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MASS TRANSIT

Use of Alternative Fuels in Transit Buses

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Resources, Community, and
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The Honorable Phil Gramm
Chairman
The Honorable Paul Sarbanes
Ranking Minority Member
Committee on Banking, Housing, and Urban Affairs
United States Senate

The Honorable Bud Shuster
Chairman
The Honorable James Oberstar
Ranking Democratic Member
Committee on Transportation and Infrastructure
House of Representatives

Improving air quality in urban settings has been a long-standing national objective. Transit buses powered by diesel engines have been identified as contributors to air pollution in these areas. To help address this problem, various fuels that are alternatives to diesel have been proposed for use in transit buses. Alternative fuel buses use such fuels as compressed natural gas (CNG), liquefied natural gas (LNG), methanol, ethanol, biodiesel fuel, and propane. Some of these buses use various propulsion technologies that are being designed and tested, such as hybrid electric systems.

The Transportation Equity Act for the 21st Century (TEA-21) mandated that we study low- and zero-emissions (alternative fuel) technologies for transit buses. This report focuses primarily on the use of CNG because the vast majority of alternative fuel buses are using this fuel. As agreed with your offices, this report addresses (1) the status of the development and use of alternative fuel technologies in transit buses, particularly the use of CNG as a fuel; (2) the air quality benefits of such technologies; (3) the costs incurred by transit operators to use CNG buses, as well as other alternative fuels, compared with the costs to use diesel buses; and (4) the primary incentives and disincentives for using these technologies. Appendix I, which describes the scope and methodology of our review, includes a list of the 12 transit operators we contacted, their locations, and the types of fuel they use. Appendix II provides a list of all of the other parties we contacted. Appendixes III through X provide detailed information on the status and costs of the alternative fuel technologies other than CNG that can be used in transit buses.

Results in Brief

Alternative fuel buses account for a very small, but growing, portion of the nation's transit bus fleet. In 1997, 5 percent of the nation's approximately 50,000 transit buses operated on some alternative fuel system.[1] The most commonly used alternative to diesel fuel is compressed natural gas—accounting for an estimated 75 percent of the full-sized alternative fuel transit buses in 1998. Transit operators are also beginning to test and demonstrate new propulsion system technologies—hybrid electric systems and fuel cells—in their transit buses. According to Federal Transit Administration officials, hybrid electric transit buses are currently available, and fuel cell buses will be commercially available by 2002.

Data are limited on the extent to which alternative fuel transit buses provide air quality benefits in urban areas. On a national scale, transit buses do not significantly affect air pollution levels because, according to the Department of Transportation, they constitute only about 0.02 percent of the approximately 208 million automobiles, trucks, and other vehicles in the United States. However, because individual alternative fuel transit buses emit less pollution than do individual diesel buses, alternative fuel buses have some beneficial effect on the air quality of the urban areas in which they operate.

Transit operators pay more to buy, maintain, and operate compressed natural gas buses than they pay for diesel buses. Eight of the 12 transit operators that we contacted operate compressed natural gas buses. At the outset, operators that buy compressed natural gas buses typically pay approximately 15 to 25 percent more for each of these buses than they do for diesel buses. Also, the costs of installing fueling facilities and upgrading maintenance garages for compressed natural gas buses vary among transit operators. However, constructing a compressed natural gas fueling station typically costs about $1.7 million, and modifying a maintenance facility typically costs about $600,000. In addition, six of the eight transit providers that we spoke with who were able to provide us with operating cost estimates reported higher operating costs for their compressed natural gas buses than for their diesel buses. Also, almost all of these operators reported higher maintenance costs for their compressed natural gas buses, and half of them reported higher fuel costs for these buses.

Transit operators approach the decision of whether to switch to alternative fuels by considering a range of factors. According to the transit

[1]The data from 1997 were the most recent data that were available from the Federal Transit Administration's national transit database at the time we completed our review.

operators we talked to, factors such as adhering to more stringent emissions standards and the public's concerns about transit bus pollution encourage them to operate alternative fuel transit buses. However, factors such as the increased costs and reduced reliability of alternative fuel buses experienced to date discourage the use of fuels other than diesel. Also, diesel buses have become significantly cleaner over the past 11 years, thereby reducing the environmental advantages of shifting to alternative fuel buses.

Background

Automobiles, diesel-fueled trucks, and transit buses emit pollution that affects the air quality in many large cities in the United States. The automotive, truck, and transit industries have been experimenting with ways to reduce vehicle emissions. Since 1992, transit operators have tested alcohol-based fuels (methanol and ethanol), natural gas fuels (CNG and LNG), biodiesel fuel (a fuel derived from such biological sources as vegetable oil), liquefied petroleum gas, and batteries. Fuel cell and hybrid electric technologies—defined as alternative propulsion systems—are also currently being developed for use in transit buses. Fuel cell systems convert fuel to an electric current without combustion. Hybrid electric systems use a small internal combustion engine and electricity for propulsion.

The Environmental Protection Agency (EPA), the Department of Energy (DOE), and the Department of Transportation (DOT) have programs in place that encourage the use of alternative fuels in vehicles, including transit buses. EPA is responsible for implementing programs designed to reduce air pollution. The agency regulates the emissions of certain pollutants from motor vehicles by establishing standards for how much pollution mobile sources can emit.[2] EPA tests heavy-duty engines and certifies them when they meet mobile source emissions standards. DOE is responsible for providing federal leadership on the acquisition and use of alternative fuel vehicles. Among other activities, DOE conducts research on alternative fuels, operates the alternative fuel data center, and runs the Clean Cities Program, all of which are designed to provide information on and promote the use of alternative fuels. In addition, DOT's Federal Transit Administration (FTA) provides funding for the acquisition and use of transit buses and sponsors the development of and demonstrations of alternative fuel bus technologies. In fiscal year 1998, FTA obligated almost $1.5 billion

[2]Mobile sources of pollution are those that move, such as automobiles, tractors, airplanes, and buses.

for the procurement and operation of transit buses.[3] These funds are used for expenditures for both diesel and alternative fuel buses, although the ratio of federal to local matching funds can vary, depending upon whether bus-related equipment complies with the Clean Air Act.[4]

Other federal actions may also affect the future use of alternative fuels in transit buses. TEA-21 established the Clean Fuels Formula Grant Program and authorized up to $200 million a year to finance the purchase or lease of clean diesel buses and facilities and the improvement of existing facilities to accommodate clean diesel buses.[5] The program focuses on urban areas that do not attain the Clean Air Act's ozone or carbon monoxide standards. FTA has not implemented the program because of a lack of funding in fiscal year 1999. Similarly, no funding has been provided for fiscal year 2000. DOE is currently considering whether to promulgate a rule that would require certain operators of bus fleets to acquire and use alternative fuel vehicles. If implemented, this rule could lead transit operators to acquire more alternative fuel buses. DOE officials do not anticipate publishing a notice of proposed rulemaking before the end of 1999.

The Use of Alternative Fuel Technology in Transit Buses Is Limited but Increasing

Since 1992, alternative fuel transit buses have accounted for a very small proportion of the total number of transit buses in the United States. According to DOT's national transit database, the number of full-sized alternative fuel transit buses increased from 815 buses in 1992 (2 percent of the total number of full-sized transit buses) to 2,659 buses in 1994 (5 percent of the total number of full-sized transit buses). This percentage generally remained unchanged through 1997, the most recent year in

[3]The urbanized area formula grant program and capital program are the primary federal sources of mass transportation funding. Through the formula program, FTA provides capital, operating, and planning assistance for mass transportation. In fiscal year 1998, FTA obligated a total of $2.4 billion for this program, including $1.3 billion for bus-related activities. Through the capital program, FTA provides funding for the establishment of new rail or busway projects, the improvement and maintenance of existing rail and other fixed-guideway systems, and the upgrading of bus systems. In fiscal year 1998, FTA obligated a total of $1.6 billion for this program, including about $213 million for bus projects.

[4]The typical ratio for federal funds to state and local funds is 80 percent to 20 percent. Transit operators can qualify for a higher federal match for vehicle-related equipment purchased to be in compliance with the Clean Air Act or the Americans With Disabilities Act. Transit operators purchasing buses that meet these guidelines can receive up to a 90 percent federal share for a discrete piece of vehicle-related equipment or an 83 percent federal share for the entire vehicle cost.

[5]While "clean diesel" vehicles would be eligible for funding from the Clean Fuels Formula Grant Program, there is no standard definition of clean diesel. According to some industry officials, clean diesel refers to newer diesel engines that emit lower levels of pollution, while, according to other industry officials, clean diesel refers to diesel fuel with lower levels of sulfur.

which data are available from this database.[6] The transit industry has tested some diesel alternatives over the past several years. As a result, alcohol-based fuels are being discarded, and newer fuels and propulsion systems are coming to the forefront. The current alternative fuels and propulsion systems available range from CNG—the most common alternative fuel—to hybrid electric and fuel cell propulsion systems, which are still under development. Diesel is by far the most common fuel used by transit operators. In 1998, 44,318 full-sized transit buses—93 percent of all full-sized transit buses—used diesel. (See table 1.)

Table 1: Number of Full-Sized Transit Buses by Type of Fuel, 1992 Through 1997

Type of fuel	1992	1993	1994	1995	1996	1997
Diesel	50,181	49,118	48,119	47,644	47,389	47,034
Diesel alternatives:						
CNG	116	249	465	575	857	1,469
Ethanol	5	29	33	22	347	338
Diesel (particulate trap)[a]	236	411	1,265	1,212	418	218
Methanol	57	392	402	402	63	54
LNG	10	52	9	50	50	50
Liquefied petroleum gas	59	59	2	2	4	4
Electric battery	0	0	0	0	1	3
Other[b]	332	334	463	418	421	378
Total diesel alternatives	815	1,526	2,659	2,681	2,161	2,515
Total	**50,996**	**50,644**	**50,778**	**50,325**	**49,550**	**49,549**

Note: The table covers transit operators in urbanized areas with populations of 50,000 or more. The number of buses includes those on order but not received.

[a]A particulate trap is a diesel engine exhaust after-treatment device designed to trap or otherwise destroy particulate matter.

[b]"Other" includes fuel types in the national transit database categorized as other, kerosene, dual fuel, and gasoline.

Source: national transit database, The Volpe Center, FTA.

DOE's Energy Information Administration (EIA) estimate that the number of full-sized alternative fuel transit buses in all of the United States will

[6]We have categorized a "full-sized transit bus" as a bus that is at least 35 feet long or has at least 35 seats.

increase from about 4,500 in 1999 to more than 6,000 in 2000.[7] In 1999, the most commonly used alternative to diesel fuel is CNG, accounting for about 3,400 full-sized transit buses—75 percent of all alternative fuel transit buses. According to an FTA official, it is difficult to estimate the future long-term demand for transit buses or for alternative fuel transit buses because of funding uncertainties. However, according to the American Public Transit Association, as of January 1, 1999, 17 percent of its members' new bus orders were for alternative fuel buses. Of the 12 transit operators we spoke with, 6 plan to acquire diesel buses, 5 plan to acquire CNG buses, and 1 plans to acquire both diesel and CNG buses.

As shown in table 1 and as estimated by EIA, the use of alcohol-based fuels (methanol and ethanol) has declined in recent years. According to FTA and industry officials, this decline has occurred because of the decreased performance and high operating cost of alcohol-fueled buses. For example, the Los Angeles County Metropolitan Transportation Authority, which tested both natural gas and alcohol-based fuels in the late 1980s and early 1990s, eventually converted its alcohol-fueled buses to diesel because of the high rate of engine failures and low engine reliability. By September 1999, the agency's original alcohol-fueled fleet of 333 buses had been reduced to approximately 10 buses that were operational. Heavy-duty engine manufacturers no longer produce alcohol-fueled engines, and EIA estimates that only 89 alcohol-fueled buses have operated across the United States in 1999.

According to FTA officials, hybrid electric transit buses are currently available from two bus manufacturers, and fuel cell buses will be commercially available by 2002.[8] Various types of hybrid vehicles are in the developmental and demonstration stages by FTA's bus technology program, the Advanced Technology Transit Bus Program, the New York State Consortium with Orion Bus Industries, and Demonstration of

[7]Because at the time we completed our work FTA's data on the use of fuels for full-sized buses were current only through the end of 1997, we used data from EIA for additional analysis on trends in fuel use from 1998 through 2000. FTA's data pertain only to metropolitan areas with 50,000 people or greater, while EIA's data estimate fuel use nationwide.

[8]Two types of hybrid electric-drive configurations exist. The first is primarily battery-electric but uses a small engine-driven generator set to reduce the battery output that would otherwise be needed, thereby extending the operating range between charges. The vehicle's batteries are externally recharged and constitute the primary energy source. The second is a system with generator sets large enough to directly power the drive motors in all operating modes without being supplemented by a discharging energy storage device. The engine's fuel is the primary energy storage medium, and the vehicle is not equipped for external battery recharging. Fuel cells are electrochemical devices that convert a fuel's energy directly to electrical energy. These cells can be fabricated in a wide variety of transportation applications and offer the potential to significantly increase fuel economy and reduce vehicle emissions. Currently, fuel cells are fueled by hydrogen that can either be stored on-board or generated from other fuels, such as methanol.

Universal Electric Transportation Subsystems. Officials of two transit operators that we contacted said they are also testing diesel hybrid electric buses: the Metropolitan Transportation Authority's New York City Transit recently took delivery of the first five diesel hybrid buses and placed them into service, while Minneapolis Metro Transit recently ordered five diesel hybrid buses and expects to receive them in early 2000. Moreover, the Chicago Transit Authority is testing three prototype fuel cell buses.

Data on the Extent of Air Quality Improvements in Urban Areas Caused by Alternative Fuel Buses Are Limited

There are limited data to quantify the extent to which alternative fuel transit buses provide air quality benefits in urban areas. DOT, EPA, and DOE officials told us that these agencies had not studied how a transit operator's use of alternative fuel transit buses has affected regional air quality. Moreover, EPA does not routinely monitor the effects of transit buses on urban air quality. On a national scale, transit buses, including alternative fuel buses, do not significantly affect national levels of air pollution because they constitute a very small portion of the total number of automobiles, trucks, and other vehicles in the United States. The Federal Highway Administration estimated that there were 208 million such vehicles on the road in 1997. The approximately 50,000 full-sized transit buses that were operating in that year constituted about 0.02 percent of all vehicles nationwide. Alternative fuel buses account for only about 5 percent of all full-sized transit buses. In addition, EPA estimates that heavy-duty diesel buses, in general, account for 5 percent of all emissions from heavy-duty vehicles.[9]

At the same time, because individual alternative fuel buses emit less pollutants than do individual diesel buses, it is likely that the use of alternative fuel buses causes some yet-to-be-quantified beneficial impact on air quality in the urban areas in which they operate. Individual alternative fuel transit buses produce less major emissions—nitrogen oxides and particulate matter—than diesel buses do.[10] EPA has certified that both the Detroit Diesel and the Cummins heavy-duty CNG engines produce lower levels of nitrogen oxides and particulate matter than

[9]EPA's estimate is based on information from its Mobile model—a computer model that is designed to estimate vehicle emissions. The California Air Resources Board recently reported that transit buses account for only 0.03 percent of the total vehicles operating in the state of California and that urban buses consisting of both transit and tour buses, contribute only 1.1 percent of the total nitrogen oxides and 0.34 percent of the total particulate matter emissions statewide.

[10]Nitrogen oxides include several gaseous compounds made of nitrogen and oxygen. Particulate matter is a collection of small particles emitted by an engine.

comparable heavy-duty diesel engines.[11] In addition, West Virginia University and others found that CNG buses have the potential to significantly lower nitrogen oxides.[12]

Some beneficial impact on urban air quality through the use of cleaner alternative fuel buses is also indicated by the nature of bus travel in urban areas. For example, the typical route of a transit bus—involving frequent stops and starts because of traffic congestion and passenger boarding—creates high particulate emissions in those areas in which it operates. West Virginia University and others found that CNG buses emit virtually no particulate matter. Moreover, FTA reported that, in 1997, 73 percent of transit bus service occurred in urban areas with populations greater than 1 million, including such areas as Los Angeles, Chicago, and New York, where pollution levels have exceeded the national standards.

Diesel buses are also becoming much cleaner. According to EPA, emissions from individual diesel buses have declined substantially over the past 11 years. Improvements in diesel engine technology have resulted in heavy-duty diesel engines that are more reliable, durable, and less polluting than the diesel engines of the past. Many of these improvements are the result of more stringent EPA emissions standards promulgated under the Clean Air Act.[13] Initially established in 1985, these standards, under EPA's current test procedures, have become more restrictive over time, leading to increasingly cleaner mobile source emissions. The emissions regulations for full-sized buses target the engines rather than the entire vehicle (as with automobiles) because heavy-duty engine manufacturers often do not assemble complete vehicles. As shown in table 2, permissible nitrogen oxide levels declined 63 percent (from 10.7 grams per brake horsepower per hour [g/bhp-hr] to 4.0 g/bhp-hr) from 1988 to 1998, while permissible particulate matter levels declined 83 percent (from 0.60 g/bhp-hr to 0.10 g/bhp-hr).[14]

[11]Both diesel and CNG engines that meet EPA's requirements will be available in 2002.

[12]West Virginia University, under contract with DOE and the National Renewable Energy Laboratory, has been conducting studies to evaluate emissions of alternative fuel transit buses. The University also found that the reduced emissions from alternative fuel buses are highly dependent on the engine technology and the condition of the vehicle. Improperly tuned buses had to be repaired before being able to achieve low emissions.

[13]According to DOE officials, it is not clear that heavy-duty diesel engines operate on the road with the type of emissions promised by the manufacturer. The Department of Justice and EPA alleged that seven engine companies, including Cummins and Detroit Diesel, installed computer software in their engines that allowed the engines to pass EPA's emissions tests but then function differently during highway driving.

[14]Grams per brake horsepower per hour (g/bhp-hr) is an emission rate that is based on the amount of work performed by the engine during the federal transient test procedure.

Table 2: EPA's Exhaust Emission Certification Standards for Heavy-Duty Diesel Engines

Year	Nitrogen oxides (g/bhp-hr)	Diesel particulate matter (g/bhp-hr)	Hydrocarbons (g/bhp-hr)	Carbon monoxide (g/bhp-hr)
1984-87	10.7	Not applicable	1.3	15.5
1988-89	10.7	0.60	1.3	15.5
1990	6.0	0.60	1.3	15.5
1991	5.0	0.25	1.3	15.5
1993	5.0	0.10, new buses; 0.25, all other	1.3	15.5
1994	5.0	0.07, new urban buses; 0.10, all other	1.3	15.5
1996	5.0	0.05, new urban buses;[a] 0.10 all other	1.3	15.5
1998	4.0	0.05, new urban buses; 0.10, all other	1.3	15.5
2004[b]	2.4 or 2.5 with a limit of 0.5 on NMHC[c]	0.05, new urban buses; 0.10, all other	Not applicable	15.5

[a]In 1996 and later, the standard for urban buses is 0.05, and the in-use standard for diesel particulate matter for new urban buses is 0.07 g/bhp-hr.

[b]As a result of a July 1999 consent decree, heavy-duty diesel engine manufacturers will be required to produce engines that meet the 2004 standards by October 1, 2002.

[c]Nitrogen oxides plus non-methane hydrocarbons.

Source: EPA.

FTA requires that transit operators operate buses that they purchase with federal funds for at least 12 years.[15] However, officials from the American Public Transit Association indicated that transit operators will typically extend this time frame to 15 or more years. Consequently, some transit buses that were manufactured in the late 1980s are still in operation. Since then, permissible levels of nitrogen oxides and particulate matter—pollutants disproportionately attributable to diesel engines—have declined. EPA has mandated a further reduction in nitrogen oxides from new engines. Beginning in 2002, heavy-duty engines will be limited to 2.4 g/bhp-hr of a combination of nitrogen oxides and non-methane hydrocarbons, further reducing nitrogen oxide emissions by 40 percent from 1998 levels (from 4.0 g/bhp-hr to 2.4 g/bhp-hr). In addition, EPA is already developing more stringent emissions standards for diesel engines that, according to an EPA official, would further significantly reduce permissible levels of nitrogen oxides and particulate matter.

[15]According to FTA, minimum service life requirements are either 12 years or 500,000 miles.

Compressed Natural Gas Buses Cost More Than Diesel Buses

This section addresses CNG-fueled transit buses because CNG is the predominant fuel among full-sized alternative fuel buses. Adding those buses to an existing diesel bus fleet generally increases capital and operating costs. The capital costs of bus fleets include both vehicle and infrastructure costs.[16] Operating costs are those associated with transit agency operations, such as vehicle operator labor, vehicle maintenance, and general administration. Eight of the 12 transit operators we contacted operate CNG buses. According to these transit operators as well as transit bus manufacturers, the capital costs of CNG buses exceed those of diesel buses. In addition, the transit operator must make additional capital outlays to install fueling facilities and upgrade maintenance facilities. The costs of vehicle maintenance associated with the fuel and propulsion systems are typically higher for CNG buses than for diesel buses because of more frequent maintenance and the higher costs for parts.[17] In addition, the operating costs of CNG buses are increased by reduced fuel economy and lower vehicle reliability.

The Capital Costs of CNG Bus Fleets Are Greater Than Those of Diesel Fleets

According to transit bus manufacturers, transit operators who operate CNG buses pay approximately 15 to 25 percent more, on average, for full-sized CNG buses than for similar diesel buses. On the basis of recent bus procurements, typical CNG buses cost between $290,000 and $318,000, while typical diesel buses cost between $250,000 and $275,000. Manufacturers charge more for CNG buses to cover their costs for development, certification, and warranty service. Also, the relatively low number of CNG bus orders contributes to the higher prices of CNG buses. However, according to some economists, if the production of these buses were to increase significantly, then the production costs per bus would likely decrease, and therefore the price of the buses would likely decrease.

In order to operate CNG buses, transit operators generally must construct fast-fill fueling stations with gas compressor systems. These new capital investments would not be necessary to operate diesel buses. The costs to construct CNG fuel facilities can range from hundreds of thousands to millions of dollars. FTA estimates that a CNG fueling facility for a typical

[16]The additional capital costs for alternative fuel buses relative to diesel buses consist of the extra cost to purchase the buses and the extra cost, if any, to modify the facilities to fuel, service, and maintain those buses.

[17]The overall operating costs for running a transit bus fleet include those costs that can be directly attributed to the vehicle, such as fuel and vehicle maintenance, and those general costs that are not specific to a particular vehicle, such as driver labor, facilities maintenance, and administration. The costs likely to be affected by the use of an alternative fuel include fuel and lubricant costs and vehicle maintenance costs. Together, these constitute about one-fourth of the total operating costs.

200-bus transit fleet costs $1.7 million.[18] Similarly, Tacoma, Washington's, Pierce Transit Authority spent about $950,000 for its fueling facility; the Greater Cleveland Regional Transit Authority spent $3 million for one of its fueling facilities; and New York City Transit and Los Angeles County Metropolitan Transportation Authority each spent $5 million for a fueling facility.[19] At the same time, some transit operators that we interviewed avoided the costly investment of installing a CNG fueling facility. The Miami Dade Transit Agency, for example, refueled its few experimental CNG buses at an airport's CNG fueling station and spent about $16,000 to modify its facilities.

In addition, transit operators that switch to CNG buses must modify their maintenance facilities to include proper ventilation and leak detection and monitoring systems and typically spend $600,000 to modify one maintenance garage, according to FTA. For example, Thousand Palms' SunLine Transit (Calif.) reported spend about $320,000; Tacoma's Pierce Transit Authority spent about $645,000; the Greater Cleveland Regional Transit Authority and Los Angeles County Metropolitan Transportation Authority spent $750,000 and $1 million, respectively; and New York City Transit spent $15 million to modify its facilities.

In Many Cases, the Operating Costs of CNG Buses Exceed the Operating Costs of Diesel Buses

Eight of the transit operators that we contacted operate CNG buses. Seven of these operators provided assessments of the operating costs of their CNG buses relative to their diesel buses. Six of these operators stated that the overall operating costs of CNG buses are higher than those of diesel buses, while one said that the operating costs of its CNG buses were less than those of diesel buses.

Seven of the transit operators that we contacted that operate CNG buses provided us with maintenance cost data. According to six of these operators, the maintenance costs of CNG buses (an operating cost that includes engine and fuel system repairs and parts replacement) exceed those of diesel buses. For example, Pierce Transit reported that the engine-related maintenance costs of its CNG buses were 16 percent higher than the costs of its diesel buses. Among the factors that contribute to the cost difference are increased fuel system inspection and tune-up costs and

[18]The Transit Cooperative Research Program (a program sponsored by the FTA) and the Transportation Research Board published an assessment of the state of alternative fuels in transit systems: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, TCRP Report 38 (1998). We used information about the costs and characteristics of alternative fuels from that report.

[19]Cost figures are represented in 1998 dollars unless indicated otherwise.

more expensive parts.[20] On the other hand, SunLine Transit said that the maintenance costs of its CNG buses were lower than the costs of its diesel buses.[21] Transit operators noted that many of the additional costs are hidden while the engines are under the manufacturer's warranty and only become apparent once the warranty expires.

In some cases, the fuel costs of operating the CNG buses are higher than those of diesel buses, while in other cases, those costs are lower. Three of the six CNG transit operators that we interviewed that provided us with fuel costs reported that their costs for CNG fuel exceeded their costs for diesel fuel. However, Pierce Transit of Tacoma, Washington, and SunLine Transit of Thousand Palms, California, reported that their costs for CNG fuel are less than what they would be for diesel fuel, while the St. Louis Bi-State transit operator replied that its costs for CNG fuel are the same as they would be for diesel fuel. According to DOE, for 1999, the nationwide average price of diesel fuel was 25 percent higher, on an energy-equivalent basis, than the fuel price of CNG.[22] However, transit operators' CNG costs can vary, depending on geographic location, the cost to compress the natural gas, and the extent to which any special arrangements have been made with the local natural gas company. Some of the transit operators we interviewed—Tacoma's Pierce Transit Authority, the Los Angeles County Metropolitan Transportation Authority, New York City Transit, and SunLine Transit—have been able to decrease their costs for CNG fuel by negotiating contractual arrangements to purchase the fuel at decreased prices from their local gas distributors. Also, the fuel costs of using CNG can be higher in part because, according to a recent FTA study, CNG buses are 20 to 40 percent less fuel-efficient than diesel buses.

[20]According to a draft study by the Los Angeles County Metropolitan Transportation Authority (Fuel Strategies for Future Bus Procurements [Mar. 12, 1999]), the inspection and tune-up costs of CNG engine and fuel systems are expected to continue to outpace the costs of diesel systems because of the time and frequency associated with these maintenance activities. However, the differential cost between the two systems is expected to decrease, as fuel and ignition systems for CNG vehicles become more durable with the continued advancement of this technology.

[21]Three-Year Comparison of Natural Gas and Diesel Transit Buses, SunLine Transit of Thousand Palms, California (May 1999). The report compares the experiences of the transit operators in Thousand Palms and Sacramento. Of the eight CNG transit operators we contacted, SunLine was the only one that reported lower fuel and maintenance costs.

[22]According to DOE, for 1999, the average price of diesel fuel was $7.91 per million British thermal units (1998 dollars), while the average price of CNG was $6.31 per million British thermal units (1998 dollars).

Incentives and Disincentives of Using Alternative Fuel Technologies in Transit Buses

The transit operators that we interviewed identified a number of incentives and disincentives for using alternative fuel technologies.

Incentives for Using Alternative Fuel Technologies Identified by Transit Operators

Nine of the 12 transit operators we interviewed cited concerns about vehicle emissions standards and air quality as among the most important reasons for using alternative fuel buses. The Los Angeles County Metropolitan Transportation Authority began purchasing and testing methanol buses in 1989 in response to impending changes in federal emissions standards. Also, operators in areas that were already meeting air quality standards—such as the Tri-County Metropolitan Transportation District of Portland, Oregon—cited the need to further improve air quality as a reason for using alternative fuel buses.

Emissions from transit buses are a very visible public concern. According to an EPA official, the agency receives more complaints from the public about emissions from transit buses than all other environmental issues combined. According to 8 out of the 12 transit operators we contacted, improving the public's perception of transit and responding to the public's desire for cleaner fuels were factors that influenced their decisions about the use of alternative fuel buses. By replacing diesel buses with alternative fuel buses, transit operators believe that transit will be perceived as more environmentally friendly and as a more desirable alternative. For example, an official from the Greater Cleveland Regional Transit Authority said that, after beginning to operate alternative fuel buses, the Authority received very favorable comments from the public because its buses no longer emitted the black smoke typical of older diesel engines.

Transit operators also cited the federal funding of alternative technologies and state and local mandates as incentives. Officials of 4 of the 12 transit operators we contacted said that they began using alternative fuels because of the availability of federal government funding. For example, the Miami Dade Transit Agency became an alternative fuel test site because of an FTA program that funded a number of alternative fuel activities. In this case, the program provided funding for the purchase of 40 alternative fuel buses and clean diesel buses used in Miami's Alternative Fuels Test program. Other transit operators were encouraged to try alternative fuels because, under federal bus procurement programs, the federal funding match for alternative fuel vehicles is higher than it is for standard diesel vehicles. Also, state and local mandates have encouraged the use of alternative fuels. For example, Houston began purchasing LNG because the state of Texas Clean Fleet Program required that transit operators convert half of their fleets to consist of low-emission vehicles.[23] The Los Angeles County Metropolitan Transportation Authority adopted a policy in 1993 to purchase only buses that use alternative fuels.

Disincentives for Using Alternative Fuel Technologies Identified by Transit Operators

Officials from 9 of the 12 transit operators we interviewed indicated that the higher costs of alternative fuel bus operations—both capital and operating costs—were a deterrent to switching from diesel fuel. For example, most operators of CNG buses had concerns about the capital investment associated with these buses. As noted earlier, the capital investments include more costly vehicles as well as significant outlays for installing fueling stations and modifying maintenance facilities.

The transit operators who use alternative fuel buses also found the reduction in reliability to be a major disincentive to using these buses. Officials of 10 of the 12 transit operators we contacted said that the reduced reliability of alternative fuel buses was a disincentive. For example, both Los Angeles County and the Greater Cleveland Regional Transit Authority reported more engine and fuel system failures in their CNG bus fleets than in their diesel bus fleets. Recent studies indicated that, despite great strides by engine manufacturers, CNG buses' engine and fuel system will likely remain less reliable than these components in diesel buses for the foreseeable future.

The higher costs and reduced reliability of alternative fuel transit buses have led some transit operators to discontinue operating alternative fuel transit buses. For example, Houston's Metropolitan Transit Authority has switched its dual-fuel LNG buses exclusively to diesel fuel. The Miami Dade Transit Authority has discontinued its experiments with various alternative fuels and converted all of its buses to diesel. These operators indicated that they might reconsider their decisions in the future if the alternative fuel technologies become more reliable and less expensive. Transit operators that are committed to running alternative fuel buses tend to view the reduction in reliability as a cost of doing business for using alternative fuels. For example, officials of such transit operators as

[23] The Texas Clean Fleet Program requires that participating local governments ensure that certain percentages of their vehicle purchases are EPA-certified low-emission vehicles. In 1998, the program was amended to exempt vehicles over 26,000 pounds—effectively exempting all full-sized transit buses.

SunLine Transit, Pierce Transit, and the Greater Cleveland Regional Transit Authority stated that they approach the challenges of alternative fuel fleets by solving problems as they arise. They take the necessary measures to ensure the success of their alternative fuel bus fleets.

In addition, diesel buses have become significantly cleaner over the past 11 years. According to the transit operators and industry experts we contacted, the environmental advantages that CNG and alternative fuels once enjoyed over diesel have dissipated, making transit operators less likely to switch to CNG and other alternative fuel technologies for this reason. As previously described, the manufacturers of diesel bus engines have produced buses that meet EPA's emissions standards. Some of the transit operators we spoke with first experimented with or began using alternative fuels in the early 1990s, when it was unclear whether diesel engine manufacturers would be able to meet EPA's new standards. Since 1988, the manufacturers have made great strides to ensure that diesel buses emit less pollutants. For instance, permissible emissions of nitrogen oxide have been reduced by 63 percent, and particulate matter levels have been reduced by 83 percent. According to some transportation industry experts, it appears that these dramatic improvements in the emission performance of diesel engines will continue into the next decade. FTA reported that these developments are eroding the advantages in emission performance that alternative fuel heavy-duty engines offer over diesel engines.

Agency Comments

We provided DOE, EPA, and DOT with a draft of this report for their review and comment. The agencies were generally satisfied with the information presented in the draft report. All provided technical clarifications, which were incorporated as appropriate.

Scope and Methodology

We obtained information from DOT, EIA, and the transportation industry regarding the number of alternative fuel transit buses. We obtained information from EPA regarding the air quality standards for transit buses. We spoke with and obtained data from federal, state, and transportation industry officials, as well as transit operators that have used alternative fuel transit buses, about the types of costs incurred to operate alternative fuel buses as well as incentives and disincentives for using CNG as well as other alternative fuels. Appendix I provides our detailed scope and methodology. We conducted our review from March through

November 1999 in accordance with generally accepted government auditing standards.

We are distributing this report to the Administrator of the Federal Transit Administration, the Administrator of the Environmental Protection Agency, the Secretary of Energy, and the Secretary of Transportation. We will make copies available to others upon request.

If you have any questions about this report, please contact me at (202) 512-2834. Major contributors to this report were Bonnie Pignatiello Leer, Gail Marnik, Ernie Hazera, Eric Diamant, Libby Halperin, and Joseph Christoff.

Phyllis F. Scheinberg

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Associate Director,
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Contents

Tables

Abbreviations

CNG	compressed natural gas
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ETBE	ethyl tertiary butyl ether
FTA	Federal Transit Administration
GAO	General Accounting Office
LNG	liquefied natural gas
TEA-21	Transportation Equity Act for the 21st Century

Scope and Methodology

To determine the status of the development and use of alternative fuel technologies in full-sized transit buses, we obtained information from the Federal Transit Administration's (FTA) national transit database on the number of transit buses with more than 35 seats and the number of articulated buses according to fuel type for 1992 through 1997—the dates of the most recent data available at the time we completed our work.[1] Because FTA's data on the use of fuels for full-sized buses were current only through the end of 1997, we used data from DOE's Energy Information Administration (EIA) for additional analysis on trends in fuel use from 1998 through 2000.[2] EIA's data are more expansive than FTA's: FTA's data pertain only to metropolitan areas of 50,000 people or greater, while EIA's data estimate fuel use nationwide. We performed limited reliability assessments on required data elements from FTA's and EIA's data. These assessments involved reviewing existing information about the data and performing electronic tests for reasonableness. We determined that the data were reliable enough for the purposes of this report. We also spoke with 12 transit operators that have used or are currently using alternatively fueled transit buses to obtain information about their experiences. We judgmentally selected the transit operators on the basis of the number of buses, the number of unlinked passenger trips, alternative fuel experience, geographic location, federal funds obligated by the relevant state, and size of the urban area. Table I.1 lists the transit operators we contacted and the type of alternative fuel they used for transit buses.

[1]An articulated bus is an extra-long bus (54 to 60 feet) that has the rear body section connected to the main body by a mechanism that allows the vehicle to bend when in operation for sharp turns and curves.

[2]These data are estimates of alternatively fueled buses greater than 35 feet that the EIA compiled from the following sources: the American Public Transit Association's 1999 Transit Vehicle Data Book; the Federal Transit Administration's 1997 National Transit Database; the Energy Information Administration's Form EIA-886, "Alternative Transportation Fuels and Alternative Fueled Vehicles Annual Survey;" miscellaneous newsletter, newspaper, and magazine articles; and worldwide websites.

Table I.1: Transit Operators Contacted

Transit operator	Location	Type of alternative fuel used
Command Bus Company (New York City Department of Transportation)	Brooklyn, N.Y.	CNG
Metropolitan Transportation Authority: New York City Transit	Brooklyn, N.Y.	CNG, diesel hybrid electric
Greater Cleveland Regional Transit Authority	Cleveland, Ohio	CNG
Metropolitan Transit Authority of Harris County	Houston, Tex.	LNG
Los Angeles County Metropolitan Transportation Authority	Los Angeles, Calif.	Methanol, ethanol, CNG
Miami Dade Transit Agency	Miami, Fla.	Methanol, CNG
Minneapolis Metro Transit	Minneapolis, Minn.	Ethanol
Greater Peoria Mass Transit District	Peoria, Ill.	Ethanol
Portland Tri-County Metropolitan Transportation District of Oregon	Portland, Oreg.	LNG
Bi-State Development Agency, Missouri-Illinois Metropolitan District	St. Louis, Mo.	CNG
Pierce Transit Authority	Tacoma, Wash.	CNG
SunLine Transit Agency	Thousand Palms, Calif.	CNG

Legend

CNG=compressed natural gas

LNG=liquefied natural gas

We also observed the activities at the Greater Cleveland Regional Transit Authority's compressed natural gas (CNG) bus facility in Cleveland, Ohio. We obtained and reviewed studies conducted by transit operators in Cleveland, Ohio; Los Angeles, California; Miami, Florida; and Thousand Palms, California, regarding their experiences in using alternative fuels. We also obtained information on the development of alternative fuel technologies for use in transit buses from FTA as well as industry groups. Appendix II identifies the sources, other than transit operators cited in table I.1, that we contacted. To identify the air quality benefits of alternative fuel technologies, we reviewed information and spoke with Environmental Protection Agency (EPA) officials about air quality standards that apply to transit buses. We also obtained from EPA information regarding the degree to which transit bus emissions contribute to the levels of pollution. We obtained and reviewed studies conducted by West Virginia University for the Department of Energy (DOE) on the potential emissions reduction resulting from the use of alternative fuel technologies in transit buses. We spoke with West Virginia University and DOE officials to discuss the studies' findings. We spoke with a transit bus engine manufacturer about the industry's efforts to reduce emissions from transit bus engines. Finally, we obtained and reviewed information and studies from EPA and other sources regarding the potential to reduce emissions from transit buses.

To identify transit operators' costs of converting to alternative fuel technologies, we spoke with the selected transit operators that have used or are currently using alternative fuel transit buses. We obtained information about the types of capital and operating costs they incurred when switching their transit buses to alternative fuels and obtained the actual cost figures where available. We also reviewed studies produced by transit operators, as well as the Transit Cooperative Research Program, on the costs that transit operators incur when switching to alternative fuels.

To identify the incentives and disincentives for using alternative fuel technologies for transit buses, we contacted officials from the selected transit operators, industry groups, DOT, EPA, and the DOE. We obtained information on federal programs that provide funds for alternative fuel vehicle purchases as well as operating assistance.

Appendix II identifies the sources other than the transit operators listed in table I.1 that we spoke with.

Sources Contacted by GAO

Table I.1 also lists the transit operators that we contacted to obtain information as cited in appendix I.

U.S. Department of Transportation

Federal Transit Administration

National Highway Traffic Safety Administration

Research and Special Programs Administration

Advanced Vehicle Program

Volpe National Transportation Systems Center

Other Federal Agencies

Environmental Protection Agency

Department of Energy

Energy Information Administration

National Renewable Energy Laboratory

Alternative Fuels Data Center

State Groups

California Air Resources Board

National Conference of State Legislatures

Industry Groups

American Fuel Cells Association

American Methanol Institute

American Public Transit Association

Ballard Automotive

Cummins Engine Company

Gas Research Institute

National Corn Growers Association

Natural Gas Vehicle Coalition

Propane Vehicle Council

Society of Automotive Engineers

Bus Manufacturers

New Flyer Bus Company

North American Bus Industries (NABI, Inc.)

Orion Bus Industries

Other Organizations

Chicago Transit Authority

Metropolitan Atlanta Rapid Transit Authority

Transit Cooperative Research Program

University of California-Davis

West Virginia University

Liquefied Natural Gas

Overview

As a transit fuel, liquefied natural gas (LNG) has expanded in recent years. The same engines designed for CNG are used for LNG by heating and vaporizing the liquid fuel before it is fed to the engine. LNG is available from gas utility companies that store it, from gas-processing plants, or through import terminals in Louisiana and Massachusetts. LNG has a higher storage density than CNG, which gives it some advantages as a transportation fuel. Initial experiences with LNG transit buses indicated problems with engine and fuel system reliability and operating costs in exceeding those of diesel.

Fuel Characteristics

LNG is produced by cooling natural gas and purifying it to the desired methane content. The typical methane content is approximately 95 percent for the conventional LNG produced at a "peak shaving" plant. Peak shaving involves the liquefaction of natural gas by utility companies during periods of low gas demand (summer) and subsequent regasification during peak demand (winter).[1]

A number of gas utility companies store large volumes of LNG in peak shaving plants. These facilities can rapidly evaporate the product and inject it into the pipeline system at times of very high customer demand. LNG can also be produced at gas-processing plants, because these plants employ refrigeration to condense and separate undesirable constituents before it is injected into the pipeline system. In addition, imported LNG is distributed to some markets through import terminals in Louisiana and Massachusetts.

The same engines designed for CNG are used with LNG by heating and vaporizing the liquid fuel before it is fed to the engine. All commercially available LNG buses use an engine that was originally designed for CNG because the fuel enters the engine in a gaseous state. LNG offers a substantially higher storage density than CNG, which gives the former some advantages as a transportation fuel.

Current LNG buses are 30-percent less fuel-efficient than diesel buses. LNG should offer somewhat higher in-service fuel economy than CNG buses because of its lower fuel storage weight.

[1] Liquefaction is the process of turning a solid or gaseous substance into a liquid.

Status of Use and Development

EIA has estimated that 725 full-sized transit buses were fueled by LNG in 1999. According to the American Public Transit Association, as of January 1999, nine agencies operated LNG buses, including three that had additional LNG buses on order. Initial experiences with LNG were not very successful. Agencies such as the Metropolitan Transit Authority of Harris County (Houston) and Portland Tri-County Metropolitan District, tried out LNG buses and experienced reliability problems and engine and fuel system failures.

Costs

According to the Transit Cooperative Research Programs' 1998 study, the incremental price of LNG transit buses can range from $45,000 to $65,000 more per vehicle than diesel. These prices are anticipated to decrease if and when the market develops and more sales are made. The prices of heavy-duty natural gas engines are variable, depending on the manufacturer, engine, and project. Manufacturers charge a substantial premium to cover some of their costs, including development, certification, and warranty service.

Other capital costs incurred during the conversion of bus operations to LNG include those for maintenance garage modifications and fueling facilities. Because of the small number of garages actually modified, it is complicated to estimate maintenance garage modification costs. The Transit Cooperative Research Program estimates that the median cost for LNG maintenance garage modifications will be $600,000 for a 150- to 200-bus garage. The costs of an LNG fueling facility are probably more variable than the costs for a CNG facility because fewer LNG stations have been installed. A bid for the design and construction of an LNG fueling facility was $2.5 million, plus another $200,000 for the capability of fueling with both LNG and CNG.

The operating costs for LNG buses, relative to those for diesel buses, depend mainly on fuel pricing, relative fuel economy, and maintenance costs. LNG tends to be less expensive than diesel fuel when energy content is considered. In regions with favorable LNG fuel pricing, the fuel costs associated with LNG can be lower than those associated with diesel, even including LNG's 30-percent lower fuel efficiency. For most fuel sources, the price of LNG is highly dependent on the buyer's willingness to contract to purchase a given quantity over a given time period as well as on the transportation costs involved.

There are wider varieties of fuel supply scenarios for LNG than for CNG. These include on-site liquefaction, central liquefaction facilities, LNG from gas-processing plants, peak shaving LNG, and imported LNG. Each of these has supplied fuel for LNG vehicles in the United States. Because natural gas is widely used in the United States for home heating, the generation of electricity, and industrial processes, fuel supply is not expected to constrain the development of natural gas as a vehicular fuel. However, the costs of supplying LNG through various supply scenarios will vary regionally, and not all fuel supply scenarios will be economically viable at all locations.

Emissions

Because the engine technology is the same, emissions from LNG vehicles are essentially identical to emissions from CNG vehicles. They are both significantly cleaner than diesel.

Incentives and Disincentives

The use of LNG in buses offers lower emissions than diesel buses. LNG buses are commercially available and have many of the same reliability and operating cost issues as CNG buses. LNG offers a substantially higher storage density than CNG, so the former may be a better choice for buses that run longer routes. LNG buses are less fuel efficient than diesel buses. Also, the freezing temperature associated with LNG systems creates a number of generalized safety considerations for bulk transfer and storage. Most importantly, LNG is a fuel that requires intensive monitoring and control because of the constant heating of the fuel, which takes place because of the extreme temperature differential between ambient and LNG fuel temperatures. Refueling operations require operators'awareness of, and protection from, hazards that result from skin contact with very cold substances. Skin contact with leaking fuel can cause frostbite. Wearing leather gloves, a face shield, and an apron provides good protection in the event of a leak. Worn LNG fueling nozzles begin to leak fuel, and LNG nozzles have shown poor durability in transit service in the past. The latest nozzle designs are much more durable, and improvements continue to be developed to improve durability to a satisfactory level.

Liquefied Petroleum Gas

Overview

Liquefied petroleum gas, otherwise known as propane, is a by-product of both natural gas processing and petroleum refining. While rarely used as a fuel for full-sized buses, propane is used in several hundred paratransit vehicles with spark-ignited engines.[1] Along with a reduction in emissions, the use of propane as a fuel in transit bus fleets brings with it high operating and capital costs as well as some concerns about safety. Propane buses also suffer a fuel efficiency penalty relative to diesel buses. Propane's widespread use is currently hindered by the lack of a suitable commercially manufactured engine for full-sized transit buses.

Fuel Characteristics

Propane consists of a mixture of natural gas liquids, including propane, propylene, butane, and butene. It is gaseous at room temperature but liquefies at relatively low pressures. Propane's properties make it convenient for storage and transport as a pressurized liquid. The stored liquid fuel is easily vaporized into a gas with clean-burning combustion properties.

Approximately 60 percent of the propane produced in North America comes from natural gas processing. Propane can be purchased wholesale from distribution centers by fleet users with their own refueling stations or at discounted prices from public-access refueling stations. The general public can also purchase it at retail prices from public-access refueling stations.

Propane buses are less fuel efficient than diesel buses. For example, propane buses operating at a California-based transit agency were 26 percent less fuel efficient than equivalent diesel buses.

Status of Use and Development

The extensive use of propane in larger transit buses is currently hindered by the lack of a suitable commercially manufactured engine. Warranted commercially manufactured propane engines are commercially available for buses up to 30 feet long. While propane engine technology is currently available, it has not been transferred to larger engines, although the potential exists. According to an official from the Propane Vehicle Council, Detroit Diesel had been developing a propane version of a heavy-duty engine, but this program has been discontinued owing to a loss of interest, which occurred after the natural gas industry greatly increased its assistance for the development of natural gas engines. The propane

[1]Paratransit vehicles are those, such as vans or small buses (generally less than 35 feet in length), that can be used to provide transit services on a flexible basis, as opposed to operating on fixed routes and according to fixed schedules.

industry is now assessing the market demand for larger propane engines. Although rare, a few transit operators currently use full-sized propane buses in their fleets. Propane is also used in several hundred paratransit vehicles (less than 30 feet long) with spark-ignited engines. EIA has estimated that 152 full-sized propane transit buses were in service in the United States in 1999. According to the Propane Vehicle Council official, convincing manufacturers to make the investment that would move propane technology to a 350- to 400-horsepower engine is the biggest impediment to increasing the penetration of propane into the transit bus market.

Costs

According to the Transit Cooperative Research Program, in 1998, the incremental cost of a propane bus was approximately $35,000 to $45,000 greater than a counterpart diesel bus.

The use of propane requires that fueling, maintenance, and storage facilities be upgraded to different standards or that a new facility be constructed. For example, propane storage and dispensing areas must be located certain minimum distances away from buildings, adjoining property, streets, alleys, and underground tanks. A well-designed maintenance garage for propane vehicles has explosion-proof wiring and electrical equipment in low areas where propane buses are maintained. Building ventilation rates must be sufficient to remove propane from ground level. Maintenance facilities should be equipped with flammable gas detectors. These devices can detect concentrations of propane before the vapors reach flammable levels. These facility modifications entail additional capital costs. Although these costs vary substantially, depending on the specific circumstances and equipment, a typical estimate for a 200-bus transit fleet is $300,000 for modifications to one maintenance garage and $700,000 for one propane fueling facility.

Since the early 1990s, the energy equivalent price (on average) of propane has been increasing relative to the price of gasoline and diesel fuel, and propane is now nearly as expensive as gasoline and is more expensive than diesel fuel. It is difficult to be precise about the price of propane as a motor fuel because its purchase price depends on many factors. These include whether the purchase is wholesale (e.g., for a fleet) or retail, the quantity being purchased, the timing relative to yearly and seasonal propane market fluctuations, the location of purchase within the United States, and the state’s tax treatment.

Emissions

Propane bus engines generally have lower emissions than counterpart diesel engines, although generally not as low as natural gas or methanol engines. According to an official of the Propane Vehicle Council, the simple molecular structure of propane eliminates particulate matter. In addition, experimental propane buses operated at a California-based transit agency underwent tests that indicated very low nitrogen oxide emissions. It appears that proper optimization for lean combustion in spark-ignited propane engines can yield excellent emissions performance.

Incentives and Disincentives

The primary incentive to use propane is the emissions benefits. Disincentives include safety concerns due to pressurized storage of the fuel and potential fire hazards during transport. Propane is stored under moderate pressure at ambient temperatures to maintain it in a liquid state. Since it is stored in this manner during bulk transport and storage operations, there is a potential hazard associated with an inadvertent opening of a fitting or plug that could become a projectile. A major concern of the potential fire hazards during the transport of propane via tanker trucks is the setting of pressure relief valves so that the container will not vent propane vapor in the event of an unusually warm day. There are no significant environmental concerns associated with propane spills, since the liquid will quickly vaporize. Since propane for fleet use is a mixture of hydrocarbons, the toxicity of the fuel is difficult to determine. The major constituent—pure propane—is considered to be a simple asphyxiant by the American Conference of Governmental Industrial Hygienists.

Ethanol

Overview

Ethanol would appear to be a good candidate for an alternative fuel for use in transit buses because it is a liquid and has several physical and combustion properties similar to diesel fuel. These properties are so similar that the same basic engine and fuel system technologies can be used for both ethanol and for diesel fuel. However, the experiences of transit operators using ethanol as a transit bus fuel have indicated that it is not a satisfactory alternative because of higher costs and premature engine failure. At this time, no bus manufacturer is currently producing ethanol buses.

Fuel Characteristics

Ethanol is produced by the fermentation of plant sugars. Typically, it is produced in the United States from corn and other grain products, while some imported ethanol is produced from sugar cane. Pure ethanol is rarely used for transportation applications because of the concern about intentional ingestion. In fact, ethanol for commercial or industrial use is always denatured (i.e., small amount of toxic substance is added) to avoid the federal alcoholic beverage tax.

Pure ethanol is a clear liquid with a characteristic faint odor. It has a high latent heat of vaporization, like methanol. Ethanol is completely soluble in water, which presents problems for storage and handling. Current fuel distribution and storage systems are not watertight, and water tends to carry impurities with it. Ethanol will not be significantly degraded by small amounts of clean water, though the addition of water dilutes its value as a fuel.

Ethanol can be used as a transportation fuel in three primary ways. It can be used as a blend with gasoline—typically 10 percent—that is commonly known as gasohol. It can be used as a component of reformulated gasoline both directly and/or by being transformed into a compound such as ethyl tertiary butyl ether (ETBE). Or it can be used directly as a fuel—with 15 percent or more gasoline known as E85.

Ethanol can also be used directly in diesel engines specially configured for alcohol fuels. Using ethanol to make gasohol, in reformulated gasoline, or transformed into ETBE for use in reformulated gasoline, does not require specially configured vehicles. Almost all existing vehicles will tolerate these fuels without problems and with likely advantageous emissions benefits.

In 1997, the United States had a production capacity for fuel ethanol of 1.1 billion gallons per year. Ninety percent of this capacity was from 16 plants having a capacity of 10 million gallons per year and larger. Almost all ethanol production plants are located in the Midwest where the largest amount of corn is grown.

Status of Use and Development

EIA has estimated that in 1999 there are 51 full-sized ethanol transit buses in the nation. There are no orders for ethanol buses currently. No manufacturer has produced alcohol-fueled engines since 1996. The Los Angeles County Metropolitan Transportation Authority converted its methanol fleet to ethanol in 1995, believing that the ethanol engines would have to be rebuilt only once every 3 years as opposed to once every 12 months with methanol. However, the ethanol engines failed at a much quicker rate, achieving only about half the life of the methanol engines. In 1998, Los Angeles County received approval to convert the alcohol-fueled engines to diesel as the engines failed and the warranties expired. The decision to convert the alcohol-fueled buses to diesel was very controversial, but the other options were more costly and would have negatively affected service.

Costs

According to the Transit Cooperative Research Program, the actual incremental costs for ethanol buses when they were available for purchase were approximately $25,000 to $35,000. Ethanol fueling facilities and modifications to maintenance facilities entail additional capital costs. Although these costs vary substantially on the basis of the specific circumstances and equipment, a typical estimate for a 200-bus transit fleet is $300,000 for modifications to one maintenance garage and $400,000 for one ethanol fueling facility.

The operating costs for ethanol buses, relative to diesel buses, depend primarily on fuel costs and maintenance costs. Because of the limited use of ethanol transit buses, no definitive estimate of the incremental maintenance costs of ethanol buses exists. According to a 1996 DOE study, the maintenance costs of ethanol-powered bus engines and fuel systems were significantly higher than those of diesel buses. Among the fuels that the Transit Cooperative Research Program reviewed, on the basis of energy content, only hydrogen is more expensive than ethanol. Because ethanol is basically an agricultural product, agricultural economics and institutions dominate its production, and its price is related to crop prices.

Emissions

The primary emission advantage of using ethanol blends is that carbon monoxide emissions are reduced by the oxygen content of ethanol. The oxygen in the fuel contributes to combustion much the same as adding air. Because this additional oxygen is being added through the fuel, the engine fuel and emissions systems are fooled into operating leaner than designed, the result of which is lower carbon monoxide emissions and typically slightly higher nitrogen oxides emissions.

The emissions characteristics of E85 (a blend of ethanol with 15 percent or more gasoline) are not as well documented as those for M85 (a blend of methanol with 15 percent or more gasoline) vehicles. However, Ford Motor Company tested and found essentially no difference in tailpipe emissions compared to using the standard emissions testing gasoline (Indolene). In this test, the engine-out emissions of hydrocarbons and nitrogen oxides were lower than they were for gasoline, but ethanol's lower exhaust gas temperatures were believed to decrease the catalyst's efficiency only slightly, so the tailpipe emissions were the same.

Incentives and Disincentives

A significant advantage of alcohol fuels is that when they are combusted in diesel engines, they do not produce any soot or particulate matter, and such engines can be tuned to also produce very low levels of nitrogen oxides. Other inherent advantages are that their emissions are less reactive in the atmosphere, thus producing smaller amounts of ozone, the harmful component of smog. The mass of emissions using ethanol is not significantly different from that of petroleum fuels.

A bus fueled with ethanol will have a longer range than a methanol-fueled bus with the same size fuel tank, but ethanol generally costs more than methanol, and large quantities are needed for transit usage. Like methanol buses, ethanol buses suffer a fuel economy penalty compared to diesel buses.

Methanol

Overview

Methanol is a liquid fuel that has several physical and combustion properties similar to diesel fuel. These properties are so similar that the same basic engine and fuel system technologies can be used for methanol and for diesel fuel. Experience with methanol has shown unreliability of engines and high fuel prices. No manufacturer is currently producing methanol engines.

Fuel Characteristics

Methanol is a colorless liquid that is a common chemical used in industry as a solvent and directly in manufacturing processes. The currently preferred (and most economical) process for producing methanol is the steam reformation of natural gas. Methanol can also be produced from coal and municipal waste. In the United States, the primary methanol production location is the Gulf Coast area. Methanol is distributed throughout the nation as an industrial chemical. In the transportation sector, methanol has typically been sold either blended with 15 percent or more gasoline (M85) or unblended (M100).

The low vapor pressure and high latent heat of vaporization of methanol created creates cold-start difficulties in spark-ignition engines. To overcome this hurdle and improve the visibility of the methanol's flame, a consensus developed that 15-percent gasoline per volume would be added to methanol (known as M85.) The addition of gasoline changes some of the fuel properties significantly and makes them behave much more like gasoline. This facilitated the development of flexible fuel vehicles, which allow straight gasoline and M85 to be used in the same fuel tank. M100 is the predominant fuel formulation in heavy-duty methanol engines.

On an energy-equivalent basis, current methanol buses have experienced a slightly lower fuel economy compared to diesel buses. This fuel economy penalty is likely due to the additional fuel storage weight carried by the methanol buses.

Status of Use and Development

EIA has estimated that in 1999 there are 38 full-sized methanol transit buses in the United States. No transit operators currently have plans to purchase methanol buses. There is currently little effort to develop new heavy-duty methanol engines, although Caterpillar Technologies has been working, with support from DOE, to develop a modern four-stroke truck engine that uses methanol or diesel fuel or any combination of the two. Such a "fuel-flexible" engine could make a transition to the increased use of methanol fuels in the heavy-duty sector much simpler than relying on dedicated methanol engines that could be used only in areas where methanol is available.

No manufacturer has been producing alcohol-fueled engines since 1996. Some transit operators have experienced mechanical problems with methanol fleets, including premature engine failures, which failed twice as fast as they should have. Because of problems with reliability and engine failure, the Los Angeles County Metropolitan Transportation Authority converted its methanol fleet to ethanol in 1995, believing that the ethanol engines would have to be rebuilt only once every 3 years as opposed to once every 12 months with methanol.

Costs

According to the Transit Cooperative Research Program, the actual incremental costs for methanol buses, when they were available for purchase, were approximately $25,000 to $35,000. Methanol fueling facilities and modifications to maintenance facilities entail additional capital costs. Although these costs vary substantially on the basis of specific circumstances and equipment, a typical estimate for a 200-bus transit fleet is $300,000 for modifications to one maintenance garage and $400,000 for one methanol fueling facility.

The operating costs for methanol buses, relative to diesel buses, depend primarily on fuel costs and maintenance costs. Fuel costs are substantially higher for methanol buses because of current methanol fuel prices and a fuel economy penalty. Current data on relative maintenance costs for methanol buses are based largely on the experiences of Los Angeles County. According to the Transit Cooperative Research Program, methanol buses experienced high maintenance costs because of the need for frequent engine rebuilds. It is likely that additional development work could lead to better designs that could greatly improve their durability. However, there is little likelihood that a methanol engine meeting modern standards of durability will be developed for some time.

Emissions

Methanol does not produce soot or smoke when combusted so no particulate matter is formed. Peak combustion temperatures can be reduced with correspondingly low emissions of nitrogen oxides. Methanol contains no sulfur so it does not contribute to atmospheric sulfur dioxide. Since sulfur dioxide and nitrogen oxides emissions lead to acidic deposition, the use of methanol would make a minor contribution to reducing acid rain.

Incentives and Disincentives

Methanol's major advantage in vehicular use is that it is a convenient, familiar liquid fuel that can readily be produced using well-proven technology. It is a fuel for which vehicle manufacturers can, with relative ease, design a vehicle that will obtain an advantage in some combination of reduced emissions and improved efficiency. Other inherent advantages are that methanol emissions are less reactive in the atmosphere, thus producing smaller amounts of ozone—the harmful component of smog. The mass of emissions from methanol is not significantly different from that of petroleum fuels. Alcohol fuels do not produce any soot or particulate, and they can be tuned to also produce very low levels of oxides of nitrogen when they are combusted in diesel engines.

The major disadvantages of methanol include high initial costs and the impact of reduced energy density on the range of driving or large fuel tanks. Also, the additional fuel needed to achieve a diesel-equivalent range adds increased weight that may reduce legal passenger capacities in bus models, which are already heavy in diesel form. Methanol burns with a flame that is not visible in direct sunlight, and there is a need to educate its users and handlers concerning toxicity and safety.

Some transit operators have experienced higher rates of engine failure and poor engine durability with methanol buses. The poor durability appears to be mainly attributable to leaking fuel injectors as a result of mechanical wear and the accumulation of combustion deposits in the injector tips.

Methanol can cause acute toxic effects through inhalation, ingestion, or skin contact. According to one transit operator we contacted, it is necessary to conduct safety training for personnel working with methanol because of its high toxicity and its lack of a visible flame. Special precautions also must be taken to contain any spills.

Fuel Cells

Overview

Fuel cells are systems that convert hydrogen and oxygen to water. According to FTA officials, a fuel cell generates electricity from the chemical reaction of combining hydrogen and oxygen into water. Fuel cells may either be directly fueled by hydrogen stored onboard the vehicle or may use reformers to generate hydrogen from methanol, natural gas, or other hydrocarbon fuels. Still in the developmental stage, fuel cell buses are currently more expensive than CNG buses, but their combination of very high efficiency and low emissions has interested researchers for some time.

Fuel Characteristics

According to FTA officials, fuel cells are fuel conversion systems—not fuels. The basic elements of a fuel cell are the anode, cathode, electrolyte, and electric load. At the simplest level, fuel cells may be thought of as batteries that operate with hydrogen and oxygen. The complete reaction of the fuel cell combines hydrogen with oxygen to produce water and electricity. The chemical energy is converted to electrical energy with high efficiency, negligible pollution, and little noise. With this process, energy conversion efficiencies on the order of 80 percent are theoretically possible. In comparison, the energy conversion efficiency associated with burning fuels in heat engines to produce mechanical energy, and convert the mechanical energy to electrical energy, is limited to less than 40 percent.

Two types of fuel cells have been considered for transit bus applications.

- The phosphoric acid fuel cell is so named because it uses hot concentrated phosphoric acid as its electrolyte. This type of fuel cell cannot be started at room temperature but, instead, must be preheated above 100 C before any current can be drawn.
- The Proton-Exchange Membrane fuel cell offers a paramount advantage in that it may be started at room temperature without preheating. The actual efficiencies of working fuel cells are in the range of 40 to 60 percent.

Status of Use and Development

Two major programs are under way in North America to develop and commercialize fuel cell buses for transit. DOT is funding the longest running project through FTA. This project initially focused on the development of a methanol reformer-fueled phosphoric acid fuel cell in a 30-foot transit bus. FTA's fuel cell transit bus program is now moving into a new phase, which seeks to demonstrate methanol-fueled fuel cells in 40-foot transit buses. This program is also developing a Proton-Exchange

Membrane fuel cell system for a 40-foot transit bus fueled with reformed methanol. The other program involves Proton-Exchange Membrane fuel cell stacks directly fueled by compressed hydrogen. Currently, the Chicago Transit Authority is undertaking a demonstration of three Ballard-New Flyer fuel cell buses. Three additional Proton-Exchange Membrane buses are being tested at British Columbia Transit in Vancouver (British Columbia, Canada). In addition, in late 1997, Daimler-Benz announced that it had engineered a compact methanol-fueled hydrogen reformer to work with the Proton-Exchange Membrane cell. Recent developmental work appears to have led to dramatic improvements in hydrogen reformer performance for automotive fuel cells.

Costs

Fuel cell bus technology is in a developmental stage characterized by low production volumes and high unit costs. Firm cost data are hard to obtain. As with any new technology, unit costs will fall as production rates and manufacturing experience increase. Forty-foot Ballard bus prototypes to be operated by British Columbia Transit and the Chicago Transit Authority reportedly cost $1.4 million each. Ballard has estimated that the price could fall to between $500,000 and $550,000 during initial commercial production and that with large-scale commercial production, prices would be competitive with CNG buses.

Hydrogen is the basic fuel for fuel cells. The hydrogen may be stored onboard or it may be generated from other fuels by a reformer. Fueling facilities for fuel cell buses will be dramatically different, depending on whether the bus uses an onboard reformer. Reformers in existing and planned fuel cell bus and development programs are designed for methanol, although it is possible that a fuel cell engine using a natural gas, or a diesel or gasoline reformer might be developed in the future. Adding a reformer increases the cost, bulk, and complexity of the fuel cell system. Conventional methanol bus fueling facilities would be suitable for fuel cell buses as well.

Fuel cell buses not using reformers are fueled directly with hydrogen. In the Ballard bus, hydrogen is stored as a compressed gas at 3,000 pounds per square inch. The hydrogen would be compressed in the liquid state to 4,000 pounds per square inch, vaporized to a gas, and then dispensed into the onboard storage tanks.

Emissions

The fuel cell emits zero emissions with onboard hydrogen and no particulate matter, trace amounts of hydrocarbons and nitrogen oxides, and very little carbon monoxide with a reformer.

Incentives and Disincentives

Low emissions levels are the main incentive for using fuel cells in transit buses. However, the fact that they are still in the early developmental stages, characterized by low production volumes and high unit costs, is a large disincentive. In addition, directly fueling vehicles with hydrogen has a number of liabilities. These include high costs, poorly developed supply infrastructure, a storage volume greater than that required for CNG, and codes and standards for the design of electrical equipment, maintenance garages, and fueling facilities that are only now being developed.

According to FTA officials, there are also safety concerns when compressed hydrogen is stored onboard a bus to power the fuel cell. For example, compressed hydrogen systems have a tendency to leak, which presents fire safety hazards. Hydrogen leaks are difficult to detect, since hydrogen is colorless and odorless.

Battery Electric

Overview

Battery-electric propulsion systems are primarily targeted to smaller transit buses, such as those used for service in vehicle tours that are relatively short and low speed. This is due to the limited range and power of battery electric-powered vehicles. Battery-electric propulsion is being offered by several manufacturers for medium-duty buses from 22 to 30 feet long. These buses offer several attractive features, including lower noise levels, zero tailpipe emissions, and effortless cold starts. Their principal drawbacks, compared to similar motor bus models, are reduced range and performance, along with substantially higher purchase prices.

Fuel Characteristics

Electricity can be considered as an alternative source of propulsion as evidenced by the use of electrically powered fleet vehicles using batteries as the storage medium. The bulk transport of electricity via the electric power distribution system is a fundamental part of the nation's infrastructure. The hazards associated with high-voltage power lines, substation transformers, and local power distribution centers are well known. Low energy density and the weight of batteries limit vehicle performance and driving range. Typical battery recharging times are on the order of 6 to 8 hours, requiring that fleets be recharged overnight. According to FTA officials, battery pack changes or rapid recharging may be used to extend the operating range of a battery-electric bus.

Status of Use and Development

Many U.S. companies have electric bus development projects. The current research focus for electric propulsion vehicles is in the area of battery development, where the goal is to develop batteries that have low initial cost, high specific energy, and high power density. Battery-electric buses currently in use are predominantly 22- to 30-foot buses, not full-sized buses. EIA has estimated that in 1999, there were only 150 full-sized electric-powered transit buses used in the United States. Although full-sized battery-electric buses have been successfully operated in downtown shuttle routes with limited speed and range, their performance limitations make them impractical for conventional route service but quite appropriate for niche routes requiring only 22- to 30-foot vehicles and ranges of 100 or fewer miles.

Costs

The capital costs of battery-electric buses are substantially higher than those of similarly sized diesel transit buses. A 25-foot battery-electric shuttle bus is slightly more than twice as expensive as a comparable diesel model when the battery-electric bus is equipped with a lead-acid battery pack. With the larger 33-foot buses, the cost premium for battery-electric buses falls to approximately 33 percent. A Nickel Cadmium battery option, which yields greater range per battery charge and increases a battery's life from 3 to approximately 7 years, appears to be widely available. Specifying the Nickel Cadmium instead of a lead-acid battery pack will add from $40,000 to $48,000 to the price of a battery-electric bus.

The operating costs for battery-electric buses that may differ from those of diesel motor buses include energy costs, maintenance costs, and the costs or savings associated with lower or higher vehicle availability. The energy costs per mile reported for battery-electric buses are similar to those for similarly sized diesel buses.[1] Very little maintenance cost data for battery-electric buses are reported in the literature. This may be because the power trains in many of the buses in service to date have been developmental and so have had maintenance requirements that are higher than would be expected in fully commercialized production vehicles and therefore are not comparable to production diesel vehicles.

Emissions

Battery-electric propulsion buses have no emissions, smoke, or exhaust odor.

Incentives and Disincentives

While battery-electric systems provide lower noise levels, emissions benefits, and effortless cold starts as incentives, some disincentives of battery-electric propulsion systems must be considered, including reduced range and performance, and substantially higher purchase prices. There are some safety concerns as well. One of the advantages of electricity compared to other alternative motor fuels is that all facility personnel are generally familiar with the hazards associated with electrical power. Therefore, personnel working with the recharging system can be expected to be aware of the dangers and follow the proper safety procedures. There are no specific health or environmental hazards associated with the transmission and use of electricity at a fleet facility.

The disadvantages associated with battery-electric propulsion for transit buses include the limited range and performance capabilities, as previously discussed. In addition, the battery-electric buses cost more than diesel. All of the safety issues associated with electricity are directly related to the transmission of electric power to the recharging station at

[1]Cost information presented in the study for battery-electric buses focused generally on buses shorter than 40 feet.

the fleet facility. There is no storage issue, since the electrical energy is stored in the onboard batteries. The major safety concern is the exposure of personnel to electrical hazards as they work with the recharging system and connecting the vehicles to that system. This is not expected to be a serious safety hazard because the normal design practices for setting up the connections involve safeguards to ensure that personnel are protected from direct exposure to electrical hazards.

Hybrid Electric

Overview

Hybrid-electric transit buses may be a promising alternative to diesel transit buses. Major bus manufactures are examining this technology, and two of the transit operators we spoke with are either currently testing or planning to test hybrid-electric buses. Since the system is still in the developmental stage, the costs are high. However, the potential exists to greatly reduce nitrogen oxide emissions with the hybrid-electric drive system.

Fuel Characteristics

In a hybrid-electric drive system, the engine is used to drive a generator set, which, in turn, powers one or more propulsion motors. In a hybrid-electric vehicle, a relatively small engine is used to power an alternator, which more or less continuously recharges the propulsion batteries. The smaller engine operates primarily at steady state, using batteries to store and discharge energy as needed under transient conditions. This can improve fuel economy and emissions over traditional internal combustion engines.

Hybrid-electric vehicles have a longer range than pure-electric vehicles because they are not limited to stored battery energy. This also enables them to reduce the necessary battery weight on the vehicle, which further reduces overall energy consumption. To the extent that hybrid-electric drive improves fuel economy in service, fuel fills and dispensing time would decrease, or lower dispensing rates could be used with unchanged dispensing times. For all of the hybrid-electric technologies being developed for full-sized transit buses, a diesel, propane, or natural gas engine ultimately provides all the energy for propulsion. Therefore, hybrid-electric buses would be fueled in a normal manner for one of these fuels.

Status of Use and Development

According to FTA, all major bus manufacturers have hybrid-electric projects under way. Hybrid-electric drive systems are being aggressively investigated as a means of facilitating several important transit bus design goals, including improved fuel economy, lower emissions, and lower maintenance requirements to reduce operating expenses. Hybrid-electric vehicles use both an internal combustion engine and an electric driveline to provide propulsion energy. This combination of an internal combustion engine with an electric drivetrain provides certain advantages over pure battery-electric or internal-combustion engine-driven power trains. Two of the transit operators we spoke with are testing diesel hybrid-electric buses—New York City and Minneapolis. The Metropolitan Transportation

Authority's New York City Transit recently took delivery of five diesel hybrid buses and placed them in revenue service. In addition, Minneapolis Metro Transit recently ordered five diesel-hybrid buses and expects to receive them in early 2000.

Research is currently being conducted on a variety of hybrid-electric drive configurations. At one extreme are systems that are primarily battery-electric but use a small engine-driven generator set to reduce the battery output that would otherwise be needed, thereby extending the operating range between charges. With this system, the vehicle's batteries are externally recharged and constitute the primary energy source. At the other extreme are systems with generator sets large enough to directly power the drive motors in all operating modes without being supplemented by a discharging energy storage device. With this system, the engine's fuel is the primary energy storage medium, and the vehicle is not equipped for external battery recharging. Given that the goal of lower floor height is being sought by transit operators for new bus designs, the large generator set option appears to be the most feasible for general-purpose transit buses.

Costs

The development of full-sized hybrid-electric buses has now progressed to the advanced demonstration phase. However, bus manufacturers are only now planning product design and marketing strategies for commercialization. This makes it difficult to accurately project the capital and operating costs of production vehicles. The prices for these buses have reportedly ranged from $550,000 to $600,000, but it is anticipated that fully commercialized diesel hybrids eventually may be priced similarly to CNG motor buses—at over $300,000. The maintenance facilities for hybrid-electric vehicles will need a variety of new tools and equipment. If hybrid-electric propulsion allows for significant reductions in transmission and brake maintenance, fewer service bays and maintenance spares may be needed than with a similarly sized fleet of motor buses. But provisions for storing and replacing propulsion batteries may be needed.

The operating costs for hybrid-electric buses ultimately should be lower than they are for conventional motor buses. On the basis of the performance of electric rail propulsion systems, mature, commercialized hybrid-electric drive systems should be quite reliable and durable. Operating data and performance simulations indicate hybrids will consume approximately 30 percent less fuel than similar motor buses. The braking capabilities of the hybrid-electric bus should result in dramatically lower wear rates and extended repair intervals of the mechanical service brakes as well.

Emissions

Hybrid-electric vehicles can use conventional fuels much more efficiently than conventional vehicles and do so with greatly decreased emissions.

Incentives and Disincentives

The electric-motor drive systems in hybrid-electric buses typically use high voltages with high currents. These systems present shock and electrocution hazards to service personnel. Transit personnel have safely serviced similar power systems in rail cars and trolley buses for some time. However, training in appropriate work practices is essential.

Hybrid-electric buses using alternative fuels will carry volatile fuels in the same vehicle as powerful electric propulsion systems. Careful system engineering will be called for to prevent electrical shorts or ground faults in the power system from presenting ignition sources for fuel leaks. According to FTA, the lack of an emissions certification protocol for hybrid-electric transit buses is a barrier to their accelerated development.

Biodiesel Fuel

Overview

Biodiesel fuel is an alternative motor fuel that is derived from biological sources such as soybean oil, rapeseed oil, other vegetable oils, animal fats, or used cooking oil and fats. It is nontoxic and nonvolatile and will naturally degrade if spilled or otherwise exposed to the environment. The information regarding the current usage of biodiesel fuel in transit buses is limited. While transit operators would not necessarily need to modify their buses or maintenance garages to accommodate biodiesel use, biodiesel fuel generally costs more than diesel. However, this cost can be offset to a certain extent through the use of biodiesel blends.

Fuel Characteristics

The chemical process for creating biodiesel fuel involves mixing the oil with alcohol in the presence of a chemical catalyst. This process produces a methyl ester if methanol is used (typically the most common, for economic reasons) or an ethyl ester if ethanol is used. Either methyl ester or ethyl ester can be used neat (100 percent) or blended with conventional diesel fuel (petrodiesel) as a fuel for diesel engines. Biodiesel fuel is typically blended with diesel fuels at a 20-percent soy ester/80-percent diesel ratio. Blending tends to extend biodiesel fuel's storage life and also reduces its cost.

Status of Use and Development

The current efforts to commercialize biodiesel fuel in the United States were started by the National Biodiesel Board (formerly the National SoyDiesel Development Board) in 1992. The emphasis of their activity is on the use of soybean oil methyl ester blended with petrodiesel fuel at various volume percentages. These blends are believed to offer the best balance of cost and engine emissions characteristics. As soy ester is a surplus by-product, the soybean industry is interested in developing new markets for it.

The National Biodiesel Board reported that as of the beginning of 1994, biodiesel buses had accumulated nearly 8 million miles in demonstrations involving more than 1,500 vehicles across the country, particularly in urban buses. Neither DOT nor EIA collect data on biodiesel use in transit buses. However, according to the American Public Transit Association, as of January 1, 1999, eight transit buses were operating with biodiesel fuel. There is a much larger base of operating experience with biodiesel buses in Europe, amounting to several hundred times more vehicles and miles than in the United States, because of a total or near-total exemption from fuel taxes in most European countries. No manufacturer has certified an engine calibrated to run on biodiesel fuel.

Costs

No modifications to maintenance garages or safety procedures are necessary when using biodiesel fuel. Blends can also be used in diesel engines with no modifications. According to the National Biodiesel Board, a 20/80 blend of vegetable oil to diesel fuel will be generally about 50 to 75 percent more than diesel fuel. In 1998, the Transit Cooperative Research Board reported that biodiesel prices at the time were quite high—in the range of $4.50 to $5.00 per gallon. In addition, in 20-percent blends with diesel fuel, the blended product would cost from $1.54 to $1.64 per gallon.

Emissions

Transient cycle emissions testing with biodiesel blends consistently shows moderate reductions (10 to 20 percent) in particulate matter, exhaust opacity, and carbon monoxide, which may be accompanied by moderate increases in oxides of nitrogen.

Incentives and Disincentives

An important incentive for the use of biodiesel fuel is that transit operators may use conventional diesel fueling equipment because biodiesel fuel has mechanical and ignition properties that are very similar to diesel fuel. In addition, biodiesel is even less volatile than diesel fuel, and no modifications to safety procedures practiced with diesel fuel are needed. The data for the properties of soybean oil methyl ester indicate that it is safer than diesel fuel, which, in turn, makes it safer than the other alternative motor fuels considered.

The disincentives for the use of biodiesel fuel include cost and the potential for fire hazards. As previously stated, biodiesel fuel is generally more expensive than diesel fuel—biodiesel blends can cost as much as 50 to 75 percent more than diesel. In addition, an unusual physical characteristic of biodiesel that has a fire hazard implication is the possibility of spontaneous combustion in highly saturated materials, such as some vegetable oils and methyl ester, which oxidize in the air. It will be necessary to alert personnel at the fleet operator’s fuel storage and maintenance facilities of the potential for spontaneous combustion. This is not a serious problem and can be simply resolved by having closed metal cans for oily combustible material. Owing to the low volatility of biodiesel fuel, there are no specific fire hazards during transport. Any leak or spill is less likely to ignite than diesel or gasoline under equivalent conditions. There are no specific fire hazards during unloading to storage, or during storage, other than the potential spontaneous combustion issue.

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