Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive for Urban Buses?

by

Nicolas B.C. Ahouissoussi and Michael E. Wetzstein [1]

Abstract: The purpose of this paper is to provide an expected cost comparison for operating a transit-bus fleet on three different alternative fuels—biodiesel, compressed natural gas (CNG), and methanol. Petroleum diesel is the base fuel. Infrastructure, refueling, and maintenance costs are all part of running an urban transit bus. Additional expenditures would be needed to change fuel storage and delivery systems, as well as bus engines and fuel systems, to use methanol or CNG.

Using a 5-percent discount rate, the present value per bus per mile was calculated for the total cost (the sum of infrastructure, bus-alteration, refueling, and maintenance expenses) of a transit fleet over the estimated 30-year life cycle of a refueling infrastructure. Not surprisingly, diesel buses had the lowest cost at 24.7 cents per mile. As biodiesel is blended with diesel, the cost per mile ranged from 27.9 to 47.5 cents, depending on the amount of biodiesel used and its estimated price. CNG's cost varied from 37.5 to 42 cents per mile, while methanol's cost was 73.6 cents per mile. This analysis indicates that, although biodiesel and biodiesel blends have higher total costs than diesel fuel, they have the potential to compete with CNG and methanol as fuels for urban transit buses.

Keywords: Diesel fuel, biodiesel, compressed natural gas, methanol, transit buses, life-cycle cost, present value.

Alternative fuels for urban mass-transit vehicles have been receiving a lot of attention lately. This interest is generated by the necessity for cleaner emissions as mandated by the Clean Air Act Amendments of 1990 (CAAA) and by concern for reliable sources of energy. Under the CAAA, the U.S. Environmental Protection Agency (EPA) established National Ambient Air Quality Standards for several pollutants: carbon monoxide, inhalable particulates, nitrogen oxides, ozone, sulfur oxides, reactive hydrocarbons, and lead. These standards for heavy-duty urban buses (table A-1) have resulted in programs to lessen emissions of these pollutants.

The CAAA and the Energy Policy Act of 1992 have opened the market for clean burning, nontoxic, biodegradable fuels. However, these laws control access to that market, requiring extensive testing and demonstrations for verifying performance and emission reductions compared with low-sulfur diesel. For example, CAAA set tighter particulate-matter controls on pre-1994-model-year urban buses in areas with a 1980 population of over 750,000. The standards become effective when engines are rebuilt or replaced after January 1, 1995.

The industry is currently looking for least-cost methods to meet the new particulate-matter standards. Promising options include retrofitting buses with emission-control equipment, such as catalytic converters and particulate traps. There is also interest in using alternative fuels that emit less particulate matter compared with petroleum diesel. However, the equipment or fuel must first be tested and certified by EPA to determine if it meets the new standards. EPA currently is reviewing alternative fuel systems for the Urban Bus Retrofit Rebuild Program.

Because of these stricter environmental regulations, the market for domestic alternative fuels is becoming more important. However, there is a gap in the literature comparing the costs of these fuels. The purpose of this paper is to provide an expected cost comparison for operating a transit-bus fleet on three different alternative fuels—biodiesel, compressed natu-

Table A-1--Emission standards for heavy duty urban bus engines

Pollutant	1991	1993	1994	1998
	Grams per horsepower hour			
Hydrocarbons	1.3	1.3	1.3	1.3
Carbon monoxide	15.5	15.5	15.5	15.5
Nitrogen oxides	5.0	5.0	5.0	4.0
Particulate matter	0.25	0.10	0.05	0.05 1/

1/ The U.S. Environmental Protection Agency may relax the particulate standard to 0.07 if 0.05 is determined not to be technologically achievable.

[1] Ahouissoussi is a research assistant, and Wetzstein is a professor, (706) 542-0758, in the Department of Agricultural and Applied Economics, University of Georgia, Athens, Georgia. Some of this research was funded by USDA's Office of Energy and New Uses under Cooperative Agreement 43-3AES-3-80153.

ral gas (CNG), and methanol. Petroleum diesel is the base fuel.

Overview of Competing Fuels

Biodiesel is a clean-burning, renewable, nontoxic, and biodegradable transportation fuel that can be used alone or in blends with petroleum-derived diesel (*2*). U.S. farmers are interested in biodiesel because advanced agricultural practices and changing dietary habits in the United States have put downward pressure on prices for vegetable oils and animal fats, the feedstocks for biodiesel. Greater dietary use of lighter, more unsaturated vegetable oils is leading to lower demand for saturated oils and fats in human and animal feeds, thus, increasing the availability of animal fats and vegetable oils for conversion into biodiesel.

From an environmental standpoint, biodiesel/diesel blends can reduce significantly emissions of particulates, carbon monoxide, and unburned hydrocarbons. For economic and engine-compatibility reasons, biodiesel often is blended with diesel at a 20/80 rate. Research results indicate that power, torque, and fuel economy with a 20-percent biodiesel blend are comparable with petroleum diesel (*3*).

Producing biodiesel is a relatively simple process. Typically, it is made by esterifying vegetable oil, such as soybean or rapeseed oil, and/or animal fat. This process involves mixing the oil or fat with an alcohol in the presence of a catalyst (potassium or sodium hydroxide) and allowing them to react. If methanol is used, the process produces a methyl ester called methyl soyate from soybean oil or methyl tallowate from animal fat. As the methyl soyate/tallowate is formed, glycerine, which can be sold as a valuable coproduct, separates out and sinks. Once degummed, the methyl soyate/tallowate is decanted off, and can be used in most diesel engines with no modification.

CNG is another fuel that can meet tighter vehicle-emission requirements. Extracted from underground reservoirs, natural gas is a fossil fuel composed primarily of methane, along with other hydrocarbons, such as ethane, propane, butane, and inert gases, such as carbon dioxide, nitrogen, and helium. Interest in using CNG as a transportation fuel has increased in recent years, particularly in urban areas because it offers the potential for reducing exhaust emissions. Also, the United States has large resources of natural gas, so this fuel could help reduce dependence on foreign oil at a competitive price.

Methanol is another alternative fuel that can be produced from domestic resources. It can be used in neat (100 percent) form as a diesel substitute or potentially blended with diesel. Very little methanol in the United States is used to fuel diesel engines. Significant amounts are used to produce methyl tertiary butyl ether (MTBE). Originally developed in the 1970's as an octane enhancer, MTBE is now blended with gasoline to help cities meet the oxygenate requirements mandated by the CAAA. The majority of the methanol made in the United States is produced from natural gas. Other sources of methanol include coal and residual oil.

Petroleum-derived diesel is used as the base fuel in this study. It is the most common fuel used in urban buses and other heavy-duty vehicles. About 25 billion gallons were consumed in the United States in 1994 for on-road use. In the past, petroleum refining was controlled primarily for gasoline yield and quality; thus, the quality of diesel fuel varied widely depending on the demand for gasoline (*1*). This has changed over the last few years. Diesel fuel now faces significant fuel-quality and engine-emissions requirements. EPA regulations set a maximum limit of 0.05 percent by weight on the sulfur content and a minimum cetane index of 40 for diesel fuel used in on-road vehicles.

Bus Refueling Facilities

Most urban transit authorities operate refueling facilities for their buses. Often at a central location, these facilities are devoted exclusively to refueling buses and house sheltered chassis lanes with eight to ten doors, fueling pumps, storage tanks, maintenance equipment, and emergency fire equipment. A chassis lane is a driveway next to the refueling pump. In a lane, maintenance equipment is used to clean one bus while another one is being fueled. The regional transport district refueling station in Denver, Colorado, which was used to gather the data for this analysis, refuels approximately 280 buses per night in a three-lane system. The three lanes can service 360 buses at full capacity. Diesel fuel is stored in underground tanks, with a capacity of 20,000 gallons each.

No infrastructure changes or engine modifications are needed for using biodiesel. Only the fuel is modified by blending diesel fuel with biodiesel. In this analysis, fuels using 20, 35, 60, and 100 percent (neat) biodiesel were considered. However, the level of BTU's associated with biodiesel-blended fuels is lower than with diesel, which results in a lower level of fuel efficiency. The Colorado Institute for Fuels and High-Altitude Engine Research has estimated the fuel efficiency of biodiesel blends compared with diesel at 99.16, 97.66, 92.97, and 88.87 percent for 20, 35, 60, and 100 percent biodiesel, respectively.

To handle methanol or CNG, a diesel refueling station would need to be modified. For methanol, alcohol-compatible fuel tanks, new dispensers, and safety equipment would need to be added. Also, additional fuel storage capacity would be necessary because methanol buses require, on average, 2.5 times as much fuel as diesel buses. To service dual CNG/diesel buses, additional equipment to handle CNG would be necessary, including gas supply equipment, compressors, control valves, piping, gas conditioners, dispensers, and safety equipment. The compressors condense the gas to 3,000 pounds per square inch. Also, a CNG fuel system would need eight lanes instead of three to service the same number of buses. It takes longer to refuel with CNG because the refueling rate slows as the tank fills and the pressure increases.

In addition to new facilities, the buses themselves would have to be modified to use methanol or CNG. To run on methanol, buses would need a new engine and fuel system. CNG buses would use a modified diesel engine with a new fuel system.

Cost Analysis Procedures and Data

The economic performance of alternative fuels for urban transit buses can be measured by estimating and comparing the expected total cost of running a bus fleet during its anticipated operating life using different fuels. The comparison of total costs is enhanced by considering the present value of total fleet costs over the fleet's life cycle. Present value explicitly incorporates the time value of money by comparing the costs in one time period, say a given month, with the costs in another period. The time value of money assumes that a dollar forthcoming a year from now is not worth as much as a dollar today. Thus, future costs are reduced by a discount rate so they are comparable with current costs. The present value of costs is then the sum of all discounted costs over the total number of years a fleet is in operation by a transit authority.

Infrastructure, refueling, and maintenance costs are all part of running a bus. Infrastructure costs represent lane building and tankage installation expenditures. Changing fuel storage and delivery systems, as well as bus engines and fuel systems, to use methanol or CNG will require additional expenditures. Refueling costs include actual fuel expenditures and refueling labor charges. Maintenance expenses include repair, rebuild, and insurance costs, and costs associated with the loss of ridership and good will due to unexpected breakdowns.

Generally, the purchase prices for engines that run on diesel, biodiesel, CNG, and methanol are comparable. However, engine-rebuild and fuel-system costs differ by fuel type and the number of miles between rebuilds. Calculating engine-rebuild costs for alternatively fueled buses is at present a tricky proposition. The date when an engine was rebuilt and monthly mileage since the last rebuild are key bits of information. Unfortunately, data on monthly mileage and time of rebuilds for alternatively fueled buses are still quite limited.

Most experiments on alternative fuels have been mainly for demonstration purposes, resulting in short duration times and little, if any, collected data. One exception was an experiment by the Denver, Colorado, regional transportation district. As part of its commitment to meet Clean Air regulations, the district has conducted research on alternative fuels using transit buses. The experiment, which lasted from June 1989 to December 1993, used five diesel buses, which could use both diesel and biodiesel fuel, and five methanol buses (table A-2). Five dual CNG/diesel buses, which are diesel buses converted so they can also use CNG, were added in 1991.

The three fleets of buses were exposed to similar operating conditions such as scheduled speeds, stops per mile, traffic conditions, and passenger loading. They were also maintained under the same preventive maintenance program. This unique data set allows a cost comparison of alternative fuels based not only on fuel cost and usage, but also on maintenance, repair, engine-rebuild, and in-service failure costs for the total operational life of the transit buses.

In this experiment, the variation of mileage at rebuild was large, particularly for diesel and methanol buses. This indicates that rebuild decisions are based upon other information besides the odometer value. CNG/diesel buses were rebuilt in approximately half the time and mileage of diesel and methanol buses, which resulted in higher maintenance costs. However, these higher costs are potentially offset by the CNG/diesel buses' considerably lower standard deviation. A lower standard deviation implies less uncertainty regarding timing of rebuilds and, thus, possibly lower costs in terms of less unexpected rebuilds.

The transportation district's data suggest that a set time frame or mileage may not be a good indicator for when engines need to be rebuilt. In this case, Rust proposes taking observed engine rebuilds as optimal and infer the total maintenance costs leading to these rebuilds (*4*). Basically, this method assumes that transit authorities have developed a procedure

Table A-2--Experiment statistics

Item	Diesel	Methanol	CNG/Diesel
Number of Buses	5	5	5
Bus characteristics			
Engine	6V-92 TA DDEC I	6V-92 TAM DDEC II	6V-92 TA DDECII
Transmission	Allison HTB-748 ATEC	Allison V-731 ATEC	Allison HTB-748 ATEC
Purchase price (1991 model)	$217,400	$188,500	$252,400
Gross weight (pounds)	35,130	34,970	38,000
Fuel tank (gallons)	125	285	1/
Mileage at rebuild			
Maximum	89,600	110,100	34,500
Minimum	12,150	14,590	20,200
Mean	55,271	53,432	26,833
Standard deviation	28,861	27,016	5,901
Elapsed time between rebuilds		Months	
Maximum	28	34	10
Minimum	3	5	6
Mean	17.57	17.33	8.33
Standard deviation	9.93	8.79	1.63

1/ 8,084 cubic feet of compressed natural gas (CNG) and 62.5 gallons of diesel.

Source: The Denver, Colorado, regional transportation district.

for optimally determining when a bus should be rebuilt. A computer program developed by Rust was used in this analysis to calculate engine-rebuild and monthly maintenance costs. Actual rebuild expenses were used for scaling these parameters and estimating maintenance costs.

Comparing Life Cycle Costs

The Denver transportation district scaled up their data to estimate the costs for running a fleet of 300 buses on diesel, biodiesel, methanol, and CNG. The costs of alternatively fueled buses are based on the assumption that regional transportation districts already have diesel-bus refueling facilities. Therefore, the fixed costs for alternative-fuel facilities are incremental to diesel-facility fixed costs. This assumption may favor diesel and biodiesel, but it is realistic given current transit operations.

Total infrastructure cost per bus is only $1,461 for diesel and biodiesel (tables A-3 and A-4) compared with about $10,000 per bus for methanol and CNG/diesel buses (tables A-5 and A-6). Not only are six more storage tanks needed for methanol, they are approximately 6.5 times more expensive than diesel storage tanks. The infrastructure for CNG/diesel buses also are significantly more expensive than diesel due to the requirement of eight fueling lanes instead of three and storing pressurized fuel. In addition, the cost to change a bus so it will run on methanol instead of diesel is $29,900 and the cost of altering a diesel bus to use CNG is $35,000. In this analysis, these expenses accrue every 10 years for replacing the engine and fuel system.

In addition to infrastructure and bus expenses, transit operators also face refueling and maintenance costs. Refueling labor costs are based on one supervisor and three laborers per lane. Two laborers drive the buses to the lane and a third laborer refuels the buses. The hourly wage rate for supervisors and laborers is $16.00 and $13.95, respectively. Adding in benefits of 29 percent, 15 days of paid vacation, and 8 days of paid sick leave results in actual wage rates of $22.89 per hour for supervisors and $19.95 for laborers.

The wholesale, pretax price of diesel used in the study was 67 cents per gallon, and the price for methanol was 59 cents per gallon. Given the current thin market for biodiesel, the long-run equilibrium price has yet to be determined. Therefore, three prices for biodiesel were used: $1.75, $2.50, and $3.00 per gallon. The $2.50 per gallon represents the average price of biodiesel. The $1.75 represents an optimistic near-term scenario and assumes that some lower cost feedstocks are used, while the $3 price reflects higher production costs.

Three prices for CNG also were considered: 14.06, 28.12, and 42.18 cents per equivalent gallon. These prices are associated with $1, $2, and $3, respectively, per 1 million BTU's of CNG. (An equivalent gallon is the number of BTU's in a gallon of diesel fuel. One million BTU's of CNG divided by 140,600 BTU's per gallon of low-sulfur diesel yields 7.1123 equivalent gallons of CNG.) The price of natural gas is set by local utilities and approved by state public utility commissions. Thus, fleet operators around the country face different prices for CNG.

Annual refueling costs are $21,102 per bus for methanol buses, which is about twice the refueling cost for diesel buses. The 2.5-times higher fuel consumption for methanol buses requires 4.5 times more labor for refueling. The additional labor needed for the extra five refueling lanes for CNG/diesel buses account for most of its 37 percent higher annual refueling cost per bus compared with diesel buses. Conversely, most of the additional cost for biodiesel was for the fuel itself, 73 percent of the $14,795 annual refueling costs.

Major maintenance costs involve engine rebuilds and general bus maintenance and repair. Rebuild costs are $6,500 per engine for diesel, biodiesel, and CNG/diesel and $9,500 for methanol buses. In this analysis, rebuilds were estimated to occur every 20, 21, and 10 months for diesel and biodiesel, methanol, and CNG, respectively. These rebuild cycles were derived by dividing average mileage at rebuild by monthly travelled mileage.

Given monthly mileage and considering marginal maintenance cost changes every 5,000 miles, maintenance cost estimates are used in calculating average monthly maintenance costs over a rebuild cycle, which are then used to calculate the present value of total costs. Because regional transportation districts expect average monthly maintenance costs to rise over time, they were increased every 5,000 miles in this analysis. The estimated maintenance cost per month, based on Rust's model, for diesel and biodiesel, $4.34, is quite low compared with the cost for methanol of $31.84 (table A-7). However, this marginal maintenance cost per month is higher than the $1.80 cost for CNG/diesel.

Present value per bus per mile was calculated for the total cost (the sum of infrastructure, bus-alteration, refueling, and maintenance expenses) of a transit fleet over the estimated 30-year life cycle of the refueling infrastructure. Considering a 5-percent discount rate, it is not surprising that diesel buses result in the lowest per-mile cost, 24.7 cents (table A-8). Diesel and biodiesel buses have the lowest infrastructure cost per bus compared with methanol and CNG/diesel buses. Also, diesel and biodiesel buses do not incur the added cost of engine and fuel-system conversion required every 10 years. Another reason for this relatively low cost per mile for diesel is that the estimated increase in maintenance costs per month is quite low compared with the maintenance costs for methanol.

As biodiesel is blended with diesel, the cost per mile ranges from 27.9 cents to 47.5 cents, depending on the amount of biodiesel used and its price. The present value of using neat biodiesel ranges from 43.8 cents per mile to 64.5 cents. Although this is 1.8- to 2.6-times higher than diesel's 24.7 cents, it is still lower than methanol's cost of 73.6 cents per mile. However, methanol blended with diesel should have cost reductions similar to biodiesel blends, making it potentially

Table A-3--Estimated infrastructure and refueling costs for a fleet of 300 diesel buses

Item	Unit cost	Units	Total cost
Infrastructure cost per lane 1/			
Building cost 2/	$92,000 per lane	3	$276,000
Tankage 3/	$40,600 per tank	4	162,400
Total			438,400
Infrastructure cost per bus		300	1,461
Refueling labor costs per lane per day 4/			
Supervisor 5/	$22.89 per hour	1/3	61
Labor 6/	$19.95 per hour	3	479
Total			540
Annual refueling labor costs 7/	$3,240 per day	365	1,182,600
Annual refueling costs per bus			
Labor costs		300	3,942
Fuel usage 8/	67 cents per gallon	10,392	6,963
Total			10,905
Annual cost per mile 9/			0.298

1/ Three lanes can service 360 buses at full capacity. The District refuels approximately 280 buses per night in a three-lane system. 2/ $1,000 per square foot. Service life for the building is 30 years. 3/ A tank capacity of 26,666 gallons is required per lane. Four FTP-3 fuel tanks, with a capacity of 20,000 gallons each, were used to meet this requirement. Material and installation costs equal $40,600 per tank. 4/ Refueling labor includes one supervisor per three lanes and three laborers for each lane. Two laborers drive the buses to the lane and a third laborer refuels the buses. 5/ The wage rate for supervisors is $16.00 per hour, plus benefits of 29 percent. A 40-hour work week equals 2,080 hours per year. Subtracting 15 days of paid vacation, 9 paid holidays, and 8 paid sick-leave days yields 1,824 hours per year. Therefore, the actual hourly rate is $16.00[(2,080/1,824) + 0.29] = $22.89. 6/ The same formula yields an actual wage rate of $19.95 per hour for laborers based on an hourly rate of $13.95. 7/ Three lanes at $540 per lane times an overhead multiplier of two equals $3,240. 8/ With buses using an average of 866 gallons per month. 9/ With 36,578 miles driven per bus per year.
Source: The Denver, Colorado, regional transportation district.

Table A-4--Estimated infrastructure and refueling costs for a fleet of 300 buses running on a 20-percent biodiesel blend

Item	Unit cost	Units	Total cost
Infrastructure cost per lane 1/			
Building cost 2/	$92,000 per lane	3	$276,000
Tankage 3/	$40,600 per tank	4	162,400
Total			438,400
Infrastructure cost per bus		300	1,461
Refueling labor costs per lane per day 4/			
Supervisor 5/	$22.89 per hour	1/3	61
Labor 6/	$19.95 per hour	3	479
Total			540
Annual refueling labor costs 7/	$3,240 per day	365	1,182,600
Annual refueling costs per bus			
Labor costs		300	3,942
Fuel usage 8/	$1.036 per gallon	10,476	10,853
Total			14,795
Annual cost per mile 9/			0.404

1/ Three lanes can service 360 buses at full capacity. The District refuels approximately 280 buses per night in a three-lane system. 2/ $1,000 per square foot. Service life for the building is 30 years. 3/ A tank capacity of 26,666 gallons is required per lane. Four FTP-3 fuel tanks, with a capacity of 20,000 gallons each, were used to meet this requirement. Material and installation costs equal $40,600 per tank. 4/ Refueling labor includes one supervisor per three lanes and three laborers for each lane. Two laborers drive the buses to the lane and a third laborer refuels the buses. 5/ The wage rate for supervisors is $16.00 per hour, plus benefits of 29 percent. A 40-hour work week equals 2,080 hours per year. Subtracting 15 days of paid vacation, 9 paid holidays, and 8 paid sick-leave days yields 1,824 hours per year. Therefore, the actual hourly rate is $16.00[(2,080/1,824) + 0.29] = $22.89. 6/ The same formula yields an actual wage rate of $19.95 per hour for laborers based on an hourly rate of $13.95. 7/ Three lanes at $540 per lane times an overhead multiplier of two equals $3,240. 8/ With buses using an average of 873 gallons per month. The fuel is a 20-percent biodiesel blend, with biodiesel at $2.50 per gallon. 9/ With 36,578 miles driven per bus per year.
Source: The Denver, Colorado, regional transportation district.

Table A-5--Estimated infrastructure and refueling costs for a fleet of 300 methanol buses

Item	Unit cost	Units	Total cost
Infrastructure cost per lane 1/			
Building cost 2/	$92,000 per lane	3	$276,000
Tankage 3/	$268,148 per tank	10	2,681,480
Total			2,957,480
Infrastructure cost per bus		300	9,858
Fuel alteration costs per bus 4/			29,900
Refueling labor costs per lane per day 5/			
Supervisor 6/	$22.89 per hour	1/3	61
Labor 7/	$19.95 per hour	7.5	1,197
Total			1,258
Annual refueling labor costs 8/	$7,550 per day	365	2,755,546
Annual refueling costs per bus			
Labor costs		300	9,185
Fuel usage	59 cents per gallon	19,867	11,722
Lubrizol 9/	$15.69 per gallon	12.42	195
Total			21,102
Annual cost per mile 10/			0.708

1/ Three lanes can service 360 buses at full capacity. The District refuels approximately 280 buses per night in a three-lane system. 2/ $1,000 per square foot. Service life for the building is 30 years. 3/ Ten fuel tanks are required instead of four because methanol buses use, on average, 2.5 times more fuel. 4/ The additional cost per bus for a methanol engine and fuel system. 5/ Refueling labor includes one supervisor per three lanes and 7.5 laborers for each lane. Since 2.5 times more fuel is used, it is assumed that 2.5 times more labor is needed to refuel the buses. 6/ The wage rate for supervisors is $16.00 per hour, plus benefits of 29 percent. A 40-hour work week equals 2,080 hours per year. Subtracting 15 days of paid vacation, 9 paid holidays, and 8 paid sick-leave days yields 1,824 hours per year. Therefore, the actual hourly rate is $16.00[(2,080/1,824) + 0.29] = $22.89. 7/ The same formula yields an actual wage rate of $19.95 per hour for laborers based on an hourly rate of $13.95. 8/ Three lanes at $1,258.24 per lane times an overhead multiplier of two equals $7,550. 9/ Lubrizol is added at 6.25 gallons per 10,000 gallons of methanol. 10/ With 29,801 miles driven per bus per year.
Source: The Denver, Colorado, regional transportation district.

Table A-6--Estimated infrastructure and refueling costs for a fleet of 300 Dual CNG/diesel buses

Item	Unit cost	Units	Total cost
Infrastructure cost per lane 1/			
Building cost 2/	$92,000 per lane	8	$736,000
Fueling facility 3/			2,320,500
Total			3,056,500
Infrastructure cost per bus		300	10,188
Fuel alteration costs per bus 4/			35,000
Refueling labor costs per lane per day 5/			
Supervisor 6/	$22.89 per hour	1/8	23
Labor 7/	$19.95 per hour	3	479
Total			502
Annual refueling labor costs 8/	$8,028 per day	365	2,930,337
Annual refueling costs per bus			
Labor costs		300	9,768
Fuel usage 9/	40 cents per gallon	10,764	4,306
Maintenance costs			400
Compressor energy costs	$1.28 per day	365	467
Total			14,941
Annual cost per mile 10/			0.431

1/ Eight lanes can service 300 buses. 2/ $1,000 per square foot. Service life for the building is 30 years. 3/ Estimated installation costs are $1.7 million; plus 10 percent for contractor's markup; 10 percent for engineering; 5 percent for development and permitting; and 10 percent of the $1.7 million, engineering, development, and permitting costs for contingency. 4/ The additional cost per bus for a compressed natural gas (CNG) engine and fuel system. 5/ Refueling labor includes one supervisor per eight lanes and three laborers for each lane. 6/ The wage rate for supervisors is $16.00 per hour, plus benefits of 29 percent. A 40-hour work week equals 2,080 hours per year. Subtracting 15 days of paid vacation, 9 paid holidays, and 8 paid sick-leave days yields 1,824 hours per year. Therefore, the actual hourly rate is $16.00[(2,080/1,824) + 0.29] = $22.89. 7/ The same formula yields an actual wage rate of $19.95 per hour for laborers based on an hourly rate of $13.95. 8/ Eight lanes at $501.77 per lane times an overhead multiplier of two equals $8,028. 9/ Equivalent gallons. 10/ With 34,691 miles driven per bus per year.
Source: The Denver, Colorado, regional transportation district.

competitive with the other alternative fuels. CNG/diesel has a significantly lower cost per mile compared with methanol, but it is still approximately 1.7 times more expensive than diesel. Twenty-and 30-percent biodiesel blends, at all price levels, are competitive with CNG/diesel at the lowest price for CNG. Assuming these blends can comply with regulatory emission standards, biodiesel fuels at prices as high as $3.00 per gallon could compete with the other alternative fuels.

Table A-7--Estimated maintenance costs for diesel, biodiesel, methanol, and CNG/diesel buses

Summary statistics	Diesel and biodiesel	Methanol	CNG/diesel
Rebuild costs	$6,500	$9,500	$6,500
Structural coefficients			
Rebuild cost coefficient	5.06	4.64	3.21
Operating cost coefficient 1/	3.38	15.55	0.89
Scale parameter 2/	1,284	2,047	2,025
Maintenance costs per 5,000 miles 3/	$4.34	$31.84	$1.80

1/ Operating costs include repair and insurance costs and loss of ridership and goodwill costs due to unexpected breakdowns. 2/ The scale parameter is the actual rebuild cost divided by the rebuild cost coefficient. 3/ Estimated maintenance costs are obtained by multiplying the scaling parameter times the operating cost coefficient and dividing by 1,000.

Table A-8--Present value per mile of total cost of running a bus over a 30-year life cycle, with an annual discount rate of 5 percent

Fuel	Total cost
	Cents per mile
Diesel	24.7
Methanol	73.6
CNG/Diesel at	
$0.1406 per gallon	37.5
$0.2812 per gallon	39.8
$0.4218 per gallon	42.0
Biodiesel at $1.75 per gallon	
20 percent blend	27.9
35 percent blend	30.6
60 percent blend	35.7
100 percent	43.8
Biodiesel at $2.50 per gallon	
20 percent blend	30.2
35 percent blend	34.6
60 percent blend	42.8
100 percent	56.3
Biodiesel at $3.00 per gallon	
20 percent blend	31.6
35 percent blend	37.2
60 percent blend	47.5
100 percent	64.5

This analysis indicates that, although biodiesel and biodiesel blends have higher total costs than diesel fuel, they have the potential to compete with CNG and methanol fuels (figure A-1). As provisions of the Clean Air Act and the Energy Policy Act are implemented, and concerns about the impact of fossil fuels on the environment and health solidify, the market for alternative fuels is likely to grow. Based on this present-value analysis of total life-cycle costs, biodiesel seems well positioned to compete with other alternative fuels in the transit-bus market.

Acknowledgements

This research was partially funded by USDA's Office of Energy and New Uses and the National Biodiesel Board, Jefferson City, Missouri.

References

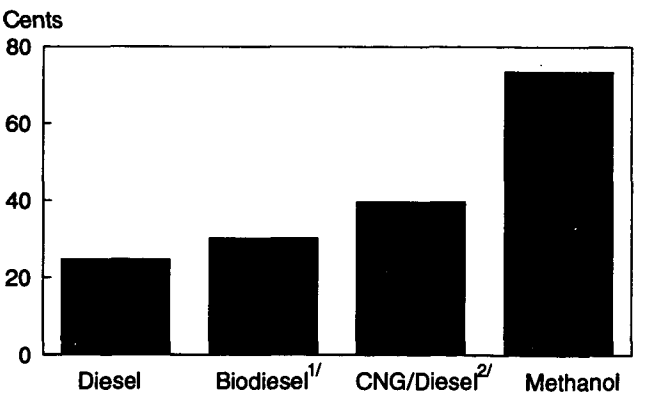
1. *Biodiesel Alert.* National Biodiesel Board, Jefferson City, MO, 1993, 1994, 1995, selected issues.

2. Holmberg, W.C., E.E. Gavett, and P.N. Merrill. *National SoyDiesel Development Board Standards for Biodiesel.* American Biofuels Association, Washington DC, 1993.

3. Howell, S.A. and A. Weber. "U.S. Biodiesel Overview." *Proceedings, Second Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry,* August 21-24, 1995, Portland, OR, pp. 840-848.

4. Rust, J. "Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher." *Econometrica,* Vol. 55, 1987, pp. 999-1033.

Figure A-1
Present Value of Total Costs Per Bus Per Mile for Diesel and Alternative Fuels



1/ A 20-percent blend, with biodiesel at $2.50 per gallon. 2/ With CNG (compressed natural gas) at 28.12 cents per gallon.