onboard fuel reforming technology is not sufficiently developed and will not be commercially viable in the near future. In June 2004, an independent review panel commissioned by DOE recommended that the department end its onboard fuel processing research and development program because the technologies currently being developed would not be capable of achieving the 2015 commercialization goals.[277]

In addition to these goals, researchers are developing alternative hydrogen production systems, including microbiological production, solar photolysis, and production from biomass. DOE speculates that US hydrogen needs will ultimately be met through a combination of centralized and distributed hydrogen production facilities that will be built to match local economics and available natural resources.[278]

Fuel Cell Bus Models

Even though technology obstacles remain, some bus manufacturers are beginning to develop fuel cell buses, some of which are involved in demonstration programs or being used in revenue service (see Table 6.1).

Table 6.1. 2005 Fuel Cell Buses

Manufacturer	Vehicle Type/Features	Status
Enova Systems	Fuel cell/battery hybrid bus with Hydrogenics fuel cell powered by compressed hydrogen	In service at Hickam Air Force Base in Honolulu, Hawaii
Evobus (division of DaimlerChrysler)	Citaro fuel cell/battery hybrid bus with Ballard fuel cells powered by compressed hydrogen	33 in service in Europe and Australia
Gillig Corporation	40-foot fuel cell/battery hybrid bus with Ballard fuel cells powered by compressed hydrogen	In service testing in California for Santa Clara VTA and San Mateo Transportation District
Hino Motors of Japan (Toyota subsidiary)	60-passenger, low-floor bus with Toyota fuel cell, powered by compressed hydrogen	In service in Tokyo
Irisbus (a Renault V.I. and Iveco company)	40-foot fuel cell/battery hybrid bus powered by UTC fuel cell, powered by compressed hydrogen	Demonstration in Torino, Italy
ISE Research/Thor Industries	ThunderPower 30-foot fuel cell/battery hybrid bus with UTC fuel cell, installed on El Dorado National E-Z Rider bus	In service in California for Sunline Transit
MAN	40-foot MAN NL 263 Bavaria I hybrid bus with Siemens fuel cell, powered by compressed hydrogen	In service in Bavaria, Germany
MAN	40-foot fuel cell/super-capacitor hybrid bus with Nuvera fuel cell, powered by liquid hydrogen	In development for EU's THERMIE program, for demonstration in Berlin, Copenhagen, and Lisbon
Neoplan	N8012 33-seat bus, flywheel hybrid with Proton Motor fuel cell, powered by compressed hydrogen	Available for sales
New Flyer Industries	40-foot, low-floor model with Hydrogenics fuel cell, powered by compressed hydrogen, incorporating vehicle-to-grid technology	Demonstration in Manitoba, Canada
North American Bus Industries	45-foot hybrid bus with UTC hydrogen fuel cell fuelled by compressed hydrogen	Demonstration at Sunline Transit
NovaBus	40-foot hybrid fuel cell bus, powered by batteries and hydrogen fuel cell with onboard methanol re-former	Demonstration with Georgetown University
NovaBus	40-foot Nova transit bus, with Arotech zinc-air fuel cell	Plans for demonstration by Nevada Transit Agency
Van Hool	40-foot bus with UTC fuel cells, powered by compressed hydrogen	Demonstration for AC Transit in California

Source: Fuel Cells 2000, available at http://www.fuelcells.org/info/charts/buses.pdf

MAJOR FLEET USERS

Buses are well suited to run on fuel cells for several reasons: they are centrally fueled, they are large enough to carry fuel cell stacks, and they have space for roof-mounted hydrogen tanks that would provide enough storage capacity for sufficient driving ranges. A survey published by the Northeast Advanced Vehicle Consortium (NAVC) in late 2003 shows that, for these and other reasons, industry experts believe that transit bus agencies will adopt hydrogen fuel cell technology at least 5 years before private passenger vehicle market.[279]

Because hydrogen fuel cell technology is not commercially viable, most of the hydrogen fuel cell buses operating on roadways can be found in demonstration programs. Table 6.2 lists some of the programs being run in the US and around the world.

Table 6.2. Major Fuel Cell Transit Bus Demonstration Programs

Program	Participant(s)	Technology / Manufacturer	Program Status
		United States	
California Fuel Cell Partnership[a]	AC Transit	3 40-foot Van Hool buses, UTC fuel cells	Planned; start date, September 2005
	SunLine Transit	1 40-foot Van Hool bus, UTC fuel cells	Planned; start date, fall 2005
	Santa Clara VTA, SamTrans	3 40-foot Gillig buses, Ballard fuel cells	Operational; start date, February 2005
Georgetown University Fuel Cell Bus Development/ Demo[b]	Washington Metropolitan Transit Authority	Generation II: UTC phosphoric acid fuel cell bus, Ballard X1 PEM fuel cell bus; Generation III buses in development, hybrids with onboard methanol reformers	Operational; Gen. II buses first demonstrated in 1998 and 2001, respectively; Gen. III still taking shape
		International	
Natural Resources Canada[c]	Winnipeg Transit	40-foot Hydrogenics bus with PEM fuel cell	Operational; performance testing
Clean Urban Transport for Europe (CUTE), Europe; Ecological City Transport System (ECTOS), Reykjavik; Sustainable Transport Energy Project (STEP), Perth[d]	Transit agencies in 11 cities[g] to provide various climate, topography, and traffic conditions in which bus performance can be observed	3 low-floor DaimlerChrysler/Mercedes-Benz Citaro buses with Ballard fuel cells delivered to each participating city	Operational; first buses delivered to Madrid, May 2003; last buses delivered to Perth, September 2004; more than 50,000 hours and 650,000 km driven by fleets; each program to run 2 years
Global Environment Facility (GEF)/United Nations Development Programme (UNDP) Fuel Cell Bus (FCB) Programme[e]	Shanghai, Beijing	6 fuel cell buses and fueling station in each city	Planned; buses to be delivered September 2005
	Mexico City	10 fuel cell buses	Planned; delivery not yet scheduled; 5-year program
	Cairo	8 fuel cell buses	Still in development; 5-year program
	New Delhi	Not yet decided	Still in development
	São Paulo	8 fuel cell buses	Planned; bus delivery in 2005–2006; 4-year program
Toyota/Hino Fuel Cell Hybrid Vehicle (FCHV-BUS2)[f]	Tokyo Metropolitan Transportation Service, Toei Bus	30-foot, low-floor Hino bus with Toyota PEM fuel cell and nickel-metal hydride battery	Operational; regular service in Tokyo since August 2003

[a] California Fuel Cell Partnership, "Hydrogen Fueling Stations and Vehicle Demonstration Programs," available at http://www.fuelcellpartnership.org/fuel-vehl_map.html

[b] Georgetown University Fuel Cell Bus Program, available at http://fuelcellbus.georgetown.edu/index.cfm

[c] Fuel Cell Market Survey: Buses, "Hydrogenics," available at http://www.fuelcelltoday.com/FuelCellToday/FCTFiles/FCTArticleFiles/Article_704_BusSurvey1103.pdf

[d] Fuel Cell Bus Club, available at http://www.fuel-cell-bus-club.com/index.php?module=pagesetter&func=viewpub&tid=1&pid=2

[e] GEF/UNDP, "GEF Project Search Results," available at http://cfapp2.undp.org/gef/site/blank.cfm?module=projects&page=webProjectSearchResults

[f] Toyota Motor Corporation, "Toyota/Hino Fuel Cell Hybrid Bus 1st to Obtain Ministry Certification," press release on September 27, 2002, available at http://www.toyota.co.jp/en/news/02/0927.html

[g] Amssterdam (Netherlands), Barcelona (Spain), Hamburg (Germany), London (United Kingdom), Luxembourg (Luxembourg), Madrid (Spain), Perth (Australia), Porto (Portugal), Reykjavik (Iceland), Stockholm (Sweden), Stuttgart (Germany)

California Fuel Cell Partnership

In 1999, a consortium of auto manufacturers, energy companies, fuel cell technology companies, and government agencies formed CaFCP to promote the development of fuel cell vehicles in California. Three CaFCP members—Alameda Contra Costa Transit (AC Transit), SunLine Transit Agency (SunLine), and Santa Clara Valley Transportation Authority (Santa Clara VTA)—are conducting separate fuel cell bus demonstration projects that will feature a total of seven buses.[280]

In spring 2002, AC Transit purchased three hydrogen fuel cell buses at a cost of approximately $3.1 million per bus. Delivered in 2004, the buses are equipped with ISE Research-ThunderVolt drivetrains on Van Hool chasses, with UTC fuel cell stacks.[281] (UTC is a subsidiary of United Technologies.) SunLine is demonstrating a similar ISE/UTC bus that uses a composite body made by North American Bus Industries (NABI).[282] Santa Clara VTA and the San Mateo Transit District put three compressed hydrogen-powered fuel cell buses in service in 2004. Gillig manufactured the 40-foot, low-floor buses, which are fitted with Ballard fuel cells and cost $10.5 million total (approximately $3.5 million each).[283]

Under this demonstration program, the buses will operate for 2 years in regular transit service, carrying passengers over normal routes. Throughout this period, each transit agency will collect extensive data in collaboration with the National Renewable Energy Laboratory (NREL).[284]

CUTE/ECTOS/STEP

In the most extensive fuel cell bus demonstration program in the world, DaimlerChrysler and Ballard are demonstrating three fuel cell buses in 11 cities (33 total) throughout Europe and Australia. In Europe, a test program called Clean Urban Transport for Europe (CUTE), sponsored in part by the EU, was initiated in February 2002.[285] In 2003, it placed three Mercedes-Benz Fuel Cell Citaro buses in nine European cities: Amsterdam, Barcelona, Hamburg, Stuttgart, London, Madrid, Porto (Portugal), Stockholm, and Luxembourg.[286]

Two additional demonstrations (which are not part of CUTE) are being conducted in Reykjavik and Perth. The Reykjavik demonstration program is an extension of Iceland’s Ecological City Transport System (ECTOS), which plans to produce all of its hydrogen through electrolysis using renewable sources: geothermal and hydroelectric energy generated from Iceland’s volcanoes and waterfalls.[287] The Perth project is part of Western Australia’s Sustainable Transport Energy for Perth (STEP) program.[288] Reykjavik and Perth also received three buses each.

Between 2003 and 2004, each city received three DaimlerChrysler low-floor, 39-foot, 70-passenger Mercedes-Benz Citaro buses, built by its EvoBus subsidiary. Designed for rigorous in-service testing on urban routes, the buses will have an operating range of approximately 120 miles and a maximum speed of nearly 50 miles per hour.[289] They will use hydrogen stored onboard in compressed form in roof-mounted tanks and the fourth-generation Mark 902 PEM fuel cell manufactured by Canada’s Ballard Power Systems, with a maximum power output of 300 kW, comparable to today’s generation of transit buses.[290] The buses cost approximately $1.5 million (US) each.[291] Testing will continue through 2007.[292]

Fueling facilities to support the CUTE project were mostly built in 2003,[293] with participating cities pursuing several avenues for producing the hydrogen dispensed at those sites, including the steam reforming of natural gas (Madrid and Stuttgart), oil refinery excess hydrogen (London and Perth), electrolysis of water with grid electricity (Luxembourg and Porto), and electrolysis from geothermal and hydropower (Reykjavik).[294]

By November 2004, the first 30 Citaros (not including Perth) had consumed more than 40,000 kg of hydrogen, driven about 420,000 km, and completed 33,000 hours of operation. Thus far, feedback from the transit agencies, passengers, and the press has been positive, and the fuel cell stacks have generally shown high reliability. According to EvoBus, the 33 buses carry up to 10,000 passengers a day throughout Europe and Australia.[295]

GEF

The Global Environmental Facility (GEF), which operates through the World Bank and the UN Development and Environment Programmes, announced a new program in 2001 that planned to deliver 46 buses over a 5-year period to São Paolo (Brazil), Cairo (Egypt), Mexico City (Mexico), New Delhi (India), Shanghai, and Beijing (China). These cities suffer from some of the worst air pollution in the world and represent a cross section of the developing nations expected to contribute most to growing fossil fuel demand in the near future. The total cost for the project was initially estimated at $140 million, with $60 million coming from the GEF, and the rest from government and private sources.[296] However, as of May 2004, no buses have been delivered, even though Brazil and China were well into the bidding process for contracts with fuel cell bus suppliers.[297]

HYDROGEN FUELING INFRASTRUCTURE

Experience with natural gas vehicles shows that the fuel cell vehicle population will not grow without a concomitant expansion of hydrogen fueling infrastructure. Today's demonstration programs examine various fueling technologies for light- and heavy-duty vehicles; some leading examples are highlighted below. Research and development efforts are accelerating to evaluate the relative merits of these technologies so that hydrogen fueling infrastructure can develop in step with vehicle development.

California Hydrogen Highway Network (CA H2 Net)

California's status as a hub for hydrogen transportation has been solidified by the CaFCP and more recently by Governor Arnold Schwarzenegger's California Hydrogen Highway Network (CA H2 Net) initiative, which he announced in his January 2004 state of the state address. An executive order he signed several months later called for the development of the California Hydrogen Blueprint, a plan for developing the CA H2 Net into a system with 250 hydrogen fueling stations to support some 20,000 vehicles.

These goals for developing a hydrogen fueling infrastructure and vehicles will be gradually achieved over the course of three phases. In the first phase (to be completed by 2010—the other two phases have no timeline as of yet), the plan is to develop 50 to 100 stations supporting more than 2,000 vehicles in and between key urban areas of the state, including Los Angeles, San

Diego, San Jose, and the San Francisco Bay area. Thirty-nine such stations already exist or are planned for completion by 2007. The blueprint envisions a 50-50 cost-sharing arrangement between the state and the private sector to develop phase-one stations.

To stimulate development, the blueprint calls for the state to provide $10.7 million in station and vehicle incentives each year for 5 years. It also calls for a program to streamline and standardize the hydrogen fueling station permitting process, with the state fire marshal's office serving as the lead agency.

In the near term, the blueprint stresses the importance of maximizing synergies with existing natural gas infrastructure, noting that California's numerous natural gas fueling stations can be adapted to produce and deliver hydrogen on-site and already have experience handling and distributing compressed and liquefied gases.[298] Ultimately, station development efforts will focus on developing a fully sustainable hydrogen economy, with hydrogen produced from renewable energy sources. The current target is to have 20 percent of the hydrogen dispensed by the CA H2 Net come from renewable sources by 2010.[299]

Las Vegas (NV)

A fueling station where natural gas is reformed into hydrogen and compressed for use in fuel cells began operating in Las Vegas (NV) in late 2002 as part of a 5-year, $10.8 million demonstration project. Developed through a public-private partnership involving DOE, the city of Las Vegas, Air Products and Chemicals and Plug Power, Inc., the station is the first in the world to co-produce hydrogen for fuel cell vehicles and electricity for use in the power grid, according to project participants. Some hydrogen produced at the station is compressed for dispensing into vehicles; the rest feeds an onsite, 50-kW stationary PEM fuel cell that generates enough electricity to power 30 homes on a daily basis.[300] Such a station could serve as the model for similar co-production facilities that help underpin a hydrogen economy. The project also underscores the important role natural gas will likely have in the development of a hydrogen fueling network.

Los Angeles (CA)

Several current efforts follow the sustainable electrolysis model, using solar power to generate electricity that is then used to extract hydrogen from water. In 2001, American Honda Motor Company opened such a facility near Los Angeles. The hydrogen is pressurized by a compressor, stored in onsite tanks, and ultimately dispensed to prototype Honda fuel cell vehicles.[301]

A facility opened by SunLine Transit in the Southern California desert in 2000 combines hydrogen generation, storage, and fueling. Hydrogen is produced on-site via two systems: one uses solar-powered electrolysis; the other, a natural gas reformer.[302] Besides the dual hydrogen production systems, the so-called Clean Fuels Mall also features a mobile trailer and tanks for the storage of 118,000 standard cubic feet (scf) of compressed hydrogen, a two-hose fueling outlet that dispenses compressed hydrogen and a natural gas-hydrogen blend (HCNG), and fueling outlets for liquefied and compressed natural gas.[303]

Sacramento (CA)

Hydrogen may be transported and stored as a super-cooled, or cryogenic, liquid, much as natural gas can be transported and stored in a liquid form (LNG). Cryogenic hydrogen, which must be cooled to –423° F to be liquefied, has the advantage having of a much higher density than compressed hydrogen; a cryogenic tank truck may transport as much as ten times as much hydrogen as a trailer carrying gaseous hydrogen. However, as with LNG, it is difficult and expensive to store and transport the fuel at the temperatures required to keep hydrogen in its liquid state. A fueling station located at the California Fuel Cell Partnership headquarters in West Sacramento uses truck-delivered cryogenic hydrogen that is gasified on site. The station includes a 4,500-gallon liquid hydrogen storage tank, a vaporizer to convert the liquid hydrogen to a gas, a compressor to pressurize the gas, and two dispenser systems that deliver the fuel to vehicles at pressures of 3,600 and 5,000 psi, depending on vehicle requirements.[304]

* * *

Even though several dozen hydrogen fuel cell buses are already on the road in demonstration projects around the world, significant technological barriers will have to be cleared to make this vision a reality. “Success is not certain” with regard to the ongoing development of inexpensive, hydrogen-powered fuel cells and the creation of the storage and transportation infrastructure needed for hydrogen fuel cell vehicles, according to a 2005 article co-authored by Rakesh Agrawal, a chemical engineering professor at Purdue University; Martin Offutt of the National Research Council; and Michael P. Ramage, a retired executive from ExxonMobil Corporation. In looking at the current state of fuel cell technology in relation to DOE’s 2015 commercialization goals, they emphasize that the technical milestones set by DOE are still a long way from being achieved. Says Agrawal:

> I believe we can probably solve the technological problems related to making hydrogen fuel cells practical as a replacement for the internal combustion engine, but it won’t be easy and it likely won’t happen very soon. An optimistic prediction would be that a significant number of hydrogen fuel cell vehicles will be entering the marketplace around 2020, and by 2050 everybody will be driving them.[305]

Chapter 7
Bus Futures

The consensus among respondents to WestStart-CALSTART's annual "Clean Fuels and Technologies Market Forecast Survey 2005" is that we are headed toward an era in which multiple alternatives to conventional diesel buses find popularity in various geographical and application-based niches. In his remarks that interpret the survey's findings, John Boesel, president and CEO of WestStart-CALSTART, noted that "Future oil supplies, costs, and sources are starting to dominate the thinking of heavy-duty vehicle industry leaders, and it affirms their belief that the future is not dominated by one fuel type."[306]

These trends have already begun to emerge in the transit sector, where natural gas, hybrid-electric, and biodiesel technologies have gained a solid and increasingly strong foothold. And even though hydrogen and fuel cell technologies have yet to reach the large-scale commercial viability that natural gas, hybrid, and biodiesel options have, the promise they hold has transit agencies eying a future in which their bus fleets will run emission-free using a sustainable fuel source, hydrogen.

Transit agencies who approach the process of transitioning to greener, more sustainable bus technologies with flexibility and a willingness to adapt will find a range of commercially viable, economically feasible and operationally practical options. Although the great majority of transit agencies using diesel alternatives have opted to take the natural gas pathway by making significant investments in CNG and/or LNG buses and fueling facilities, growing numbers are adopting hybrid-electric buses or using biodiesel in a pure or blended form. Some transit agencies, such as those in New York City, Denver, Washington (DC), and Cleveland (OH) are keeping their options open by taking both the hybrid and natural gas pathways. A select few, among them California's SunLine Transit, the Santa Clara Valley Transportation Authority, and AC Transit, have taken that commitment to a diesel-free future a step further by being among the first to integrate hydrogen-natural gas blends (HCNG) or hydrogen fuel cell buses into their operations.

In choosing to leave the status quo behind by integrating advanced-technology transit buses into their fleets, the experience transit agencies stand to gain and the capital investments they make in vehicles, fueling and maintenance facilities should prove fruitful if and when hydrogen fuel cell transportation becomes a commercial reality. Even if that reality is still more than a decade away, the investments they make today will pay immediate dividends by giving transit agencies the means to answer the public's demand for buses that are cleaner, quieter, less harmful to human health and less dependent on oil-derived diesel fuel.

Acronyms and Abbreviations

AF	alternative fuel
AF/AT	alternative fuel/alternative technology
APTA	American Public Transportation Authority
APU	auxiliary power unit (in a hybrid-electric system)
ASTM D6751	American Society for Testing and Materials standards for B100
AT	advanced technology
BRT	bus rapid transit
BTU	British thermal unit
CaFCP	California Fuel Cell Partnership
CARB	California Air Resources Board
CH_4	methane
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CUTE	Clean Urban Transport for Europe
dB	decibel
Dge	diesel gallon equivalent
DOC	diesel oxidation catalyst
DOE	US Department of Energy
DOT	US Department of Transportation
DPF	diesel particulate filter

DPM	diesel particulate matter
ECTOS	Ecological City Transport System (Iceland)
EGR	exhaust gas recirculation
EIA	Energy Information Administration
ENGVA	European Natural Gas Vehicle Association
EPA	US Environmental Protection Agency
EPACT	Energy Policy Act (1992)
FCB	fuel cell bus
FHWA	Federal Highway Administration
FTA	US Federal Transit Administration
g/bhp-hr	grams per brake horsepower-hour
GEF	Global Environmental Facility
Gge	gallon gas equivalent
H_2	hydrogen
H_2O	water, steam (water vapor)
HC	hydrocarbon
HCNG	hydrogen-natural gas blend
HTE	high-temperature electrolysis, steam electrolysis
ICE	internal combustion engine
IPCC	UN Intergovernmental Panel on Climate Change
ITS	intelligent transportation system
kwh	kilowatt-hour
LEV	low emission vehicle, an EPA category
LNG	liquefied natural gas
MATES II	Multiple Air Toxics Exposure Study II
MSAT	mobile source air toxic
NABI	North American Bus Industries, Inc.
NAVC	Northeast Advanced Vehicle Consortium
NBB	National Biodiesel Board
NGVC	Natural Gas Vehicle Coalition
NMHC	non-methane hydrocarbon
NO_x	nitrogen oxides

NREL	National Renewable Energy Laboratory
NYCT	New York City Transit
OPEC	Organization of Petroleum Exporting Countries
PAH	polycyclic aromatic hydrocarbons
PEM	proton exchange membrane
PM	particulate matter
ppb	parts per billion
psi	pounds per square inch
quad	one quadrillion British thermal units
RfC	reference concentration
SCAQMD	South Coast Air Quality Management District
SCR	selective catalytic reduction
scf	standard cubic feet
SO_2	sulfur dioxide
STEP	Sustainable Transport Energy Project (Perth)
TERP	Texas Emission Reduction Program
TUG	Natural Gas Transit Users Group
ULEV	ultra-low emission vehicle, an EPA category
ULSD	ultra-low sulfur diesel
USDA	United States Department of Agriculture
UV	ultraviolet
VOC	volatile organic compound

Glossary

1,3-butadiene	A chemical compound (C_4H_6) produced primarily during the incomplete combustion of gasoline or diesel. Recognized carcinogen and reproductive and developmental toxicant.
acid rain	Acidic precipitation caused when certain air pollutants in the atmosphere react with each other.
advanced technology bus	A bus that uses special engine, vehicle, or aftertreatment technology to reduce emissions or increase fuel efficiency.
Aftertreatment	Any engine component or technology placed after the exhaust outlet to decrease emissions.
air toxic	Any air pollutant known to cause cancer or other serious health or environmental effects.
alternative fuel bus	A bus that uses a non-diesel fuel to reduce emissions.
American Public Transportation Association (APTA)	A nonprofit organization that advocates for and informs the public about public transportation development and advances.
articulated bus	A bus with two or more compartments for increased passenger capacity, with the compartments connected by a flexible joint that enables the bus to negotiate turns while maintaining a continuous interior.
Asia-Pacific Partnership for Clean Development & Climate	An international agreement among Australia, China, India, South Korea, Japan, and the US to collaborate on developing and transferring technology for the reduction of greenhouse gases.

auxiliary power unit (APU)	A hybrid-electric engine component that produces electrical energy from fuel. May be an engine/generator, fuel cell, or turbine.
benzene	A colorless liquid (C_6H_6) found in diesel and gasoline and in the fumes from their combustion. Recognized carcinogen and reproductive and developmental toxicant.
biodiesel	An alternative fuel produced from renewable sources (first- or second-use oils) that can be used in conventional diesel engines with minimal or no engine modification. Also called "neat" biodiesel or B100.
biodiesel blend	Any mixture of biodiesel and petroleum-based diesel. Under standard nomenclature biodiesel blends are named BXX, where XX is the percentage of biodiesel content.
California Air Resources Board (CARB)	A state agency created in 1967 to address air quality issues in California by researching the causes of and solutions to air pollution, focusing specifically on vehicles.
carbon dioxide	A colorless gas (CO_2) that is found naturally in the atmosphere but has seen large increases in the past century due to anthropogenic emissions (including those from vehicles that burn carbon-based fuels). An important greenhouse gas and suspected developmental, reproductive, respiratory, and neurological toxicant.
carbon monoxide	A colorless, odorless gas (CO) formed during the incomplete combustion of carbon compounds. Recognized developmental toxicant. One of six Criteria Pollutants identified by the US EPA in the original Clean Air Act.
cetane number	A measure of diesel's tendency to auto-ignite. Inversely correlated with ignition delay.
Clean Air Act	The federal law passed in 1963 to research and reduce air pollution. Amended significantly in 1970 and 1990.
climate change	Long-term regional and global changes in temperature, precipitation, wind, climate variability, and other elements of the earth's climate system. Caused by human-created atmospheric emissions and natural biogeochemical cycles.

cloud point	The highest temperature at which wax crystals first become visible in a fuel, making it cloudy. Affects a fuel's ability to operate in cold weather.
combustion	A chemical reaction between a hydrocarbon and an oxidizer (typically air in an internal combustion engine) that produces carbon dioxide, water vapor, and large amounts of energy.
commercialization	The transition from a technology's research phase to its operational phase.
compressed natural gas (CNG)	Natural gas that has been purified and compressed to facilitate transport and storage. Most common form of natural gas used for transportation in the US.
criteria pollutant	A common air pollutant meeting certain US EPA criteria for health and environmental threats. Six listed in the original Clean Air Act: lead, carbon monoxide, ground-level ozone, particulate matter, sulfur dioxide, and nitrogen oxides.
crude oil	An energy resource created from organic materials, composed primarily of carbon and hydrogen. Provides the raw material for producing diesel and gasoline.
dedicated engine	An engine designed to operate on a specific fuel such as natural gas.
demonstration project	A program that receives external funding to test and evaluate a new technology or system.
diesel	A liquid fossil fuel produced from petroleum. Most common fuel used in buses and other heavy-duty vehicles.
diesel oxidation catalyst (DOC)	An aftertreatment device that reduces particulate matter by oxidizing organic compounds adsorbed onto carbon particulates such as carbon monoxide and hydrocarbons.
diesel particulate filter (DPF)	An aftertreatment device that captures diesel exhaust particulates before they can be emitted through the tailpipe.
drivetrain	All of the vehicle components responsible for transmitting an engine's power to the wheels.
dual-fuel engine	An engine that can operate on one of two fuels or a combination of both.

economy of scale	A production system in which proportionally increasing all inputs decreases the cost per unit of production.
ecosystem	A unit consisting of organisms, the environment they inhabit, and the flow of nutrients between the two.
electric drive motor	A hybrid-electric engine component that draws energy from the energy storage device or auxiliary power unit and uses it to drive the vehicle's wheels.
Electrolysis	The technique of extracting hydrogen and oxygen from water (H_2O) using an electrical current. Also refers to the general decomposition of a compound using an electrical current.
electronic controller	A hybrid-electric engine component that controls the current from the energy storage device or auxiliary power unit to the motor and that monitors the energy storage device to direct recharging independent of driver signals.
energy storage device	A hybrid-electric engine component, frequently a battery pack, that stores energy and can be recharged by an electric motor system or an off-board electric energy source.
eutrophication	The severe disruption of aquatic ecosystems that occurs when excessive nitrogen or sulfur over-stimulate plant growth, which chokes off the ecosystem's oxygen supply.
exhaust gas recirculation (EGR)	An aftertreatment technique used primarily in gasoline and diesel engines to reduce NO_x by recirculating inert exhaust gas to the engine so that it dilutes the fuel and slows combustion, lowering the high temperatures that stimulate NO_x formation.
Feedstock	Raw material used in a chemical or biological process.
first-use vegetable oil	Vegetable oil, such as soybean or rapeseed oil, that is used directly as a feedstock for biodiesel.
flash point	The lowest temperature at which a fuel or other volatile substance produces enough vapor that mixes with air at the fuel's surface and forms an ignitable mixture.
flywheel	A device that stores kinetic energy in its rotation. Can be used as an energy storage device in an engine.
formaldehyde	A chemical compound (CH_2O) that forms during the incomplete combustion of a hydrocarbon or in the

	atmosphere when organic compounds are exposed to sunlight. Recognized carcinogen.
fuel cell vehicle	A vehicle powered by stacks of fuel cells that produce energy through a chemical reaction between hydrogen and oxygen, generating water as its only emission.
fuel economy	A measure of the distance a vehicle can travel on a given amount of fuel.
fuel efficiency	A measure of the distance a vehicle can travel on a given amount of fuel.
gasoline	A petroleum-derived liquid fuel. The most common fuel used in light-duty transportation applications.
global warming	A long-term increase in average atmospheric and oceanic temperatures, caused by human-created atmospheric emissions and natural biogeochemical cycles.
greenhouse gas	An gas that traps solar heat in the earth's atmosphere and contributes to global warming and climate change. Can be natural or artificial compounds, such as carbon dioxide, methane, nitrogen oxide, chlorofluorocarbons, carbon tetrafluoride, and water vapor.
ground level ozone	A gas formed by the photochemical reaction of NO_x and volatile organic compounds in the atmosphere. One of six Criteria Pollutants identified by the US EPA in the original Clean Air Act. Known to cause or exacerbate respiratory health problems.
heavy-duty vehicle	Defined by EIA as a vehicle with a gross vehicle weight rating of 26,001 lbs and above. Defined by the California Air Resources Board as a vehicle with a gross vehicle weight rating of 14,001 lbs and above.
high-temperature electrolysis (HTE)	A process by which hydrogen can be produced from water (H_2O) by passing an electrical current through steam to more efficiently decompose the water molecule.
Hybrid-electric vehicle	A vehicle that combines a fuel-powered engine with a energy storage device (usually a battery pack) that stores energy produced by the engine and deploys it to optimize fuel usage.
hydrocarbon	A chemical compound made of hydrogen and carbon. Commonly used as fuel in combustion reactions.

hydrogen	A gas consisting of two hydrogen atoms that can be used as a fuel in internal combustion engines or fuel cells.
hydrogen economy	A hypothetical economic model in which renewably produced hydrogen is the main energy source.
hydrogen fuel cell vehicle	A vehicle powered by stacks of fuel cells that produce energy through a chemical reaction between hydrogen and oxygen.
hydrogen reformation	A technique in which steam is reacted with natural gas to produce hydrogen and carbon dioxide.
incomplete combustion	A process in which a carbon-based fuel is not burned using a sufficient amount of oxygen so that some of the fuel remains unburned.
incremental cost	The price difference (cost differential) between two products.
internal combustion engine	An engine that generates power by burning some type of fuel that has been compressed before being ignited.
jatropha	A small tree (*Jatropha curcas*) that can be used to produce jatropha oil, which can be used to make biodiesel.
Kyoto Protocol	An international treaty that requires industrialized signatories to reduce their emissions of greenhouse gases (specifically carbon dioxide, methane, nitrogen oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons) by 5.9 percent compared to 1990 levels through a mandatory cap and emissions trading system. Entered into force on February 16, 2005 with 154 signatories.
light rail	Lightweight passenger rail cars (such as trolleys) powered by overheard electric sources and traveling on fixed rails that share the road with automobile traffic.
light-duty vehicle	Defined by EIA and the California Air Resources Board as a vehicle with a gross vehicle weight rating of less than 8,500 lbs.
liquefied natural gas (LNG)	Natural gas that has been super-cooled so it can be stored and transported in liquid form. Must be re-gasified before being used in internal combustion engines.

lubricity	Fuel's ability to reduce wear on engine and refueling equipment.
medium-duty vehicle	Defined by EIA as a vehicle with a gross vehicle weight rating between 8,501 and 26,000 lbs. Defined by the California Air Resources Board as a vehicle with a gross vehicle weight rating of between 8,501 and 14,000 lbs.
methane	The simplest hydrocarbon consisting of one carbon atom and four hydrogen atoms (CH_4).
methanol	The simplest alcohol (CH_3OH), used as an antifreeze or occasionally as an alternative fuel. Can be produced from wood or other renewable organic sources but cannot be used in unmodified conventional vehicle engines.
mobile source air toxic	Any air pollutant known to cause cancer or other serious health or environmental effects.
model year	In the US, the approximate year in which a vehicle was produced.
natural gas	A gaseous fossil fuel made mostly of methane (CH_4). Can be used in liquid or gaseous form.
nitrogen oxides (NO_x)	The range of nitrogen-oxygen compounds produced when nitrogen and oxygen in air are combined during the burning of a fuel. Suspected respiratory, cardiovascular, immunological, neurological, endocrine, reproductive, and developmental toxicant. One of six Criteria Pollutants identified by the US EPA in the original Clean Air Act.
nonattainment	A US EPA designation for localities that fail to meet National Ambient Air Quality standards for one or more criteria pollutants.
octane number	A measure of gasoline's resistance to auto-ignition.
parallel hybrid configuration	A hybrid-electric engine configuration in which the engine and battery pack are connected separately to the motor, allowing independent propulsion by either or allowing combined propulsion by both.

particulate matter (PM)	A mixture of vehicle exhaust particles consisting of an elemental carbon core, trace elements, and adsorbed organic compounds. Known carcinogen. One of six Criteria Pollutants identified by the US EPA in the original Clean Air Act.
petroleum	An energy resource created from organic materials, composed primarily of carbon and hydrogen. Provides the raw material for producing diesel and gasoline. Also called “crude oil.”
pour point	The lowest temperature at which a fuel can be poured. Affects a fuel’s ability to operate in cold weather.
powertrain	A vehicle’s engine and all of the components involved in transmitting the engine’s power to the wheels.
propane	A petroleum-derived fuel. Also known as liquefied petroleum gas.
proton exchange membrane (PEM) fuel cell	The hydrogen fuel cell most commonly used in transportation applications.
reference concentration (RfC)	A toxic substance’s maximum exposure level that is considered safe for humans
regenerative braking	A mechanical process in which an electric or hybrid-electric motor system controls deceleration and the braking energy recaptured from the vehicle propulsion system is returned to the energy storage device.
revenue service	The period of operation during which a bus or other vehicle either carries fare-paying passengers or operates in free service under a government or private contract.
second-use vegetable oil	Vegetable oil, such as recycled cooking oil, that has been used before becoming a feedstock for biodiesel.
selective catalytic reduction (SCR)	Aftertreatment technology that reduces NO_x emissions by using urea or ammonia to convert NO_x into nitrogen and oxygen.
series hybrid configuration	A hybrid-electric engine configuration in which the engine is connected to the motor only through the battery pack, allowing propulsion by either the battery pack or the battery pack and motor.
steam electrolysis	A process by which hydrogen can be produced from water (H_2O) by passing an electrical current through steam to more efficiently decompose the water molecule.

steam reformation	A technique in which steam is reacted with natural gas to produce hydrogen and carbon dioxide.
stoichiometric engine	An engine in which fuel and air are combined in a chemically correct (stoichiometric) ratio to ensure complete the burning of the fuel.
torque	A measure of the rotational force of a vehicle’s engine on its axle or on the axis of rotation of its wheels. A factor in an engine’s power output.
transesterification	A chemical process in which an alcohol is reacted with the triglycerides contained in vegetable oils and animal fats to produce biodiesel and glycerin.
ultracapacitor	A device that stores energy in the electrostatic field between two equal but oppositely charged conductors.
ultra-low sulfur diesel (ULSD)	Diesel with a sulfur content less than 15 ppm (compared to 500 ppm in conventional diesel).
volatile organic compounds (VOCs)	Organic compounds that have vapor pressures high enough for them to vaporize under normal conditions. Includes small hydrocarbons, aldehydes, and ketones.
zero-emission vehicle (ZEV)	A vehicle that produces no air pollutants during operation or fueling.

Notes

Introduction

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