PB92-182567

PUBLIC TRANSPORTATION ALTERNATIVE FUELS

A PERSPECTIVE FOR SMALL TRANSPORTATION OPERATIONS

EXECUTIVE SUMMARY
1992

FOR USE BY OPERATORS OF MOTOR BUS AND DEMAND RESPONSIVE FLEETS

CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF MASS TRANSPORTATION

PUBLIC TRANSPORTATION ALTERNATIVE FUELS

A Perspective for Small Transportation Operations

For Use by Operators of
Motor Bus and Demand Responsive Fleets

June 30, 1992

EXECUTIVE SUMMARY

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16. Abstract

This Executive Summary is a brief review of the key information and issues presented in the complete "Public Transportation Alternative Fuels" report (Report # FTA/DMT-CA-08-PB92-120120)

The purpose of this study is to provide small, public transportation operators in the State of California with information necessary to evaluate alternative fuels and technologies for complying with future State and Federal emission regulations. The alternative fuels examined include "clean diesel" fuel, methanol, natural gas (both compressed and liquefied), ethanol and liquefied petroleum gas (LPG). These fuels are examined across a variety of criteria including fuel availability and costs, vehicle reliability, durability, safety, fuel economy and emission characteristics. The equipment and facilities needed for refueling alternative technology buses are also examined along with modifications needed to maintenance garages to ensure safe operations with these new fuels. All capital and operating costs associated with implementing each of the alternative fuels are detailed for different size transit properties.

Advanced electric propulsion technologies including batteries, hydrogen fuel cells, and electric trolley buses are also briefly examined but in less detail than the other alternative fuels.

17. Key Words

ALTERNATIVE FUELS, EMISSIONS, PROPULSION TECHNOLOGIES, METHANOL, ETHANOL, CNG, LNG, LPG, DIESEL

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BACKGROUND

Emission regulations currently being proposed by the California Air Resources Board (CARB) for heavy-duty urban buses are significantly more stringent than Federally mandated transit bus emission standards, and more stringent than regulations for heavy-duty trucks which utilize similar powertrain components. The implications of these standards is critically important for California transit operators. The exhibit on the following page graphically shows the proposed CARB regulations in relation to Federal urban bus and heavy-duty truck standards.

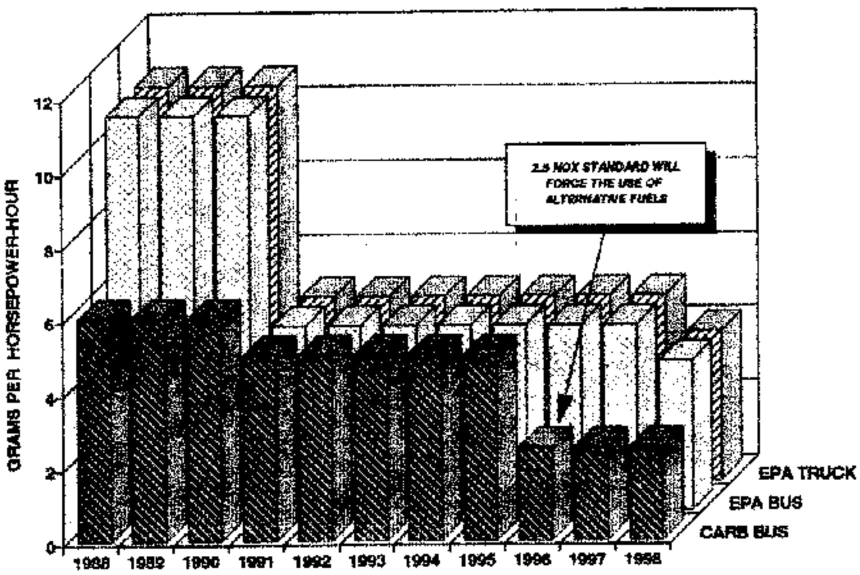
California transit operators would be required to meet a NOx standard that is likely to force the use of alternative fuels beginning in 1996, while other segments of the heavy-duty vehicle market are not required to meet any similar technology forcing standards - - - at least through the year 2000. ***Based on CARB regulations, and the California Energy Commission's directive to reduce petroleum dependence, it is likely that the 1990s will mark the end of the diesel powered bus era in California.*** A transition to alternative fuels will perhaps be the single most important change affecting bus operations in the last 30 years. Nearly every aspect of bus operations will be affected including facility requirements, vehicle capital costs, route scheduling and planning, safety, training, fuel costs and maintenance costs.

The conversion of a transit property to alternative fuels will be expensive in terms of both capital and operating costs. Transit property managers should begin the development of a strategic plan for meeting new emission regulations and, if required, moving to alternative fuels.

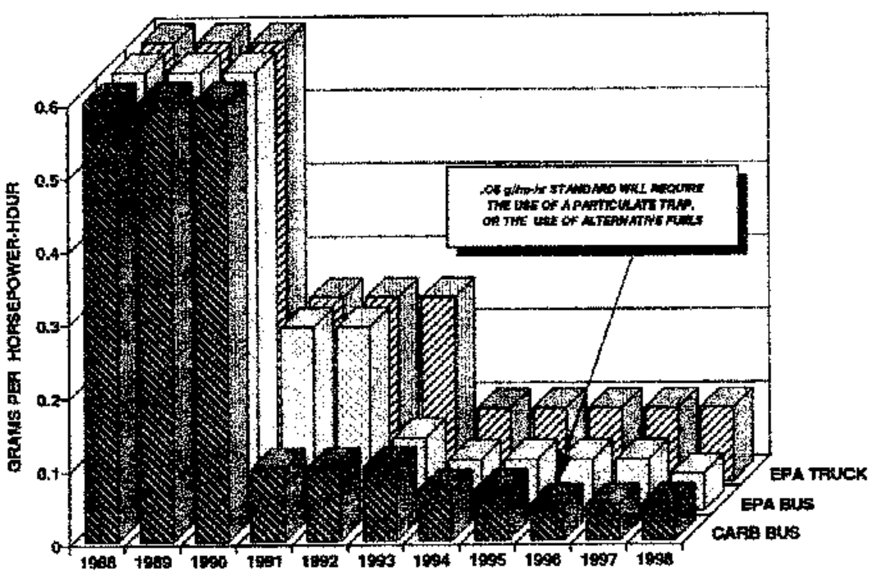
The purpose of this project is to provide small, public transportation operators in the State of California with information necessary to evaluate alternative fuels and technologies for complying with future State and Federal emission regulations. The various alternatives examined include "clean diesel" fuel, methanol, ethanol, natural gas and LPG. These fuels, and associated technologies, were examined across a variety of criteria including fuel availability and costs, vehicle reliability, durability, safety, emission characteristics, and required maintenance facility and fueling facility modifications. All capital and operating costs associated with implementing each of these fuels were examined for different size transit properties. Advanced electric propulsion technologies including batteries, hydrogen fuel cells, and electric trolley buses are also briefly examined but in less detail than the other alternative fuels.

FUTURE HEAVY DUTY VEHICLE EMISSION REGULATIONS

NOX EMISSION STANDARDS
(EPA VS CARB:CURRENT AND PROPOSED)



PARTICULATE EMISSION STANDARDS
(EPA VS CARB:CURRENT AND PROPOSED)



ORGANIZATION

This Executive Summary is a brief review of the key information and issues presented in the complete "Public Transportation Alternative Fuels" report. The Executive Summary is organized as follows:

These chapters parallel the full report. The complete report also contains; a profile of the transit industry in California; a review of the methodology used in developing the report; a complete bibliography; a listing of supplier references and industry contacts in the alternative fuels area; a listing of alternative fuel demonstration sites and contact persons; providers of training in alternative fuels; and a complete listing of acronyms.

1.0 EXISTING AND FUTURE EMISSION REGULATIONS

Existing and planned regulations by the EPA and CARB have a powerful impact on the capital cost of vehicles operated by transportation agencies, and on the available choices of fuel. It is important to recall that in California, the regulatory situation with respect to motor vehicle emission standards is unique, in as much as the authority of the State preempts that of the EPA. In general, CARB sets emission standards based on the same test procedures as specified by the EPA, but has traditionally set more stringent numerical standards for NOx and hydrocarbon.

This section focuses on emission standards for medium and heavy duty vehicles since public transit vehicles will generally fall into one of these two categories. Exhibit 1-1 defines vehicle categories for the State and at the Federal level.

EXHIBIT 1-1

1995 and Later Federal and California Vehicle Categories

Vehicle Category	California	Federal
Passenger Car	Designed to carry passengers with a capacity of 12 or fewer persons	Designed to carry passengers with a capacity of 12 or fewer persons
Light-Duty Truck	GVWR < 6000 lb and designed primarily for transporting property, or has special equipment enabling use off-road.	Curb Weight <6000 lb and GVWR < 8500 lb. Passenger capacity > 12, if designed primarily for carrying passengers.
Medium-Duty Vehicle	Prior to MY '95: 6000-8500 lb GVWR; MY '95 & later: 6000-14000 lb GVWR	not defined
Heavy-Duty Vehicle	Prior to MY '95: GVWR > 8500 lb; MY '95 & later: GVWR > 14000 lb	GVWR > 8500 lb or curb weight > 6000 lb
Urban Bus	Heavy-duty vehicle with passenger capacity of 15 or more, intended for intra-city service with frequent stops, and equipped with a farebox	Same as California, except that the category applies only to heavy-duty vehicles (GVWR > 33,000 lbs)

Medium-Duty Vehicle Emission Standards

The medium-duty category, covering vehicles in the range of 6,000 to 8,500 lb GVWR, was created by CARB in 1978. CARB has recently extended the medium-duty category upward to include vehicles in the range of 6,000 to 14,000 lb GVWR, effective MY 1995. This action means that nearly all vans and mini-bus vehicles will likely fall into the medium-duty category beginning in 1995 (smaller vans will remain in the light-duty vehicle category). Also, beginning in 1995 the emission standards for medium-duty vehicles will become considerably more stringent.

There are no particulate standards included in medium-duty emission regulations from 1990 thru 1994. Therefore, diesel engines are available to compete against gasoline engines in this category. Starting in 1995 CARB imposes a particulate standard on medium-duty vehicles and lowers the standards for the other effluents (the weight classification also changes as previously noted).

These regulatory changes represent a dramatic tightening of the emission standards for medium-duty vehicles. The post 1994 NOx and particulate standards will be extremely challenging for diesel engine manufacturers to meet, and may set back the trend toward increased dieselization that this market segment has experienced in recent years. For example, it will be difficult for medium-duty diesel engine manufacturers to meet the 1995 standards without exhaust aftertreatment devices. ***Because the diesel engine market in this category is already fairly small, it is possible that manufacturers may abandon the California medium-duty diesel market.*** ULEV medium-duty standards, which begin to take effect in 1998, will be all but impossible for diesel engines to meet barring the development of as yet unknown technology. It does appear, however, that gasoline powered vehicles operating on reformulated gasoline fuels, will be able to meet both conventional and LEV medium-duty vehicle standards.

EXHIBIT 1-2

Emission Standards for Heavy-Duty Engines Resulting from the Clean Air Act Amendments of 1990 (g/bhp-hr)

	EPA				CARB			
	BUSES		TRUCKS		BUSES		TRUCKS	
Model Year	NOx	PM	NOx	PM	NOx	PM	NOx	PM
1985	10.7	—	10.7	—	5.1	—	5.1	—
1987	10.7	—	10.7	—	6.0	0.6	6.0	0.6
1988	10.7	0.6	10.7	0.6	6.0	0.6	6.0	0.6
1991	5.0	0.25	5.0	0.25	5.0	0.1	5.0	0.25
1993	5.0	0.1	5.0	0.25	5.0	0.1	5.0	0.25
1994	5.0	0.05[a]	5.0	0.1	5.0	0.1	5.0	0.1
1998	4.0	0.05	4.0	0.1	5.0	0.1	5.0	0.1

a The EPA has authority to relax this standard to 0.07 if 0.05 is not feasible.

Future California Heavy-Duty Emission Standards

As shown in Exhibit 1-2, CARB independently adopted a schedule of heavy-duty engine emission standards that are very similar to the original 1985 EPA regulation. Since California's right to set its own standards was unchanged by the 1990 Clean Air Act amendments, California's standards were unaffected by the changes in the Federal urban bus standards contained in the CAA. Accordingly, beginning with MY 1991, the California urban bus PM standard is 0.1 g/bhp-hr. Without further regulatory action, this standard will remain in effect indefinitely. As of early 1992, no diesel fueled bus engine had been certified to this standard. The only engines presently certified are Detroit Diesel Corporation's methanol 6V-92, and a Tecogen natural gas engine, recently certified by CARB.

An additional important difference between the California and Federal emission regulations for urban buses is the definition of "urban bus". California considers all heavy-duty passenger vehicles equipped with a farebox, and operating in fixed route service, to be urban buses. California's definition presently includes all such vehicles heavier than 8,500 lb GVWR, while the Federal definition of urban bus has been revised to exclude vehicles lighter than 30,000 lbs GVWR. This means that all transit vehicles operating in California in fixed route service that are heavier than 8,500 lbs GVWR must meet a 0.1 gram per bhp-hr PM standard beginning in 1991. Vehicles in this weight range include mini-buses as well as standard 30-foot, 35-foot. and 40-foot transit buses. Engines used in these vehicles span a wide HP range and are available from several engine OEMs. However as noted, only two engines (DDC 6V-92 and Tecogen) have been certified to meet currently applicable emission standards, and these engines must operate on alternative fuels to do so. The DDC 6V-92 engine is designed primarily for the 40-foot transit bus. ***As a result, there are essentially no engines currently certified for use in smaller transit buses, and we have found that such vehicles are presently not available for sale in California except on an "experimental permit" basis.***

California Senate Bill 135 (Boatwright), signed into law on October 5, 1991, adds provisions to the Health and Safety Code that direct CARB to develop emission standards for transit buses that reflect the best available emission control technologies, and which "consider the engine and fuel as a system." The standards must be adopted by January 1, 1993, and take effect by January 1, 1996. CARB staff has interpreted this language to mean that alternative fuels may be considered as part of a best available emission control technology. Based on the emission performance demonstrated by DDC's methanol 6V-92 engine, CARB staff is proposing the following transit bus emission standard (shown in Exhibit 1-3), to take effect as of January 1, 1996:

EXHIBIT 1-3

1996 CARB Proposed Urban Bus Emission Standards
(g/bhp-hr)

THC[1]	NMHC[2]	CO	NOx	PM
1.3	1.2	15.5	2.5	0.05

(1) Total hydrocarbon

(2) Non-methane hydrocarbon

Since the medium-duty category will be broadened to vehicles with GVWRs between 6,000 and 14,000 lbs in 1995, the 1996 transit bus standards would apply to vehicles heavier than 14,000 lbs GVWR. It is unlikely that any heavy-duty diesel engine would be able to certify to such a stringent NOx standard. ***If this regulation passes as proposed, it would require California transportation agencies to begin***

wholesale conversion to alternatively fueled vehicles. Transportation agencies which have not carefully planned for this event will experience substantial expense and disruption of operations. It is possible that CARB will make provisions to exempt smaller transit operators and/or operators located in attainment areas from meeting the NOx standard of 2.5 g/bhp-hr, or at least delay implementation of the standard for these transit operations.

Proposed CARB Rebuilt Urban Bus Emission Standards

CARB is in the very early phase of developing emission standards for rebuilt urban buses in California. Staff is considering options ranging from standards that would require upgrading diesel engines to 1990-model performance levels, to those that would require installation of particulate traps or even retrofitting alternative fuel systems. The regulation proposed by the EPA appears to be the least stringent option among those that CARB staff may propose to the Board. The proposed regulation is scheduled for consideration by the Board in late 1993. The earliest date the regulation would become effective is January 1, 1995, coinciding with that of the EPA urban bus rebuild standards.

2.0 FUEL, ENGINE AND VEHICLE TECHNOLOGY

OVERVIEW OF ALTERNATIVE FUELS

Available fuels that have emission benefits, and/or would help diversify the State's fuel supply sources include:

- Reformulated gasoline
- Methanol
- Ethanol
- Natural gas - compressed or liquefied
- Liquefied petroleum gas
- Clean diesel
- Electricity.

This section is a review of the properties of each fuel that impact its use by transportation agencies, and associated technological issues .

Reformulated Gasoline

Oil companies are developing reformulated gasoline to accomplish several goals:

- Reduce the ozone forming potential of the hydrocarbons in the gasoline
- Lower evaporative emissions through reduced vapor pressure
- Reduce CO exhaust emissions by addition of oxygenates
- Decrease sulfur content.

Advances in reformulated gasoline could reduce overall reactivity in the atmosphere to about 30 to 50 percent of that of current gasolines, thus making reformulated gasoline competitive with methanol. These fuels reduce exhaust emissions of total hydrocarbons (THC) and non-methane organic gases (NMOG) over normal gasolines.

It is still unclear what the long-term processing cost impacts will be from reformulated gasoline. ***Most industry experts believe that the cost increases will be slight, and that gasoline will remain the most economical fuel for light-duty and selected medium-duty applications. From a technical perspective, it appears that reformulated gasolines will be capable of meeting even the most stringent California emission regulations for light-duty and many medium-duty vehicles.***

Methanol

Methanol or methyl alcohol is a clear, colorless liquid that can be made from a variety of sources including coal, natural gas, and various grains. All methanol used commercially in the United States is manufactured from natural gas because this is by far the most economical feedstock. Methanol, by volume, has slightly less than half the energy content of diesel fuel and slightly more than half the energy content of gasoline. Therefore, to achieve equivalent power output, a methanol engine will consume a little over twice the volume of fuel as compared to diesel and a little less than twice the volume compared to gasoline. Methanol can be handled and stored much like petroleum fuel although some special materials are required. Methanol is much more toxic than the other chemical fuels used by the transportation sector, so greater care in handling methanol is necessary. All of these storage and handling peculiarities have been identified and resolved by the fuel suppliers.

Arguments promoting methanol use have focused primarily on its potential to reduce urban ozone in areas with significant smog problems (e.g., Los Angeles and the Northeast Corridor). Exhaust and evaporative emissions of neat (pure) methanol are generally considered to be about half as reactive as an equal mass of emissions from gasoline or diesel vehicles. Methanol's potential energy security benefits as well as its potential for improving fuel efficiency are also important.

Methanol offers some substantial advantages as an alternative fuel.

- Being a liquid at room temperature, methanol can be handled and dispensed through the existing liquid fuel infrastructure.
- Compared to the other fuels being investigated for use in motor buses, methanol has the highest heat of vaporization per unit mass, and the lowest energy density. This combination gives by far the greatest heat of vaporization per unit of energy content, resulting in the strongest charge cooling effect. In spark ignited engines, this effect may be used to promote high volumetric efficiency, and in combination with methanol's high octane rating, allows for very high knock-limited compression ratios and consequently, very high specific power ratings.

In compression-ignition engines, charge cooling suppresses NOx formation, allowing considerably lower NOx emission rates than are presently achievable in diesel engines. A liability associated with methanol's charge cooling is slower and less complete combustion, so that emissions of unburned fuel and partially oxidized products of combustion (particularly carbon monoxide and formaldehyde) are much higher than in diesel engines. Since compression-ignition engines operate with large amounts of excess air, engine manufactures typically use oxidation catalysts with methanol engines to burn these products (formaldehyde).

Ethanol

Ethanol is produced by the fermentation of plant sugars. It has been heavily promoted as a motor vehicle fuel in the farm states, and is subsidized by the federal government at a rate of $0.60 per gallon when blended with gasoline and sold as "gasahol." Ethanol's major use is currently as an octane additive and oxygenate for gasoline. ***As a pure or nearly pure fuel, economics of production strongly favor methanol over ethanol. For example, recently quoted Gulf Coast wholesale prices for ethanol are more than twice as high as those of methanol, on the basis of energy content.*** Because ethanol production requires surplus cropland, significantly increased production would eliminate the surplus, and divert land now being used to produce food and animal feed. This would have the indirect effect of increasing the price of agricultural products. Although attractive to farmers, this result would be unacceptable to consumers, especially when much cheaper fuels are available. Therefore, ethanol will continue to have only limited use as a motor vehicle fuel.

Natural Gas

Natural gas has been used as a transportation fuel for many years in light and medium-duty trucks operated by gas utilities. About 35,000 natural gas vehicles are operated in the United States today. Existing natural-gas-powered vehicles generally are gasoline vehicles modified by after-market retrofitters, and they retain dual-fuel capability (i.e., they are able to use either gasoline or natural gas).

Natural gas has several properties that make it an attractive motor vehicle fuel, including the following:

- An extensive pipeline supply infrastructure exists.
- Photochemical reactivity of organic gas emissions from natural gas engines is very low because the major species are unburned methane and ethane, and minor amounts of formaldehyde.
- Potentially, natural gas is a very economical vehicle fuel. The problem of getting it into the vehicle aside, natural gas is cheaper (per BTU) than gasoline and diesel fuel (this cannot be said of methanol and ethanol).
- Commercialization of natural gas vehicles will reduce U.S. dependence on imported petroleum.

- Cold start enrichment is not required, therefore, the associated organic gas and carbon monoxide emissions are eliminated.
- Methane gas has a very high octane rating (116 to 120), which allows for compression ratios of up to 12:1 in spark-ignited engines. Combustion characteristics and engine efficiency will benefit from high compression ratios.
- Very little carbon or varnish is formed on combustion chamber surfaces and very little acidification or dilution of lubricating oil occurs as a result of natural gas combustion. These properties allow for very long service times between rebuilds.
- Natural gas can burn without misfiring at very lean mixtures, and produces high thermal efficiency and low engine-out NOx emissions.

The major drawbacks of natural gas stem from its very low condensation temperature (e.g., -260°F). For acceptable vehicle range, natural gas must be compressed to very high pressures (2,500 to 3,600 psi) in heavy, bulky storage tanks, or liquefied to cryogenic temperatures.

Compressed Natural Gas (CNG)

Natural gas storage in motor vehicles is the major technical problem limiting commercialization of natural gas vehicles (NGVs). Ramifications of this problem are that NGVs have larger and heavier fuel tanks (or have shorter range), and are not as easy to refuel as gasoline and diesel vehicles. Also, certain safety issues, which derive more from the lack of experience with NGVs than from fundamental safety problems, need to be resolved.

The most common method of storing natural gas on motor vehicles is in a highly compressed state. ***Steel or high-strength fiberglass-wrapped aluminum, cylindrical tanks are used to store natural gas at up to 3,600 psi. Even at this pressure, a BTU of natural gas occupies over four times the volume of a BTU of diesel fuel. Therefore, a large storage volume (and substantial tank mass) is required if CNG vehicles are to have ranges equivalent to diesel or gasoline vehicles.***

To achieve fill rates equivalent to liquid fuels (such as methanol, diesel, or LNG), very large compressor stations are required. If fast fill rates are not mandated by the application at hand, CNG vehicles can be refueled over long periods (such as overnight) with smaller and less expensive compressors.

Because of these rather severe refueling requirements, use of CNG to date has been limited to commercial fleets.

Liquefied Natural Gas (LNG)

An alternative to compressed storage of natural gas is to store it as a liquid in a supercooled (cryogenic) state. This requires that the natural gas be liquefied somewhere in the fuel supply infrastructure, that vehicle refueling stations capable of dispensing LNG be established, that precautions be taken to maintain the natural gas on the vehicle in a liquefied state, and that the LNG be vaporized before being introduced into the engine. Technology for accomplishing all of these requirements has been developed and demonstrated. Today LNG is considered a viable alternative fuel approach with certain advantages compared to CNG. It is likely that each type of storage medium will find particular market niches that are best suited to accommodate each of them.

The primary advantage of LNG is that it can be stored at a lower pressure (20 to 50 psi), at about one-third the volume, and at one-third the weight of an equivalent CNG storage tank system. LNG also has storage tank size and weight advantages over methanol.

These on-board storage advantages translate into improved vehicle fuel economy, extended range, and increased payload capacity.

The biggest drawback to LNG implementation will be supply availability and infrastructure development. LNG is only now beginning to emerge as an alternative to CNG. Availability of LNG in California is very limited at present, but, a supply infrastructure could be established quite readily if sufficient demand were to emerge. ***Our preliminary assessment of LNG price/supply indicates that under certain circumstances, when demand is sufficiently high, the economics of LNG could be the most favorable of any of the alternative fuels.***

Liquefied Petroleum Gas

The advantages and drawbacks of operating engines on LPG are similar to those of natural gas, except that the fuel can be stored as a liquid without refrigeration. LPG allows extended intervals between oil and spark plug changes, and has demonstrated exceptional engine durability (50 to 100 percent greater than with gasoline). Delivering the fuel as a gas exerts a performance penalty, however. Converting a gasoline engine to LPG will usually cause a 10 to 15 percent power loss, because of the loss of the charge cooling effect of the evaporating gasoline droplets. This can be compensated for, to a certain extent, in engines specifically designed for LPG since a higher knock-limited compression ratio can be used. Also, a liquid-phase injection system is presently under development at Ortech, an engine development and testing laboratory in Ontario, Canada. This injection system will give precise electronic control to LPG fuel systems, and utilize LPG's heat of vaporization plus expansion to achieve a charge cooling effect and volumetric efficiency similar to that of gasoline.

Of the alternative fuels considered here, LPG is the best established. It is the third most heavily used automotive fuel, after gasoline and diesel fuel. Approximately 350,000 LPG vehicles are in operation in the United States. Most of these are aftermarket conversions of gasoline vehicles. The main motivation for converting is cost savings. Usually a surplus commodity, LPG is normally cheaper than gasoline on a BTU basis.

LPG powered vehicles were used extensively in transit applications from the 1940s through 1970. The largest single user of LPG was the Chicago Transit Authority (CTA). In 1970, CTA operated 1,400 propane buses and consumed 19,750,000 gallons. CTA reported excellent durability from the LPG fleet, a complete elimination of smoke, and an excellent safety record.

Clean Diesel Fuel

Cleaner diesel fuels are an important part of an integrated strategy to reduce emissions from heavy-duty diesel engines. Features of clean diesel fuel specifications include:

- Reduction in sulfur content
- Reduction in aromatic content
- Reduction in 90 percent point
- Increase in cetane number.

Diesel fuel typically contains between 0.2 and 0.35 percent sulfur. The aromatic content of diesel fuels is ordinarily between 20 and 35 percent, with the remainder consisting mostly of paraffins. Diesel fuels with high aromatic content and high distillation temperatures tend to form more particulate emissions. Aromatics and larger hydrocarbons do not burn as readily and are more inclined to pyrolize into particulate than the lighter paraffins.

The CARB has adopted new diesel fuel standards that will limit sulfur content to less than 0.05 percent and aromatic content to less than 10 percent. These fuel regulations will take effect October 1, 1993. The impact of this action on diesel fuel prices is the subject of considerable debate. The petroleum industry has suggested that prices could increase by $0.20 to $0.25 per gallon while CARB has suggested a price increase of between $0.10 to $0.20 per gallon. ***For planning purposes, an increase of $0.15 per gallon in the price of diesel fuel beginning in October 1993 appears likely (in addition to any other price increases caused by normal supply/demand dynamics).***

In California, the future viability of clean diesel as a fuel for transit will depend primarily on the level set by CARB for the 1996 transit engine NOx standard.

ALTERNATIVE FUEL ENGINE DEVELOPMENT AND DEMONSTRATION PROJECTS

Transit engine manufacturers are emphasizing several fuels and engineering approaches to meet existing and future emission standards:

- Direct injection of neat methanol
- Spark-ignited natural gas using lean combustion
- Direct injection of natural gas with compression ignition
- Clean diesel fuel with catalytic converters or traps.

A lower level of development effort is being directed toward ethanol and LPG engines. [Electric propulsion technologies are also being developed and these are briefly reviewed in this section]

Methanol Engine Development and Demonstrations

Two stroke engines are particularly adaptable for compression ignition of methanol. Methanol has a very low cetane rating and a high autoignition temperature. In blower-scavenged, two-stroke engines, the scavenging of exhaust gases can be reduced by incorporating a blower bypass valve. This causes some of the exhaust gas to be retained in the combustion chamber, which mixes with the intake air charge, increasing its temperature enough to allow autoignition of methanol to take place.

Today there are 57 DDC methanol-powered buses operating at 8 transit properties. Transit properties report that as of January 1992, DDC methanol-fueled demonstration engines had accumulated over 4 million vehicle miles. The 30 buses at the Southern California Rapid Transit District (SCRTD) have gained the most operating experience. SCRTD's buses went into revenue service in June 1989.

Based on performance improvements during the course of its methanol demonstration program, and the availability of DDC's certified and fully warranted engine, SCRTD has recently accepted a bid by Transportation Manufacturing Corporation to produce 300 methanol 6V-92 powered buses. This purchase will create the nation's first all methanol fueled operating division, and marks methanol's transition from demonstration to commercial status.

Note: Cummins, after doing some research with methanol, has concluded that natural gas is a more viable fuel and will not offer a methanol engine.

Methanol Engine Fuel Economy

Fuel economy data reported by the three transit operators with the highest number of in-service DDC methanol buses (Exhibit 2-1) indicate that methanol fleet fuel economies are roughly one-third those of the diesel fleets. The large disparity among fuel economics (for both diesel and methanol), across the transit properties identified in Exhibit 2-2 reflects the differences between in-use duty cycles.

EXHIBIT 2-1

DDC Methanol Engine Demonstration Fuel Economy Results

Property	Number of Methanol Units	Diesel Fleet Average Fuel Economy (MPG)	Methanol Fleet Average Fuel Economy (MPG)	Average Fuel Economy Ratio
Denver RTD	5	3.85	1.53	(2.52)
SCRTD	30	3.20	1.13	(2.83)
Triboro	6	3.1	1.14	(2.7)
RTA	3	3.44	1.49	(2.31)

The average fuel economy ratio—diesel MPG/methanol MPG—for all DDC demonstrations is 2.59:1. DDC methanol engines have shown improving fuel economy during the last year, as a result of ongoing optimization of injector design, injection timing and blower bypass ratio. It appears likely that methanol engines in urban service will soon achieve an average diesel/methanol fuel economy ratio of about 2.5:1.

Methanol Engine Emissions

The emission performance shown by methanol engines has been impressive. Data reported by DDC for the production version 6V-92 equipped with an oxidation catalyst (Exhibit 2-2) indicate NOx emission rates at one-half of the current standard, and particulate emission rates below the 1991 California standard of 0.10 g/bhp-hr.

EXHIBIT 2-2

Certified 1991 Methanol DDC 6V-92 Emissions

Engine Condition	Fuel	OMHCE [g/bhp-hr]	CO [g/bhp-hr]	NOx [g/bhp-hr]	PM 10 [g/bhp-hr]	BSFC [lb/bhp-hr]
At break-in	M100	0.1	0.5	2.5	.05	0.974
Deteriorated	M100	0.4	4.8	2.3	0.06	1.083

DDC has recently announced its intention to recertify both the M85 and M100 versions of the 6V-92, to incorporate recent improvements in fuel injectors and engine control system calibrations. Certified NOx emission rates substantially lower than current rates are promised.

Natural Gas Engine Development and Demonstrations

Several modern operating techniques exist for utilizing natural gas in internal combustion engines, including the following:

- Lean-burn Otto-cycle
- Stoichiometric Otto-cycle
- Compression ignition Diesel-cycle.

In recent months, natural gas has been gaining momentum over methanol as an alternative fuel for transit buses. Heavy-duty engine manufacturers are vigorously pursuing development of natural gas engines for this market. Natural gas development programs began more recently than the DDC methanol program, therefore, in terms of design maturity, natural gas engines are one to two years behind the methanol 6V-92. Both Cummins and DDC are developing natural gas versions of their transit engines.

The Cummins diesel L-10, offered in recent years as an alternative to the DDC 6V-92 for transit applications, has been converted into two natural gas fueled variants that are currently being demonstrated in transit service. Both engines are spark-ignited. One engine being developed by Cummins uses an Impco carburetor to produce a lean homogeneous air/fuel charge. This engine however is considerably less fuel efficient than the diesel L10 due to the need to add an intake throttling valve, and because the compression ratio has been lowered to 10.5:1 (from 16.3:1) to prevent detonation. The CNG L-10 has exhibited some mechanical problems during its development. Demonstration sites have reported piston scuffing and excessive turbocharger bearing and wastegate component wear. These failures are likely due to the higher exhaust gas temperatures in the natural gas engine. ***The original diesel engine components and lubricating oil were not designed to operate at these higher temperatures.*** Cummins has developed improved gaskets and diaphragms, as well as pistons with modified ring clearances, to control durability problems. Recent field experience indicates generally good reliability with no major mechanical problems.

A second natural gas version of the Cummins L-10 was developed at Southwest Research Institute (SwRI) with funding by the Southern California Gas Company. This engine features in-cylinder gas injection through a prechamber. Six of the SwRI engines are being demonstrated in revenue service at SCRTD. The gas injection control system is complex, and has proven to be unreliable in service. Lean misfire and uneven acceleration are typical problems. The engine's extremely lean operation also results in high hydrocarbon emission rates.

Approximately 45 Cummins CNG L-10 engine equipped buses are now in revenue service. These buses have accumulated over 630,000 miles. Cummins is continuing development work on its natural gas engine, while development of the SwRI version has ended. ***Cummins intends to offer a certified CNG L-10 for sale by MY 1993. It will be offered with the same warranty as that given to the diesel L-10 (200,000 miles).***

DDC is also aggressively developing natural gas engines for the transit market. Its program consists of two distinct 6V-92 conversion programs. The first program is a joint effort with the Gas Research Institute, Stewart & Stevenson Denver, and Ortech International to develop a retrofit kit for converting existing 6V-92 engines to operate on a mixture of diesel fuel and natural gas. The engine is referred to by the name, Pilot Injection Natural Gas (PI-NG). The engine burns a mixture of 80 percent CNG and 20 percent diesel, with ignition of the natural gas accomplished by diesel pilot.

The transit authorities receiving the PI-NG engine will have the option of replacing it with a 100 percent CNG, two-stroke, direct injected engine currently being developed. The objective of converting the 6V-92 engine to 100 percent natural gas will be to achieve both complete combustion and efficient scavenging. In this engine, the fuel is compression-ignited when the engine is at normal operating temperatures, and ignited by glow plugs during start-up, warm-up and idle. Thus, its ignition control system is very similar to that of the methanol 6V-92. Direct injection is similar to diesel operation in that the engine is unthrottled, and power is controlled solely by fuel flow rate. ***Diesel engines achieve superior fuel efficiency by eliminating throttling losses and utilizing high compression ratios. These features are retained in the direct injection CNG engine to achieve similar fuel efficiency. Laboratory testing at several high load operating points gave thermal efficiencies between 33 and 40 percent, with NOx emissions between 1 and 3 g/bhp-hr.***

Field testing of a prototype DDC direct injection high pressure NG engine is expected in mid-1992. DDC plans to certify the engine and begin commercial production by July 1993.

CNG Engine Fuel Economy

Because of variation in route characteristics, vehicle weight and accessories (e. g., air conditioning), fuel economy comparisons between transit properties is difficult. The most meaningful comparisons are those made between different engine types operated by a single property. Transit properties operating both diesel and CNG versions of the L-10 include Mississauga, Toronto, SCRTD and Orange County. Average fuel economy of their diesel coaches is 4.84 miles/gallon and equivalent fuel economy of their NG coaches is 3.29 miles/gallon. Thus the CNG version is generally 32 percent less fuel efficient than the diesel engine with equal power. This data however reflects an average of both early vintage L-10 natural gas engines as well as updated versions. The efficiency of lean burn natural gas engines will likely reach about 80 percent of diesel cycle efficiency as development work continues. ***The compression ignition natural gas engines that are being developed by both Cummins and DDC have the potential to achieve thermal efficiencies similar to a conventional diesel engine.***

CNG Engine Emissions

Relatively little emission data exist for natural gas transit engines. Cummins has run transient emission tests on a laboratory version of the lean burn CNG L-10 at low engine hours as a part of its optimization effort (Exhibit 2-3). Hydrocarbon emissions at the high end of the range shown are generally coincident with NOx at the low end of its range, and vice-versa. Durability testing is currently being performed to measure engine deterioration characteristics. The durability data will be used to adjust the final calibration, in order to meet emission standards over the useful life of the engine.

EXHIBIT 2-3

Cummins L-10 CNG Lean Burn Engine Emissions
(g/bhp-hr Over the Transient Cycle)

	Total HC	NOx	CO	Particulate
1991 Ca. STD	1.3	5.0	15.5	0.10
Engine-Out	4 - 6	2.5 - 3.5	3 - 4	0.06
With Catalyst	0.6 - 0.9	2.5 - 3.5	0.3 - 0.4	~ 0.05

At a recent Sacramento Regional Transit District Board meeting, during which the Board elected to purchase 75 CNG fueled coaches, Cummins stated that it would be able to meet a 2.5 g/bhp-hr NOx emission standard by October, 1992, while also meeting the CARB urban bus emission standards for NMHC, CO and PM.

Status of LNG Demonstrations

Transit demonstrations of LNG buses are just beginning. The Metropolitan Transit Authority of Harris County (Houston Metro) has recently announced its intention to completely convert its fleet to LNG. At the time of writing, Houston Metro has taken delivery of three, 40-foot LNG buses. These buses were engineered for LNG by Stewart & Stevensen, and use DDC's diesel pilot-ignited engine. They are also operating ten, 29-foot Stewart & Stevenson LNG mini-buses. SCRTD, OCTA and other transit properties in the state have expressed interest in imitating LNG demonstration programs. Commercial fleet operators such as Federal Express, Roadway, and WalMart fleets are already operating LNG vehicles.

LNG Engine Fuel Economy – The efficiency of a natural gas engine will be unaffected whether the fuel is CNG or LNG. However, we estimate the fuel tank weight penalty for the CNG bus to be approximately 1,500 pounds over that of an LNG bus. Our analysis shows that a 1,500 pound weight penalty will result in a 2 percent decrease in fuel economy, i. e., an LNG bus should enjoy 2 percent greater fuel efficiency than a similar CNG bus.

LNG Engine Emissions – The discussion on CNG engine emissions is relevant to LNG engines, since the fuels are very similar from an engine perspective. However, LNG fuel quality will be extremely consistent, potentially allowing lower emissions than from CNG engines via more precise calibration.

Clean Diesel and Particulate Traps

Diesel engine emission control technology is evolving rapidly in response to emission standards. Improved understanding of the diesel combustion process, electronic injection systems with variable timing and injection rate, optimized turbocharging with aftercooling, and improved control of lubricating oil will dramatically reduce engine out particulate emission rates. Given these improvements, along with the 1993 diesel sulfur limit of 0.05 percent, manufacturers state that for many engine families, they will be able to meet a 0.10 g/bhp-hr particulate standard ***without aftertreatment. For example, DDC has announced that the Series 50, which is a 4 cylinder version of the very successful Series 60 heavy duty truck engine, will be certified later this year to meet the California 0.10 g/bhp hr PM standard, using clean diesel fuel without aftertreatment.***

DDC believes that the 50 series engine will be able to meet a .07 g/bhp-hr standard using only a catalytic converter and will approach the .05 g/bph-hr level. A particulate trap however may be required to ensure compliance over the life of the engine. The Cummins L10 diesel engine is expected to achieve similar emissions performance.

Early trap systems relied on a diesel burner to regenerate the trap by oxidizing the retained particulate. Electric heating elements are now preferred for this purpose because of their greater mechanical simplicity, and will be part of any certified system. Reliability of traps in transit demonstration projects has been improving steadily. The only major unanswered question regarding the viability of traps is their durability over the 290,000 mile useful life of the heavy-duty engine. ***Manufacturers have also discussed the possibility of certifying engines with trap replacement specified at 150,000 miles. This is allowed by federal regulation. In summary, it appears likely that particulate traps will enable diesel engines to continue to meet federal emission standards at least until 1998, when the 4.0 g/bhp-hr NOx standard takes effect. Diesel engines, with or without traps, will most likely not be able to meet CARB's proposed 1996 NOx standard for heavy duty transit vehicles.***

LPG Engine Development

The only transit engine provider pursuing LPG engine development is Cummins. The CNG L-10 is easily adapted to LPG by using an LPG fuel tank, and a different regulator and carburetor. Cummins is evaluating the performance of two

LPG L-10 equipped buses at Orange County Transportation Authority (OCTA). The OCTA project manager is pleased with the overall performance and reliability of the engine, and the ease of fuel handling. LPG demonstration bus fuel economy is averaging 2.0 miles per gallon. The two buses have accumulated a total of 60,000 miles. ***Cummins does not intend to certify or market an LPG version of the L-10 at this point in time. Cummins has indicated a willingness to pursue certification if sufficient demand develops.***

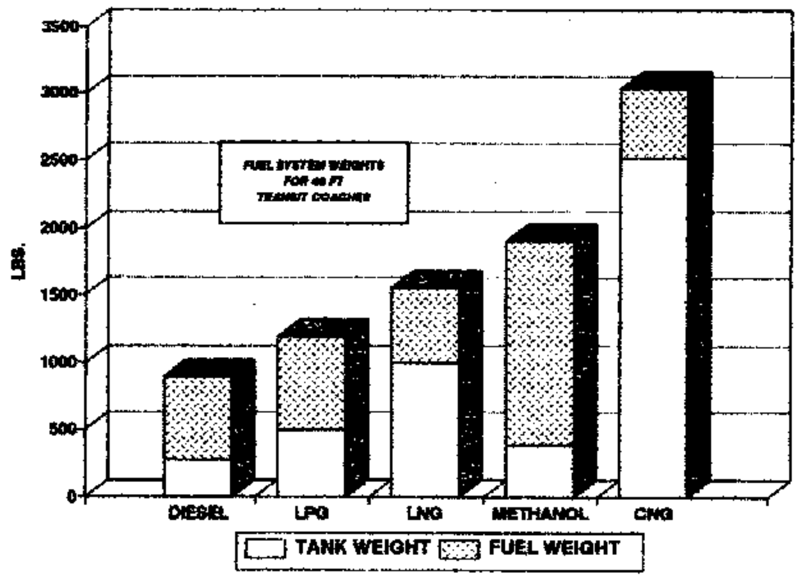
EFFECT OF ALTERNATIVE FUELS ON VEHICLE WEIGHT AND LOAD CAPACITY

Increased weight and volume are two undesirable characteristics of alternative fuels. Greater fuel volume may reduce the space available for cargo or passengers, or make the vehicle design more bulky. Increased weight compromises performance and handling, and in heavy-duty vehicles, reduces load carrying capacity. Fuel tanks on transit buses are located between the frame rails, where enough unused space exists that fuel volume is generally not a major problem. ***However, weight is critically important, in that greater fuel weight results in lower passenger carrying capacity, unless the vehicle is modified to achieve compensatory weight savings. Since urban buses are designed to carry a full seated load and a number of standees, fuel weight is an especially important concern for properties having high peak passenger loads. For these properties, reduced capacity per bus creates a need for a greater number of peak buses, if service levels are to be maintained. This increase in fleet size is a potentially large hidden cost of alternatively fueled buses.***

Fuel storage system weight consists of the fuel itself and the tank. Exhibit 2-4 presents a comparison of weights among the various alternative fuels.

EXHIBIT 2-4

Fuel System Weight Comparison



ELECTRIC PROPULSION SYSTEMS

In this section we present a review of electric propulsion system technologies.

- Battery powered buses
- Fuel cells
- Electric trolley buses.

Electric powered technology can be a viable alternative for some applications. The key to successful implementation of electric vehicles will be careful matching of propulsion system design capabilities with the duty-cycle (mission) requirements. Range and vehicle weight continue to be problem areas for electric vehicle (EV) technology. Nevertheless, continuing advancements indicate EVs will likely have an increasingly important role in the transit industry, particularly in California.

Heavy Duty Battery Buses

The application of batteries as the exclusive propulsion power for a heavy duty urban bus is much more demanding than for lighter weight, medium-duty vehicles. This is primarily due to the available space and weight for an appropriately sized battery system compared to the payload capacity and the weight of the vehicle itself. Current estimates show that a 35,000 lbs GVW vehicle will require about 4 kWh of energy per mile to operate in moderate urban and arterial driving conditions. For an EV bus with a range equivalent to a diesel fueled bus, the electrical energy requirements should be around 1,300 kWh, as shown by the following calculation:

- Average diesel bus range = 3.5 mpg x 88 gallons = 308 miles
- $308 \text{ miles} \times \frac{4\text{kWh}}{\text{mile}} \times \frac{1}{95 \text{ (efficiency factor)}} = \underline{\mathbf{1{,}297\ kWh}}$

State of the art battery designs such as Sodium/Sulfur and Sodium/Metal Chloride, capable of providing 1300 KWh of energy storage would weigh approximately 28,000 lbs and 19,000 lbs respectively. Such battery weights are clearly excessive for a 35,000 lbs GVW bus. Heavy duty buses powered exclusively by batteries are therefore not as yet practical.

Vehicle range of battery powered buses can be increased by means of a range extender, which may be a highly efficient ICE running on a clean fuel; or a fuel cell. The ICE and the fuel cell can be fueled relatively quickly to provide almost unlimited range. Such hybrid applications will require the revision of battery goals toward improved power densities rather than energy densities, along with different specifications for cycle life, internal impedance and volumetric densities.

A key to the successful development of battery powered buses (as well as hybrid buses) will be a significant reduction in vehicle weight. For example, if vehicle weight is decreased by 33 percent, peak power requirements are reduced by about this same percentage, but more importantly, energy storage requirements (which translate directly into battery size and weight) will decrease by about 50 percent or more (i.e., there is an exponential penalty for added weight with regard to energy storage requirements).

Fuel Cells

Fuel cells offer the potential to replace internal combustion engines in transportation applications and have already been used as power sources in spacecraft and stationary power units. Advantages of fuel cells include:

- Extended range (compared to battery powered vehicles)
- Zero emissions
- Multifuel capability
- High energy efficiency versus an internal combustion engine

Fuel cell powered vehicles can operate continuously as long as fuel and oxygen are supplied: Refueling can be accomplished in as short a time as can present engines—with comparable ranges between refills. Suitable fuels include methanol, ethanol, natural gas, gaseous or liquid hydrogen, and coal-derived fuels.

The electrochemical conversion of energy in the fuel cells takes place at a much higher efficiency than that of combustion in heat engines, which is limited by the Carnot cycle. The theoretical efficiency for the conversion of heat energy into electrical energy is approximately 83 percent. Efficiencies of practical cells using pure hydrogen and oxygen from air have somewhat lower efficiencies (around 60%).

Two types of cells, phosphoric acid fuel cell (PAFC) and proton exchange membrane (PEM), are considered to have potential for transportation applications. Solid oxide fuel cells (SOFC) are also under development but the commercialization timeframe is further away.

The DOE, private industry, and others are currently active in fuel cell development for transportation—from this activity, two transit bus demonstration programs have emerged in North America; the first, sponsored by D.O.E, FTA, the South Coast AQMD, and Georgetown University, focuses on development of three 28 foot buses using PAFC fuel cell technology; the second program, sponsored by the Government of British Columbia, focuses on development of three 30 foot buses using PEM technology.

While fuel cells offer tremendous promise as a vehicular powerplant, several areas of technical concern still exist.

> Performance: Weight and volume of current fuel cell systems limit acceleration, top speed, and passenger capacity and will require completely new structural designs.
>
> Reliability: Reliability is not proven to date—not a single mile has been driven by a fuel cell-powered bus.
>
> Operations and maintenance: Due to high temperature operation, some systems require about 30 minutes of warm-up time. Batteries require frequent watering, rotation, and top-off charging.
>
> Hydrogen storage: Although hydrogen may ultimately be a very desirable fuel, storage and delivery technology is not yet sufficiently developed.

Perhaps the most challenging issue of all is cost reduction—the world's leading experts in electrochemistry, materials science, and other disciplines have been using a number of approaches:

- Improved lighter weight materials
- Reduce system complexity
- Improved manufacturing processes
- Better integration of supporting subsystems
- Reduced need for precious metals.

Although a number of leading experts are grappling with the issues, there are still wide differences of opinion regarding when feasible and cost-effective fuel cell buses will be available.

In summary it appears that fuel cells will certainly replace ICE engines in the future for many applications. They will likely be integrated with advanced battery systems to provide good transient performance. Low weight buses will be a key design feature in helping fuel cell/battery hybrid buses to become a commercial success. The first commercially available buses will likely be available between years 2000 and 2005 given sufficient industry interest and Federal funding for research and development.

Electric Trolley Buses

Electric trolley buses offer transit operators a highly developed, reliable and available alternative to conventional diesel-powered buses. They also produce zero emissions at the source, and because California utilities use generally clean sources to produce electricity, trolley buses will reduce overall emission levels well below those from either diesel or alternatively fueled buses. A trolley bus system is however quite expensive to implement. A Booz-Allen study for SCRTD concluded that trolley bus catenary and the associated power distribution system would cost approximately $1.5 million per two-way track mile. Trolley buses themselves will likely cost approximately $400,000 to $450,000 for a 40-foot coach, and about $600,000 to $650,000 for a 60-foot articulated bus. Overall operating costs for a trolley system will not be substantially different than operating costs for an alternative fuel bus fleet. To justify the high initial capital costs associated with establishing a trolley bus system, the headways over a confined network of routes must *average* under 10 minutes all day long, and passenger loading must be high. Only a few transit systems in the state will have operating characteristics sufficient to justify installation of a trolley system. The Booz-Allen Trolley Bus Study for SCRTD for example showed that only about 15 to 20 routes in that system were reasonable candidates for trolley bus conversion.

3.0 FUELING FACILITIES

This section evaluates the issues and costs associated with alternative fuel facilities. Methanol, gasoline, CNG and LNG were evaluated.

Alternative fueling facilities may arouse considerable attention among public agencies that are responsible for issuing permits. The local fire department (city or county, as applicable) should be contacted first to define criteria for safe fueling system installation consistent with local requirements. Since these fueling facilities are just beginning to be installed statewide, fire personnel have not been exposed to specific methanol, LNG, or CNG facility experience.

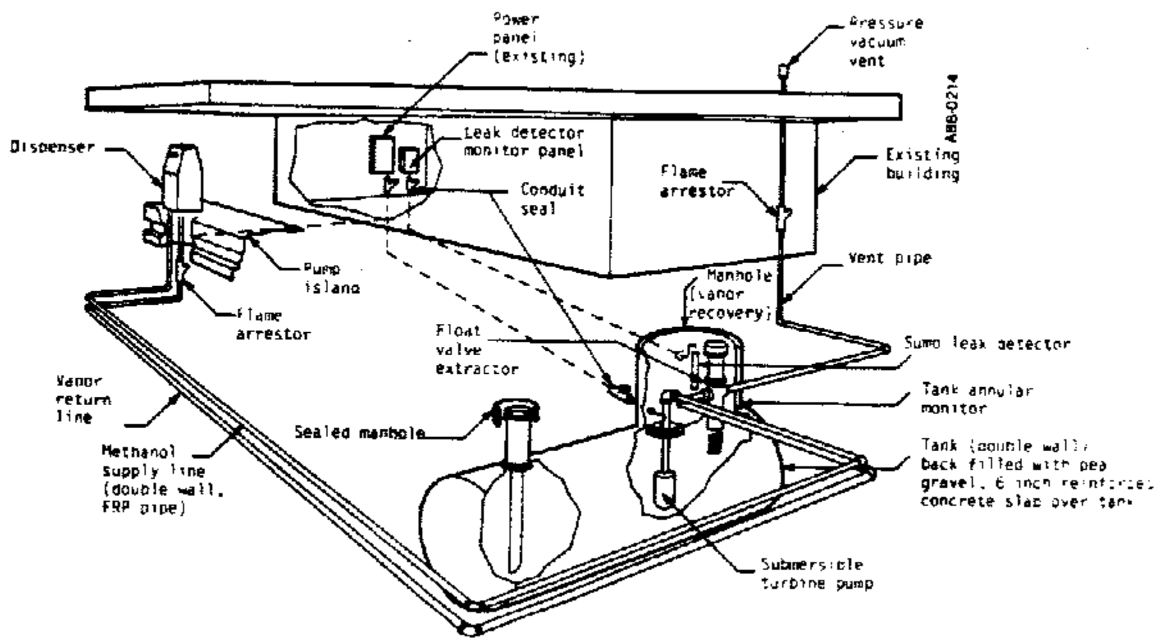
Methanol and Gasoline Fueling Facilities

Methanol and gasoline fueling facilities are considered together. Both fuels can be dispensed from underground storage tanks. State law now requires that all new underground storage tank installations be methanol compatible.

A design for a methanol fueling facility is shown in Exhibit 3-1. The facility is composed of a fuel tank(s), leak detection devices, dispensing piping, dispenser, and environmental and safety systems.

EXHIBIT 3-1

Methanol Fueling Facility Design



Fuel tanks designed for diesel or gasoline use may not be methanol compatible. Tanks should be constructed of either fiberglass (fiber reinforced plastic (FRP), or steel. FRP tanks are not methanol-compatible unless manufactured with a special resin that does not dissolve in methanol. Corning and others currently manufacture these FRP methanol-compatible tanks.

CNG Fueling Approaches

There are four approaches applicable to refueling natural gas powered transit buses, depending on the available facilities at the transit property and size of the fleet. Each approach is discussed as follows.

Fast Fill - The fast fill approach for CNG is the most similar to current liquid fueling practices. The objective is to fill the CNG tanks as quickly as diesel—approximately 3 minutes, with an upper limit of 10 minutes.

Fast fill from a utility gas supply line requires gas be tapped from the normal underground source through a regulator/meter assembly to feed the inlet of a multistage compressor. A hose and nozzle assembly dispenses gas with a quick disconnect pipe connection inside the regular bus fueling door. Generally a dispenser is included that closely duplicates the appearance and function of a gasoline dispenser.

On-site CNG storage volume must be at least 3 times (often up to 4 times) the individual bus fuel volume requirements to achieve fast fill. Also, the gas delivery piping, hose, fueling nozzle, and all the piping on the bus must be designed large enough for the fueling time desired. If the on-site CNG storage buffer is not large enough then the bus will not be capable of being completely filled.

After a bus is refueled, recharging of the CNG storage buffer is required before the next bus can be refueled. Hence, there is a required "recovery time" between refueling operations. In a properly designed system, this time is only a few minutes or approximately the time required to position the next bus for refueling. The required time between refill operations will depend on compressor size, on-site CNG storage buffer volume, and the amount of fuel delivered to the bus.

Direct Fast Fill - Direct fast fill provides the vehicle with a very large gas flow from the compression device without including the intermediate CNG storage buffer tank. Since direct fast fill provides rapid refueling of vehicles without a storage recharge time, the system size depends on the desired time for refueling. This approach is the most attractive to fleets but costs the most as the compressor required is large relative to other systems.

Slow (Time) Fill - The slow (time) fill approach is the most simple, inexpensive, and relatively common approach in practice but has not been applied extensively to buses. The objective of slow fill is to fuel many vehicles at once during regular vehicle overnight parking assignments. The compressor is sized for fueling the whole fleet simultaneously over 12 or more hours. A manifold piping system distributing high pressure gases through multiple flexible fueling hoses and individual nozzles is required. Storage tanks are not required, rather, a small receiver is included for system control. Generally, a dispenser is not useful for such systems since all vehicles are fueled at once with no need for determining fuel usage on an individual basis. Fuel flow to each bus is automatically shut off when sufficient back pressure is reached.

Fast/Slow Fill - The fast/slow fill approach is a hybrid approach. It provides the features of both the fast and slow fill approaches. Such an approach could be applicable to an agency with a few buses, smaller support vehicles, and smaller transit vehicles. This system is essentially a slow fill system but would permit an occasional fast fill or the "topping off" of a limited number of buses.

Recommended CNG Fueling Approaches

A small transit facility of approximately 10 to 15 buses may select from any of the approaches discussed above including fast fill, slow fill, fast/slow fill, and direct fast fill. However, medium and large transit operations are restricted to a direct fast fill approach since the physical amount of high pressure gas required is so large that all other approaches are generally impractical. For the small operator, the best approach will vary depending on available space for locating a fuel facility, total annual fuel consumption, and time window available for refueling the fleet. The small transit operation may also elect to purchase "compressed" natural gas directly from the local utility company.

LNG Fueling Facilities

An LNG fueling facility consists of an LNG storage tank (or tanks), fuel pump, refueling dispensers and refueling couplings. LNG refueling equipment in the past was primarily for experiments and demonstrations. There are a variety of design approaches for LNG vehicle refueling equipment (particularly LNG refueling couplings) and there are some fundamental differences of opinion regarding the requirements such equipment must fulfill. Fast fill LNG approaches are being pioneered by Houston METRO.

LNG storage tanks are available in any size up to 50,000 gallons, although tanks less than 10,000 gallons are usually not considered practical because they cannot receive a full load from a standard 10,000-gallon LNG tanker truck. These tanks are shop-built jacketed tanks with an inner pressure vessel that meets the ASME code. The jacket provides vacuum and insulation containment as well as structural support isolation of the cryogenic inner vessel, which keeps the LNG at -260°F. An onsite LNG storage capacity of 10 days of supply should be sufficient to minimize possible risks due to disruption in supply. This is more storage capacity than would normally be necessary for a conventionally fueled fleet because the extensive gasoline and diesel fuel infrastructure provides conventional fleets with much more security of consistent supply than would a newly emerging LNG vehicle fuel infrastructure.

The fill hose is typically 0.5- to 1.0-inch inner diameter flexible (corrugated) stainless steel and may be vacuum jacketed. Relative to a gasoline refueling hose, it is very large and heavy and best handled with a hose tower and counter balance system.

LPG Fueling Facilities

LPG is ordinarily stored in above-ground tanks constructed of thick-gauge steel. Since they are strong enough to support pressures of 250 to 300 psi, the tanks can be supported by concrete or steel saddles without deforming. Tanks are surrounded by heavy upright steel pipes founded in concrete, in order to prevent impacts by vehicles. Leaking propane is nontoxic and quickly evaporates, so there is no need for double wall construction and leak detectors, which are necessary with liquid fuels stored underground. LPG tanks can be sited underground, but this usually is not done in order to avoid excavation costs and corrosion.

Automotive LPG fueling facilities are fairly commonplace, and design standards are well developed. Small LPG fuel facilities utilize tank pressure to deliver fuel to the vehicle. However, in large facilities, a constant displacement pump is used for metering, and to provide a constant flow rate. No vapor recovery system is needed since the storage and dispensing system is sealed. Standard LPG dispensers are available to provide the 28 to 30 GPM needed to achieve diesel equivalent fill rates.

4.0 FUEL AVAILABILITY AND SUPPLY

Fuel prices of the various alternatives will have a substantial impact on total bus operating costs and thus play a crucial role in selecting a fuel for future transit operations. ***In fact, from an economic perspective only, fuel costs will be the most important discriminator among alternative fuels.*** This is especially true if consideration is given to the fact that Federal funding supplies a large portion of the capital costs for vehicles, thus mitigating the impact of vehicle cost in the selection process.

The major factors that will affect future fuel prices include:

- Changes in California-mandated specifications for diesel fuel.
- Increased use of oxygenates (methanol and ethanol) in reformulated gasoline.
- Reserves and availability of domestically-supplied natural gas.
- The development of a methanol vehicular fuel market.
- The development of an LNG fuel market.

There are numerous other factors that will affect the supply and demand of each of the various fuels. These factors include population growth, conservation measures, processing technology developments, discovery of new energy sources, and worldwide political stability. The factors influencing future worldwide energy pricing are complex and dynamic. A very brief review of important factors is presented here to assist the transit operator with fuel selection

Methanol

As noted in Chapter 3.0, methanol can be produced from several feedstocks including coal, natural gas, biomass and even petroleum. Production using natural gas as the feedstock is by far the most economic and practical. If a vehicular fuel demand for methanol were to develop in the U.S. and elsewhere, studies by the CEC and DOE indicate that substantial production capacity could be developed in areas of the world where natural gas feedstock costs are extremely low. The California AB 234 report predicts that the wholesale price of methanol in the year 2000 could be in the range of $0.36 to $0.51 per gallon. Assuming methanol is priced in the middle of the range predicted by the AB 234 report ($0.435 per gallon) and adding a nominal

$0.03 per gallon transportation cost, the price of methanol would be extremely competitive with gasoline and perhaps only marginally higher than diesel fuel or an energy equivalent basis.

The pricing for methanol predicted by the CEC is contingent upon a number of assumptions including:

- The development of a substantial methanol fuel market for light-duty vehicles.
- Methanol is supplied from off-shore foreign sources using low cost natural gas feedstock supplies.
- Methanol is shipped to the California coast in barge load quantities.

If, in fact, a substantial methanol fuel market were to develop in California, and the associated supply infrastructure developed concurrently, the fundamental feedstock, processing, and shipping cost of methanol appear reasonable and would be economic compared to gasoline (and probably slightly disadvantaged compared to diesel fuel). However, the development of such a market, absent clear and specific mandates from the State and Federal government, is unlikely to occur, based on either economics or emission regulations. Consequently, methanol will only enjoy commercial success in the light-duty market if made economically attractive through a variety of government incentive, taxation, or quota based programs. It would appear then that a methanol fuel market is unlikely to develop in California at least in the near term (next 5 years).

We are somewhat more optimistic regarding the development of a methanol fuel market in the medium to long term (5 to 15 years). If petroleum prices rise significantly, methanol will essentially be the only legitimate fuel substitute for the light-duty fleet of vehicles in this country. CNG and LNG have practical storage and handling limitations that make them poorly suited for most light-duty applications. Methanol, in contrast, is a liquid like gasoline and could quickly and easily be substituted for gasoline given sufficient economic incentive. The development of flexible fuel vehicles will facilitate this conversion process. It is reasonable to assume that a sharp rise in petroleum prices would be sufficient motivation for off-shore countries with low cost natural gas supplies to increase/develop their methanol production capacity.

Natural Gas

At the present time there is considerable excess production capacity of natural gas in North America versus demand. Current natural gas demand in the U.S. is relatively low compared to historical levels but is expected to increase through the year 2010. U.S. consumption of natural gas is not expected to re-attain the historical peak of 22.1 trillion cubic feet (reached in 1972) until around the year 2000. In California, the demand for natural gas is expected to increase at a very moderate rate of about 1.9 percent per year between 1990 and 2009.

Traditional markets for natural gas such as residential, commercial, and industrial are projected by the CEC and DOE to remain fairly stable over the next several years. **The use of natural gas by electric utilities represents the principal factor driving total gas consumption upward.** Use of natural gas to generate electricity is expected to increase in California by a factor of 2.3 between 1990 and 2009.

While demand for natural gas will grow in the U.S. and California, ample supply sources are available. Changing natural gas needs have encouraged development of natural gas pipeline projects in Canada, the Northeastern U.S. and California in recent years. In 1990, the Federal Energy Regulatory Commission (FERC) approved the Iroquois Gas Transmission project and the Kern River project. Additionally, there are four new pipeline projects that will serve to increase natural gas supplies to California in the near future.

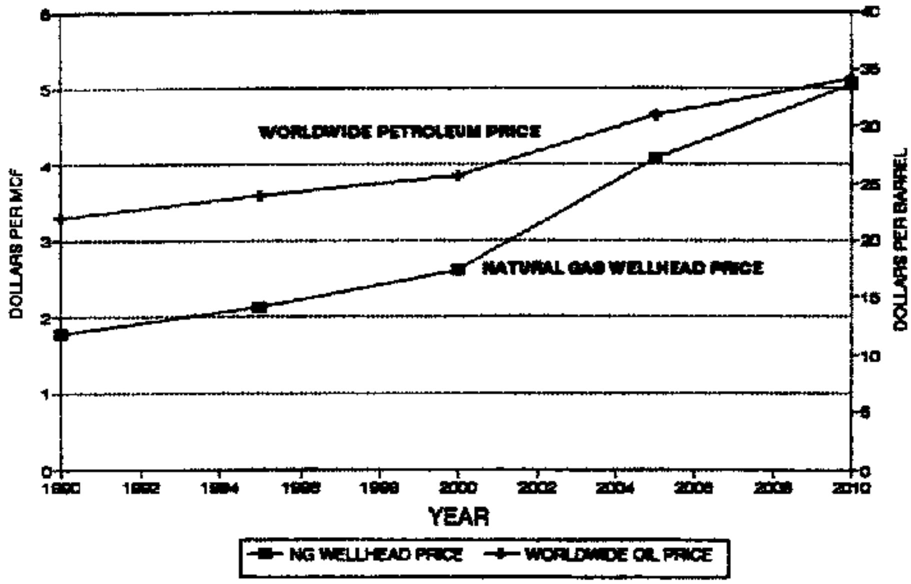
Altogether these new pipeline projects will increase supply availability to California by nearly 50 percent over 1990 levels.

Future Natural Gas Pricing

At present, natural gas prices are quite low, due to several factors including new pipeline projects, deregulation within the industry, and relatively low demand compared to historical levels (efficiency improvements and conservation are credited with reducing demand in the face of an increasing population). Both the DOE and the CEC predict natural gas prices to increase moderately through the year 2000, with higher rates of increase between 2000 and 2010, as shown in Exhibit 4-1.

EXHIBIT 4-1

Forecasted Natural Gas and Petroleum Prices



SOURCE: DOE ANNUAL ENERGY OUTLOOK 1991

LNG

For California transit properties there are essentially three options for procuring LNG:

Option 1: Purchase LNG from an independent producer such as a utility operating a peak shaving plant, or from an industrial cryogenics gas company.

Option 2: Construct and operate a small natural gas liquefaction plant to serve the needs of a single transit property. (The plant could be constructed either on site at the transit property, or remotely located outside the city and fuel trucked to the transit operating division.)

Option 3: Several transit properties (and/or other commercial fleets) could establish some type of working agreement, joint-venture, or partnership to construct a larger, more economical liquefaction plant to service the entire fuel requirements of the combined fleets.

Option 1:

Probably the most simple LNG supply scenario is for the transit property to contract with an independent producer of cryogenic liquids to supply LNG, via over-the-road tanker trucks, to an on-site storage and dispensing system at the transit facility. It is likely that several companies would respond to an RFP issued by a transit property for the supply of LNG fuel. Houston Metro, for example, recently released a Request for Technical Proposals for the supply of LNG fuel to Metro operating divisions, on an exclusive basis, for a 7-year term. A total of 10 firms responded to this RFTP.

Chicago Bridge & Iron won the Houston Metro LNG supply contract with a price of $0.46 per liquid gallon of LNG. Since the BTU content per gallon of LNG is about 87,000 versus diesel fuel at 128,000 BUT's/gallon, this translates into a bid price for LNG of about $0.70 per diesel equivalent gallon.

Other recently quoted LNG bid prices include the delivery of LNG to Roadway Express in Columbus, Ohio from Northern Indiana Public Utility in LaPort, Indiana at $0.35/gallon plus shipping costs. In California, Quadren Cryogenics has been working with Cryogenic Fuels Inc., the American Trucking Association, and the SOCAL on a plan to deliver LNG to SCRTD in Los Angeles and to Consolidated Freight commercial fleets in Southern California. Preliminary estimates of LNG cost for this program are approximately $0.45 per gallon LNG. ***It is reasonable to assume, then, that LNG procured from an independent supplier will result in a delivered price in California of about $0.40 to $0.50 per gallon of LNG.***

Option 2:

Under this option, the transit property would construct a small scale liquefaction plant whose output would be used exclusively by that transit property. Skid-mounted, turnkey liquefaction plants are available as small as 6,000 gallons per day (GPD) output capacity. This is sufficient capacity to serve a 50 to 75 bus operating division.

Natural gas feedstock for the LNG plant would likely be purchased from the local utility, since total consumption would probably not be sufficient to purchase gas directly from wellhead producers or pipeline companies. Hence, low priced natural gas feedstock would not be accessible. For this reason, as well as because of capital costs and land requirements for the LNG plant, we believe that construction and operation of an LNG plant is uneconomical at output capacities below around 15,000 GPD.

Option 3:

For this option, several transit properties (and/or commercial fleet operators) could combine their demand requirements to establish a larger, more economical liquefaction plant. Three primary advantages result from this strategy:

- Natural gas demand would be sufficient to support the direct purchase of gas from pipeline companies, wellhead suppliers and others, thus achieving low feedstock costs.
- The plant would be located well outside city limits, thus simplifying siting considerations. Also, the turbo-expander unit could be located at a pressure reduction point, which would help to keep operating costs low.
- There are basic economies of scale involved in liquefaction plant capital costs. For example, a 12,000 GPD turbo-expander unit, (without any pre-conditioning or ancillary equipment) costs about $2.8 million. A 36,000 GPD plant is estimated at about $6.0 million. Capital cost per gallon will thus be lower for larger LNG plants.

While it would clearly be organizationally difficult to execute the joint construction and operation of a large LNG liquefaction plant, the benefits in terms of lower fuel costs may be well worth it.

LPG

In the United States, LPG has a well developed distribution system utilizing 70,000 miles of LPG pipelines, 22,000 railroad tank cars and 26,000 transport and delivery trucks. LPG comes from two sources: petroleum refining, and natural gas processing.

Despite the existence of this well established infrastructure, vehicle manufacturers have traditionally viewed LPG with disinterest. Two reasons account for this attitude:

- Gasoline, LPG's closest competitor is more easily dispensed and stored, since it does not have to be compressed to remain a liquid.
- Much less LPG is produced than gasoline, leading to the belief that supplies are inherently limited.

Roughly five times as much gasoline as LPG is sold in the United States, and this relationship has been fairly stable over the last two decades. This statistic tends to support the contention that supplies are limited. It is important to point out, however, that refinery output is tailored to market demand. Through processes such as cracking, alkylation and polymerization, refiners can widely adjust their product mix. LPG demand in the United States is limited, and the fuel is ordinarily in surplus. This situation is reflected by LPG's low price, compared to gasoline. As a result, propane and butane are routinely converted by refiners into heavier paraffins that are used in gasoline. A major shift in demand away from gasoline to LPG, however, would cause refiners to adjust their processes to produce more LPG and less gasoline.

We believe that there is more than sufficient LPG production capacity in California to fully supply the entire transit market as well as other traditional LPG markets.

Average prices charged in the Los Angeles basin for full truckload deliveries of LPG during the last three years are shown in Exhibit 4-2.

EXHIBIT 4-2

Average Delivered Truckload Price of LPG in the LA Basin

Year	Average Price	Equivalent Gasoline Price	Equivalent Diesel Price
	[$/gal]		
1989	0.385	0.530	0.593
1990	0.500	0.689	0.771
1991	0.483	0.665	0.744

Notes: Price does not include sales or excise taxes.
Equivalent gasoline and diesel prices are based on relative lower heating values.

5.0 ALTERNATIVE FUEL VEHICLE SAFETY ASSESSMENT

The introduction of alternative automotive fuels is driven by the desire to improve air quality and reduce petroleum dependence. However, it is important that widespread use of alternative automotive fuels does not pose an unreasonable risk to public health and safety, relative to conventional gasoline-fueled and diesel-fueled vehicles. Potential hazards of alternative fuels include increased fire hazard and adverse health effects from exposure to the fuel. Exposure modes include ingestion, inhalation of fuel vapor or engine emissions, and direct contact. Fuel and fuel vapor may be released during normal vehicle operation and maintenance or as the result of accidental leakage or spills.

Methanol

Methanol is toxic and can be absorbed into the body by ingestion, inhalation and through the skin. Oral ingestion of wood alcohol-tainted beverages historically dominates as the most frequent mode of methanol poisoning. However, existing data on methanol toxicity in humans shows that absorption of methanol liquid or inhalation of its vapors can be as severe as oral ingestion in producing acute toxicity symptoms. In addition, available data suggests that repeated or prolonged exposures produce effects similar to acute exposure.

The U.S. Department of Transportation (DOT) classifies methanol as a flammable liquid. Methanol is categorized as a Class IB flammable liquid by the NFPA. Methanol vapors are flammable at volume concentrations in air ranging between 6.7 to 36 percent. These flammability limits correspond to temperatures between 43°F and 106°F for methanol fuel at equilibrium with air at standard pressure and temperature. ***Therefore, methanol tanks vented to the atmosphere will contain flammable vapor-air mixtures when the liquid temperature is between 43°F and 106°F. An ignition source may cause these mixtures to flash, resulting in a tank fire or explosion.***

Methanol vapors are more dense than the surrounding air and will tend to stay near the ground. Relative to gasoline or diesel fires, methanol fires are more controlled and burn cooler. However, methanol fires are invisible in daylight. The ignitability of methanol falls between gasoline and diesel fuel, which are categorized by the NFPA as a Class IB flammable liquid and a Class II combustible liquid, respectively. Methanol's higher flashpoint temperature, higher autoignition temperature, lower vapor pressure and higher lower flammability limit make methanol generally safer than gasoline.

Natural Gas

Although methane vapors are non-toxic, the oxygen content in an area surrounding a vapor cloud may be reduced, resulting in asphyxia to any person inside the cloud. An oxygen content of 10 percent is generally considered the lower physical limit of exposure without permanent damage to the human body. This corresponds to a methane concentration of 52.4 percent by volume in air.

A vapor cloud is flammable where the methane concentration in air is between 5 and 15 percent by volume. When confined, a flammable methane mixture may burn explosively.

Boiling-liquid expanding-vapor explosion (BLEVE) is the sudden and violent rupturing of a pressure vessel that occurs when the vessel is not strong enough to contain the pressure within the vessel. This occurs when either the strength of the vessel is compromised by heating or mechanical damage, or when the pressure within the tank becomes too high. The data acquired to date indicates that this is a highly improbably event providing the fuel tank is well designed and constructed and properly mounted on the vehicle. The test program undertaken by the DOT during the early 1970s to determine the crash worthiness of CNG and LNG fuel systems supports this assertion.

LNG

The structural integrity of four LNG vehicle fuel systems was assessed via simulated automobile crash tests using an impact sled during the DOT test program. Following completion of impact testing, the LNG fuel systems were returned to the manufacturer for tear-down inspection. A helium mass spectrometer test revealed a small leak from the outer tank of the Ametek/Straza system used in run four. However, the failure was non-hazardous in nature due to the small leakage rate (less than 10^{-5} cc He/sec) coupled with the absence of liquid fuel leakage to the annulus or the vehicle trunk. The tear-down inspections revealed no evidence of permanent deflection, distortion, cracks or structural failure of the inner tank support structures. None of the inner tanks sustained damage of any kind. ***In addition, one of the Houston Metro 25-foot LNG buses has been involved in a vehicle collision. The bus sustained substantial body damage, however, no LNG fuel leakage occurred.***

To further assure the structural integrity of LNG vehicle fuel tanks in the event of collision, it is recommended that tank supports be designed to withstand 40g accelerations in the forward and aft directions. Tanks should also be mounted inside the vehicle frame rail at least 2 feet from the rear bumper. Houston Metro intends to specify that all fuel tanks be frame mounted between the front and rear axles and along the center line of the vehicle for all future LNG bus procurements.

In the unlikely event of tank rupture, 10 to 15 percent of the LNG immediately flashes to vapor. The remaining volume spills to the ground and pools. As the LNG warms and the pressure rises to the service pressure (temperature and pressure follow the saturated liquid curve), expansion of the liquid will occur.

CNG

The American Gas Association (AGA) conducted a safety survey of 21 CNG vehicle fleets in the U.S. ***Results of the AGA survey indicate that injury rates per vehicle miles traveled for CNG vehicles are 84 percent lower than the national average. In addition, no fatalities were reported by the surveyed fleets. One reason cited for this excellent safety record is the structural integrity of CNG vehicle fuel systems.***

Current regulations require that CNG cylinders be manufactured, inspected, marked, tested and retested in accordance with DOT regulations, exceptions or special permits. In addition, DOT regulations require that CNG cylinders undergo hydrostatic testing every three or five years.

Five full-scale, including one rear-end, fixed-barrier tests were conducted on CNG-fueled vehicles during the DOT dual-fuel motor vehicle safety impact testing program conducted during the early 1970s. Six additional tests were conducted on CNG storage vessels and their attachment hardware via impact sled testing. Last, a series of drop tests were performed in which representative CNG cylinders were released from specified heights—10 to 30 feet—onto a concrete surface. No leakage or rupture was observed from the CNG cylinders.

Liquefied Petroleum Gas

LPG is the most widely used alternative motor fuel. The National Propane Gas Association estimates that between 2.5 and 3 million vehicles are running on LPG throughout the world. In the United States, an estimated 330,000 highway vehicles operate on LPG. Another several hundred thousand LPG engines are used in off-highway vehicles and stationary engines.

In the event of accidental release of LPG to the atmosphere, about one-third of the liquid flashes to vapor at a temperature of -70°F or lower. The LPG discharges at high velocity, atomizing the liquid into small droplets as it sprays into the atmosphere. Except for very large spill quantities and duration, the atomized spray will evaporate before it can settle to the ground.

LPG vehicle fuel tanks are constructed in accordance to ASME or DOT specifications for pressurized cylinders and are therefore more rugged than thin walled diesel and gasoline fuel tanks. The Research Institute for Road Vehicles in the Netherlands conducted several impact tests on LPG-fueled vehicles. Results of the testing indicate that LPG fuel tanks retain their integrity in collisions.

Chicago Transit Authority (CTA) operated a large fleet of propane buses during the 1950's, 1960's and early 1970's. In 1971, the fleet consisted of 1,400 propane powered buses and consumed 19,750,000 gallons of propane. CTA had 17 propane storage tanks, of 15,000 gallon capacity each, at seven different garage locations. The safety record at CTA was excellent with no occurrences of explosions, deaths, or major fires as a result of the propane operations.

6.0 MAINTENANCE FACILITY MODIFICATIONS

The objective of this section is to present those facility modifications necessary to handle safely each of the alternative fuels.

Overview

Several transit properties around the country have successfully integrated methanol, CNG and propane into their maintenance operations. To our knowledge, there has not been a single fire, explosion, leak, or other safety related incident that has resulted in the serious injury of any maintenance personnel. However, in comparison with gasoline and diesel fuel, there is comparatively little experience in handling the alternative fuels, and in maintaining new equipment associated with vehicular use of alternative fuels.

Unfortunately, there are no definitive regulations and procedures which stipulate clearly the safety precautions and maintenance facility modifications needed to accommodate each of the alternative fuel candidates. The approaches taken at demonstration sites around the country differ considerably, ranging from little or no modification of facilities or procedures, to extensive upgrading of ventilation, electrical and mechanical systems. Fortunately there are several regulations and codes contained in the National Building Code, the NFPA codes, the National Electrical Code (NEC) and the National Fuel Gas Code which can provide guidance on the conversion of maintenance facilities at transit properties. ***In the final analysis, the facility modifications required to accommodate alternative fuels will be subject to the approval of a local authority --- generally the Office of the Fire Marshall, local OSHA representatives, or other local building inspectors.***

Methanol

The facility modifications needed to accommodate methanol in most transit facilities will focus on improved ventilation systems and possible changes in electrical systems and equipment. Essentially, for all NEC and NFPA code purposes, methanol is considered within the same class of flammable liquids and hazardous material as is gasoline. Therefore, if a maintenance facility has been constructed and equipped to accommodate gasoline vehicles there will be little or no changes needed for methanol vehicles.

A methanol vehicle maintenance facility would likely be classified under Use Group S-1. As with most bus maintenance and storage facilities, the construction category most appropriate is Type 2. With this background, the maintenance facility modifications which are probably needed to accommodate methanol fueled vehicles are as follows:

Fire Suppression System. Fire suppression systems are required in all Group S-1 buildings that are more than 12,000 square feet in area, or that have more than 7,500 square feet and are more than one story high. Most transit properties will fall into one of these categories. Fire suppression system requirements for methanol are detailed in NFPA 30 along with a variety of handling and storage requirements.

Electrical System Modifications. Electrical system modifications required to accommodate methanol are governed by the National Electric Code which is identical to NFPA 70. According to NFPA 70, all wiring and electrical systems in a maintenance facility used for methanol vehicles must meet Class I, Division 2 requirements.

If interpreted strictly, the NEC Code implies that electrical outlets and other electrical equipment used below 18 inches above the floor, and/or in pits would need to meet Class I, Division 2 requirements. Again, these would be the same requirements that apply to gasoline vehicle maintenance facilities. ***Each transit property must review their own building specifications and meet with the local fire marshal to determine what electrical system changes, if any, will be required to accommodate methanol vehicles.***

Ventilation System. There appears to be several interrelated codes that effect the requirements for ventilation in maintenance garages classified as USE Group S-1 and Type 2 Construction. In general it appears that some increase in ventilation will be necessary, particularly in pits and below 18 inches above floor level. NFPA 70 implies that an air exchange rate of 1.5 cubic feet per square foot of floor space will be ample ventilation. For most maintenance facilities this will equate to about 5 complete air exchanges per hour.

LPG

Maintenance facility modifications for LPG will be very similar to those required for methanol since both fuels are heavier-than-air in the vapor state. Maintenance garages used for repair of LPG vehicles will have the same construction and use classification as methanol (Use Group S-1 and Type 2 construction). Electrical system specifications for equipment located near the floor and in pits should also be the same as methanol (i.e., Class I, Division 2 rating). Fire protection and suppression systems must conform to NFPA 58, which governs requirements for the storage, handling, and dispensing of LPG.

CNG

Modifications to maintenance facilities to accommodate CNG vehicles will involve similar changes needed for methanol and/or LPG but with selected additional provisions. CNG bus garages are classified as Use Group S-1 and Type 2 construction. The following codes contain sections that pertain to accommodating natural gas vehicles in maintenance garages:

- NFPA 52: Compressed Natural Gas Vehicular Fuel Systems
- NFPA 88B: Repair Garages
- NFPA 70: National Electric Code
- NFPA 497A: Classification of Class I Hazardous Locations for Electrical Installations in Chemical Process Areas.

Fire Suppression Systems. Similar to methanol or gasoline, NFPA and National Building codes requires that ***new*** maintenance facilities designed for CNG vehicles be equipped with a Fire suppression system and automatic sprinkler system. However, modifications of maintenance facilities at demonstration test sites for CNG in California and Canada have not included the installation of automatic sprinkler systems.

Ventilation and Methane Gas Detection System. Because natural gas is lighter than air, leaks will quickly rise to the ceiling of the maintenance facility. Ventilation system modifications will be considerably different than for heavier-than-air fuels such as methanol and LPG. The required ventilation rate, even in the event of a "massive" gas leak, is approximately 1.3 cubic feet per square foot of floor space in the maintenance area.

It is likely that existing transit maintenance facilities, especially older facilities that are designed only for diesel compatibility, will possess ventilation system ratings that are less than 1.0 CFM per sq. ft. of floor space. Therefore, the ventilation system in most transit properties will require some upgrading.

The installation of a methane detection system is also recommended. Transit properties in Canada have concluded tentatively that a methane detection system is a prudent and effective modification, especially during early use with natural gas vehicles. NFPA 52 also requires the use of a methane detection system for indoor refueling facilities. Both codes (NFPA 52 and the National Building Code) stipulate a gas detection system that is activated when sensors detect flammable vapors in amounts exceeding 20 percent of the lower flammability limit. There is, at this time, no clear description or definition of where sensors are to be installed in the maintenance facility, and how the gas detection system will be integrated with the ventilation, electrical and fire protection systems. A more clear definition of such systems will evolve over time as transit properties and commercial fleets gain more experience with natural gas vehicles.

Electrical System Modifications. Electrical system modification necessary to accommodate CNG into the maintenance garage are governed by NFPA 70 and NFPA 52. Like methanol or gasoline, electrical devices including transformers, capacitors, meters, relays, contacts, and motors which may be in proximity to natural gas vapors must meet Class I, Division 2 electrical requirements. This does not necessarily mean that all electrical systems in the maintenance facility will require upgrading. The local enforcement authority will have final say regarding the devices or systems which require upgrading. ***In general it is prudent to survey/inspect electrical apparatus located near the ceiling of the maintenance facility to identify potential spark or ignition sources.*** If such apparatus is not already in compliance with Class I, Division 2 requirements, the local enforcement authority will probably require modification of the apparatus; just as similar apparatus located in pits or near the floor in a methanol facility would require upgrading.

For some properties, particularly those in colder climates, the removal and/or replacement of air heating devices near the ceiling will be necessary. Heating systems that rely on open flame or electric element heating should be removed. Radiation type heating systems with the heat source located outside of the maintenance bay area is recommended.

LNG

Leaks and spills associated with LNG will result in elevated risk levels inside the maintenance garage that are very similar to those for CNG. LNG leaks will quickly evaporate and rise to the ceiling of the maintenance facility in a fashion similar to a leak on a CNG vehicle fuel system. Therefore the maintenance garage modifications necessary to accommodate LNG vehicles will be very similar, if not identical, to those required for CNG vehicles. NFPA 59A; Production, Storage, and Handling of Liquefied Natural Gas, details electrical system and equipment requirements as well as fire protection systems requirements for LNG. There currently does not exist codes that specifically address the use of LNG as a vehicular fuel, but such work is in progress and codes/regulations are expected to be approved and issued by late 1993.

7.0 MAINTENANCE AND OPERATIONAL IMPACTS OF ALTERNATIVE FUELS

Impact on Service and Repair Requirements

Alternatively fueled urban buses have demonstrated substantially greater maintenance requirements than conventional diesel fueled buses. The development process for alternative fuel engine technology in the transit sector has been unlike normal on-road heavy-duty engine development programs. New heavy-duty truck engines usually receive much more development on the laboratory dynamometer before prototypes are released into test fleet service. Test fleets are small, and are carefully selected from the manufacturer's best customers. The fleet operator understands that these engines are expected to fail in service, since the program is intended to identify and correct design weaknesses that adversely affect durability. The manufacturer provides a high level of service and support, since the field test operation is vitally linked to the engine development program.

Transit engine development, however, has involved less laboratory testing than is normally associated with heavy-duty truck engines. Transit's customer base is much smaller, so less development cost can be justified. The engine is less developed when it enters the demonstration service phase, resulting in poorer initial reliability and durability.

Manufacturers report that the reliability of alternative fuel transit engines is improving at rates that are normal for new engine designs. As their designs mature, we expect the alternative fuel engines to approach the reliability and durability of heavy-duty diesel engines.

However, each alternative fuel engine has systems that are not in diesel engines, and which may require additional maintenance and repair. Other features of the fuel, or fuel storage system will also affect maintenance requirements.

Design modifications will impact maintenance operations in three major areas:

- Parts inventory
- Maintenance labor hours
- Training of mechanics

Parts Inventory. The extent to which a larger parts inventory is needed depends strongly on whether or not the alternative fuel engine is a derivative of an engine already in service at the property. For example, to operate natural gas L-10s, properties that already operate coaches powered by diesel L-10s would have to increase their inventories much less than those who exclusively use DDC engines. Indeed, maintenance managers have commented that one advantage of the methanol 6V-92 is its mechanical similarity to the diesel version. One manager commented that it would be much more difficult for his agency to convert from diesel 6V-92s to diesel L-10s than to convert to methanol 6V-92s.

Maintenance Labor Hours. Previous Booz-Allen studies of maintenance practices at transportation agencies have found that maintenance of engines, exhaust systems and fuel systems constitutes about 35 percent of total fleet maintenance costs. From conversations with maintenance managers at transportation agencies conducting alternative fuel demonstrations, and our estimate of the ultimate complexity, reliability and durability of alternative fuel engines, we project the following impact on the maintenance labor hours devoted to engine, exhaust and fuel systems:

Limit	Methanol	CNG	LNG	LPG	Diesel Trap
Lower	+ 5%	+ 5%	+ 5%	+ 5%	+ 5%
Upper	+ 20%	+ 20%	+ 20%	+ 20%	+ 10%

Training of Mechanics. As with parts inventory requirements, the amount of mechanic training needed to support the operation of alternatively fueled buses will depend on the degree of commonality between the alternative fuel engine and those in the existing fleet. Mechanics at Riverside Transit Agency receive 40 hours/year of training to qualify them to service methanol 6V-92s. An important aspect of mechanic training for methanol is proper procedures for minimizing contact with methanol liquid and vapor. Information on additional training requirements for natural gas and LPG is sketchy.

8.0 ECONOMIC IMPACT ANALYSIS

This chapter provides an overview of the economic impacts of converting a transit system to alternative fuels. Cost impacts have been identified for three different size transit properties:

- 10 bus fleet: 30,000 miles per year per bus
- 50 bus fleet: 40,000 miles per year per bus
- 200 bus fleet: 40,000 miles per year per bus.

Cost impacts have been quantified for what we believe to be the major cost elements affected by a switch to an alternative fuel.

Fuel Facility Capital Costs

Clearly, fuel facility modification costs will vary dramatically among transit properties depending on fleet size, facility layout, available land, local land and construction costs, environmental compliance costs and other considerations. For CNG compression facilities it may be possible to secure both technical and financial assistance from the local gas utility for establishing a CNG refueling station. The utility company may also be able to provide temporary refueling facilities during the transition period. In the case of a methanol refueling station, the excavation costs for removal of existing underground fuel tanks will be a major variable effecting new fuel facility capital costs. If the existing diesel or gasoline tanks have leaked, then replacement costs could go up dramatically.

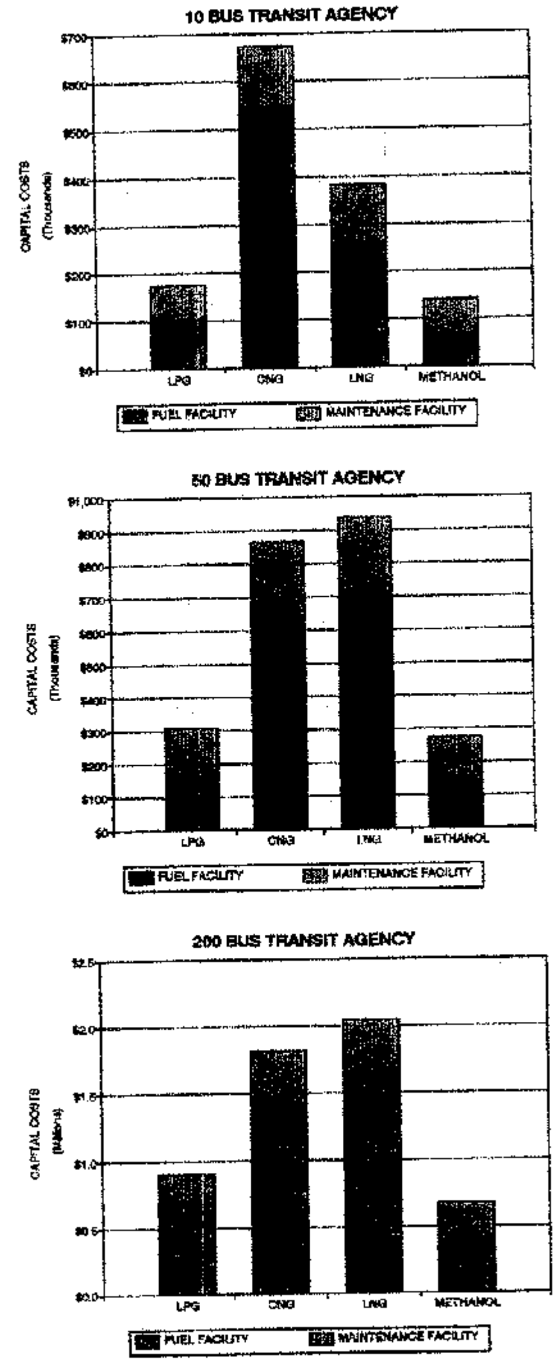
Maintenance Facility Modification Costs

The maintenance garages at transit properties will require some modification to safely accommodate a switch to alternative fuels. Even more so than with refueling station costs, maintenance facility modification costs will be highly dependent on existing facility design, requirements mandated by the local authority (Fire Marshal), and the type of alternative fuel(s) to be used in the maintenance garage. Modifications to the ventilation, heating and electrical/lighting systems may be required depending on the building code specifications which were used in designing and building the original facility. Nevertheless, to help gain a better understanding of maintenance facility modification costs, estimates have been developed by Booz·Allen based on our work with alternative fuels.

A summary of maintenance and fueling facility capital cost estimates is shown in Exhibit 8-1.

EXHIBIT 8-1

Summary of Capital Cost Estimates for Facility Modifications



Annual Fleet Replacement Costs

Capital costs of alternative fuel and particulate trap diesel coaches are higher than those of conventional diesel coaches. Costs result from additional components, the addition of fire suppression systems for alternative fuel coaches, and vehicle and engine engineering costs. Engineering costs per unit are unusually high in the transit industry due to the small number of units that these costs can be spread across. For example, annual sales of transit engines in the United States is about 3,000 units, while the total Class 8 heavy duty truck market is about 125,000 to 150,000 units per year.

Our cost estimates were based on discussions with transit managers and/or prices quoted in the press from transportation agencies ordering alternative fuel buses. Discussions with vehicle and engine manufacturers served to refine our vehicle cost estimates.

Our nominal estimates for vehicle capital costs are listed in Exhibit 8-2.

EXHIBIT 8-2

Annualized Fleet Replacement Costs

	DIESEL	LPG	CNG	LNG	METHANOL	DIESEL W TRAP
COST PER BUS	$210,000	$240,000	$260,000	$250,000	$230,000	$230,000
TOTAL ANNUALIZED COSTS						
10 BUS FLEET	$175,000	$200,000	$216,667	$208,333	$191,667	$191,667
50 BUS FLEET	$875,000	$1,000,000	$1,083,333	$1,041,667	$958,333	$958,333
200 BUS FLEET	$3,500,000	$4,000,000	$4,333,333	$4,166,667	$3,833,333	$3,833,333
INCREMENTAL COST vs DIESEL						
10 BUSES		$25,000	$41,667	$33,333	$16,667	$16,667
50 BUSES		$125,000	$208,333	$166,667	$83,333	$83,333
200 BUSES		$500,000	$833,333	$666,667	$333,333	$333,333
PERCENT INCREASE VS. DIESEL		14%	24%	19%	10%	10%

Fleet Fuel Costs

Fleet fuel costs are a function of unit fuel pricing, transit bus fuel economy, and taxes on fuels. An important point to remember is that diesel fuel prices will be increasing by approximately $0.10 to $0.20 per gallon in 1993 as a result of CARB regulations that will limit sulfur and aromatic content of diesel fuel. The direct fleet fuel cost are calculated in Exhibit 8-3 for the three different sized transit properties included in the study. Assumptions concerning bus fuel economy, price per unit fuel, and taxes on each fuel are also shown. Fuel pricing for each of the alternatives includes transportation costs and reflects prices as delivered to the transit property.

EXHIBIT 8-3

Direct Fleet Fuel Costs

	DIESEL	LPG	CNG	LNG	METHANOL
FUEL ECONOMY(1)	3.5 MPG	1.8 MPG	1.97 MILES/THERM	1.9 MPG	1.35 MPG
BASE PRICE PER UNIT FUEL	$0.75	$0.50	$0.40	$0.45	$0.47
TAXES PER UNIT OF FUEL(2)	$0.060	$0.040	$0.032	$0.036	$0.038
PRICE/ UNIT FUEL incl.tax	$0.81	$0.54	$0.43	$0.49	$0.51
FUEL COST PER MILE	$0.23	$0.30	$0.22	$0.26	$0.38
FLEET FUEL COSTS					
10 BUSES @ 30,000/mi/bus	$69,429	$90,000	$65,787	$76,737	$112,800
50 BUSES @ 40,000/mi/bus	$462,857	$600,000	$438,579	$511,579	$752,000
200 BUSES @ 40,000/mi/bus	$1,851,429	$2,400,000	$1,754,315	$2,046,316	$3,008,000
ADDED COST vs DIESEL					
10 BUSES		$20,571	($3,642)	$7,308	$43,371
50 BUSES		$137,143	($24,278)	$48,722	$289,143
200 BUSES		$548,571	($97,114)	$194,887	$1,156,571
PERCENT INCREASE VS. DIESEL		30%	-5%	11%	62%

1) Methanol fuel consumption is assumed to be 2.6 times that of diesel on a volumetric basis. Fuel consumption for LNG, CNG, and LPG engines assume 80 percent efficiency compared to a diesel engine, and are ciculated based of a comparison of lower heating values of each fuel.
2) Taxes are based of an 8 percent sales tax for all fuels. Transit properties are assumed to be exempt from all other federal and state taxes.

Fuel Facility Operating Costs

Fuel facility operating costs will consist of increased activities associated with equipment maintenance, inventory control and safety related inspections. In general, fuel facility operating costs are relatively minor with the exception of on-site natural gas compression. For CNG refueling facilities, operating costs will consist of:

- Electricity to operate the compressor
- Preventive maintenance and repair of compressors and fueling station components
- Storage tank recertification (if DOT rather than ASME cylinders are used.)

Fuel facility operating costs are summarized in Exhibit 8-4.

EXHIBIT 8-4

Fuel Facility Operating Costs

FLEET SIZE	DIESEL	LPG	CNG	LNG	METHANOL
TOTAL COSTS					
10 BUSES	$3,600	$5,250	$19,700	$8,000	$5,250
50 BUSES	$4,400	$6,300	$53,700	$20,000	$6,300
200 BUSES	$7,200	$9,600	$189,700	$45,000	$9,600
ADDED COST vs DIESEL					
10 BUSES		$1,650	$16,100	$4,400	$1,650
50 BUSES		$1,900	$49,300	$15,600	$1,900
200 BUSES		$2,400	$182,500	$37,800	$2,400

Note: LPG fuel facility operating costs are assumed to be the same as methanol.
See chapter 3, FUELING FACILITIES, for details of operating cost estimates for CNG, LNG, and methanol fuels.

Vehicle Maintenance Costs

The unique maintenance requirements and fuel system designs of alternative fuel vehicles could result in a substantial increase in operating costs at the transit property, particularly during the next few years as engine technologies mature.

There is very little credible comparative data for maintenance costs among various alternative fuel vehicle technologies. Additionally since vehicle and engine designs are changing and improving rapidly, existing field data is not likely to be a good indicator of longer term vehicle maintenance needs. In general however all of the alternative fuel technologies have fuel systems, engine designs and electrical systems that are more complex than a conventional diesel or gasoline engine. The vehicle systems that will be affected by a change to an alternative fuel include the engine, cooling, exhaust, electrical and fuel delivery systems. A general rule of thumb in the transit industry is that powertrain maintenance accounts for about 35 to 40 percent of total bus maintenance. A very rough estimate is that costs associated with powertrain repair and maintenance will increase by 20 to 25 percent over diesel baseline costs. The APTA Financial Statistics directory shows that for transit properties operating primarily 35-foot and 40-foot standard buses, a reasonable average cost for direct vehicle maintenance is $1.00 per mile. Using this baseline maintenance cost for diesel, the increase in maintenance costs for alternative fuel coaches is estimated as follows:

$1/mile (x) 40% powertrain proportion (x) 25% increase = $0.10/mile

Maintenance for particulate trap coaches will exceed baseline diesel maintenance costs but should be somewhat less than the alternative fuel coaches since there is no increase in fuel system complexity and no fire suppression system is required. For relative cost comparison purposes only, the increase in maintenance cost for diesel coaches equipped with a particulate trap is $0.044/mile over diesel baseline.

Miscellaneous Operating Costs

Additional operating cost will be incurred as a result of converting to an alternative fuel. Inspection, servicing, and maintenance of vapor detection, fire suppression, new ventilation and emergency response systems inside the maintenance garage will be required. Safety and vehicle maintenance training costs will likely increase. There will likely be some increase in daily fuel servicing cost due to added time and/or procedures required for refueling the bus.

These cost however are difficult to estimate and will vary substantially among different transit operating environments, as well as between the various fuel alternatives.

Transitional Costs

There will also be additional costs involved in transitioning to a new fuel, in addition to fuel and maintenance facility capital costs. These will include:

- Consulting services associated with determining specific fuel and maintenance facility modification requirements
- Procurement of additional/specialized shop tools that may be needed
- Development of procedural manuals for safety and vehicle maintenance
- Additional "deadheading" costs if off-site refueling is required during the transition
- Maintenance and servicing of two separate refueling stations during the transition period (added personnel, vehicle hostling, fuel procurement complexity, etc.)
- Additional spare parts inventory cost as a result of having to stock parts for two types of fleets.

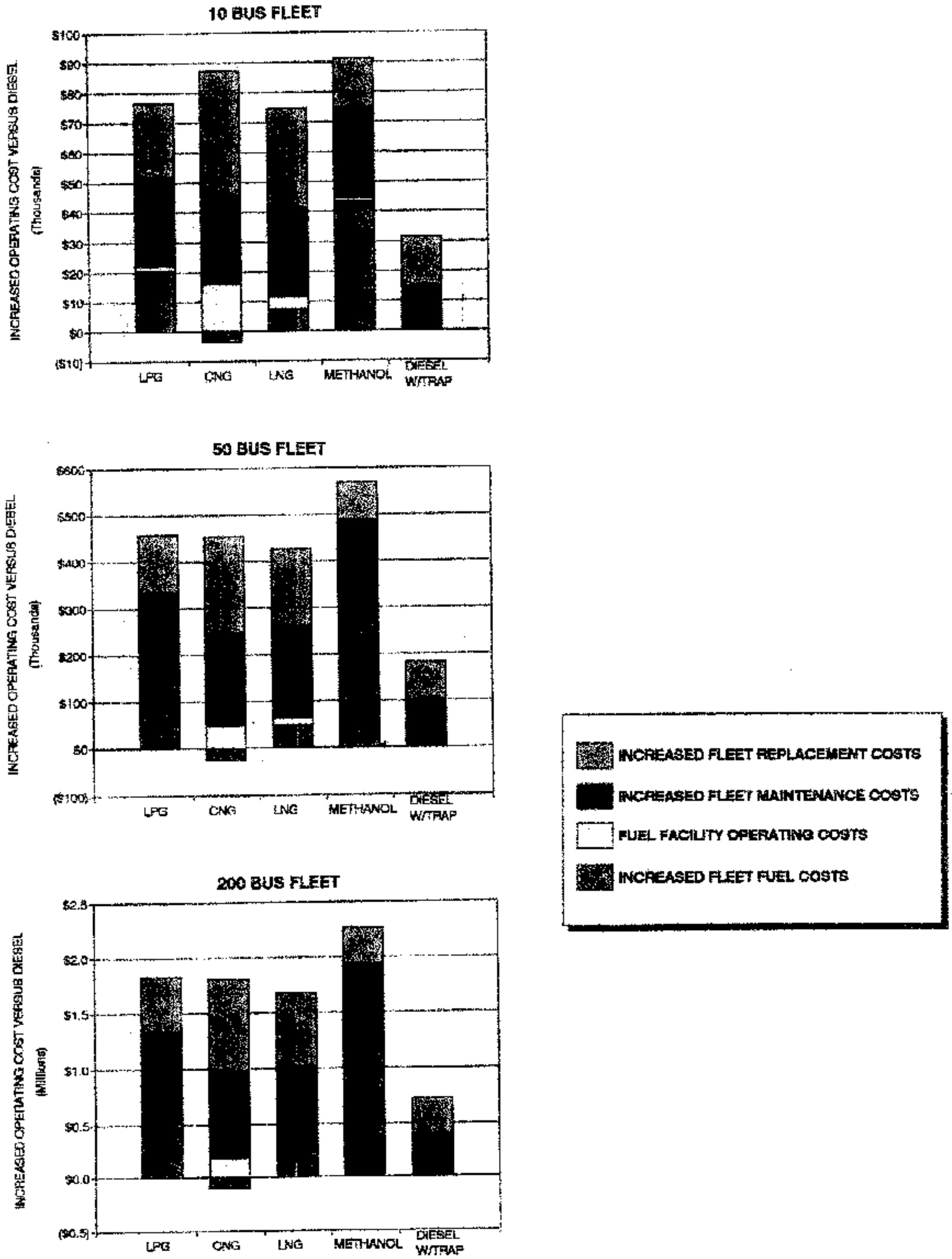
While these costs are difficult to estimate, and will vary among different fleet operators, they are nevertheless substantial. Transit operators with only a single maintenance refueling facility, and which are site constrained in terms of available land for expansion, will be faced with difficult transition and logistical issues. If additional land must be purchased to locate an auxiliary fueling facility then transitional cost could increase dramatically.

Summary—Operating Cost Impacts

The total ***increase*** in operating costs for moving to alternative fuels is and shown graphically in Exhibit 8-5. These costs include fleet replacement and fleet maintenance costs as well as direct fuel and fuel facility operating costs.

EXHIBIT 8-5

Graphic Summary of Incremental Increase in Operating Costs for "Clean Fuel" Alternatives



9.0 IMPLEMENTATION AND TRANSITION ISSUES

In this chapter a variety of issues related to transitions from diesel or gasoline fuel to an alternative fuel are explained. The objective of this section is to highlight potential areas for concern as the transit property moves forward with fleet replacement plans, and to offer suggestions on how the transition may be eased. This discussion is organized as follows:

- Contracting for vehicle purchases
- Fleet replacement strategy
- Staffing and training needs

Contracting for Vehicle Purchases

As the California transit market moves to "clean fuel" vehicles, there exists the potential for increased loss of standardization among vehicle fleets. [If operators select different fuel technologies using different engines and options.] Arguably, fleet standardization has served the transit industry well with regard to limiting vehicle capital costs and reducing maintenance training and cost.

A strategy to help maintain some semblance of standardization, at least on a regional basis, would be for transit properties to jointly procure new vehicles. Such a practice might be particularly beneficial to small transit properties.

Fleet Replacement Strategy

The small-to-medium size transit operator is in a particularly difficult situation regarding the transition to alternative fuels. Larger transit systems that have multiple divisions can convert one division at a time and subsequently redistribute the fleet and route assignments so as to operate only "mono" fuel maintenance divisions. However, a transit operator with only a single division must either convert the entire fleet to alternative fuels all at once (as well as convert refueling facilities), or be forced to operate a dual fuel refueling operation and maintenance division. Several options are available to the transit operator to ease this transition problem:

- Deploy "temporary" alternative fuel refueling facilities. Temporary refueling stations are feasible for all of the alternative fuels. For CNG, small skid-mounted compressor stations are available which may be located on the property site and connected to a low pressure gas feed line. Such systems are generally limited to "slow fill" operations but offer an acceptable means of refilling CNG fleets of up to approximately 10 vehicles. Small turn-key LPG fueling depots are also available for siting on the transit property with a minimum of site preparation or engineering. Temporary LNG refueling depots are also available and are being demonstrated at Houston Metro; Roadway Express in Columbus, Ohio; and Federal Express in New York. The installation of temporary above ground methanol fueling facilities is also possible but NFPA 30 recommends limiting the storage volume to 500 gallons.
- Another alternative for providing temporary refueling capability during a transition period would be to contract out fueling services, or arrange to use/lease, an existing nearby fuel station. For CNG, compression fill stations would likely be available at the local utility and/or through operators of light-duty natural gas fleets that might be operating in the area. Likewise, there currently exist over 40 methanol fueling stations in the state. Such stations could be used by the transit property to refuel a methanol fleet (on a temporary basis), if the location of the methanol station were convenient. The use of public methanol fueling stations, however, is not without problems. Probably the biggest problem is that the fuel at these stations is M85 and therefore not directly compatible with "neat" methanol engines. Also, the use of remote refueling stations (either CNG or methanol) could add considerably to "dead-head" miles, labor costs and operator costs. In the case of a remote, utility operated CNG station, vehicle scheduling and operation could become more tedious and complicated if the facility was rated as a "slow fill" CNG station.

In developing a fleet replacement schedule, transit properties should keep in mind the potential problems that will occur during the transition period. To this extent it may be prudent to accelerate the normal vehicle purchase/retirement schedule so as to minimize the duration of the transitional period.

Staffing and Training Needs

It will be important during the transition process to establish and implement a thorough technical and safety training program. The proper execution of such a program is critical during early phases of the technology conversion effort, so as to clearly establish and demonstrate the changes in daily operating procedures that will be necessary to safely accommodate the new fuel.

Specially-trained personnel will be required to maintain and fuel alternatively fueled vehicles, as well as fulfill general maintenance procedures throughout the facility. Training that should be required of all transit employees includes knowledge of the properties of the fuel and general safety procedures. Training that should be required of mechanics and hostelers includes storage and dispenser equipment familiarity and bus familiarity.

Manufacturers and fuel distributors often include training and technical support for proper use of the products and services they sell to transit operators. Training programs can be customized to meet an operator's needs, and can be conducted on the operator's site, at a regional facility, or at a manufacturer's headquarters.

10.0 CONCLUSIONS AND RECOMMENDATIONS

In this chapter we present a summary of key observations and conclusions developed as a result of our team's work in this area. Our comments are based on numerous interviews with transit properties in California and at alternative fuel demonstration test sites in North America, as well as on our review of a large volume of technical documents and reports. A complete list of alternative fuel transit bus demonstration test sites, number and type of vehicles operated, and a contact at the agency is presented in the technical report.

Key observations and conclusions are as follows:

- Information concerning alterative fuels is changing and being added to at a rapid pace. Engine technology, fuel pricing, regulation, fueling and maintenance facility design issues, and safety requirements are all in a transitional period. Data that is accurate today may be inaccurate or misleading tomorrow. As such, it is ***imperative*** that transit property managers make use of the supplier contacts, bibliography and transit property contacts listed in the Appendices to stay up to date regarding alternative fuel issues as they affect future transit operations.

- The conversion of a transit property to alternative fuels will be expensive in terms of both capital and operating costs. First year capital costs could indeed represent the largest expenditure made by many transit properties for several years. Fleet fuel costs could double, depending on fuel selection, and maintenance costs will also increase. This reality must be recognized by transit managers early in the budgeting process, so that financial planning, cost controls and fleet expansion plans can reflect the economic impact of moving to alternative fuels. An under funded alternative fuels program could jeopardize vehicle reliability and maintenance, public acceptance and support, and possibly even safety and training programs. As with any new technology, it is important to generate enthusiasm, professionalism and support in the program.

- Transit property managers should begin the development of a Strategic Plan for meeting new emission regulations and, if required, moving to alternative fuels. The strategic planning process will help to identify actions necessary to meet the objectives of the transit agency.

  Other benefits will result from the development of a Strategic Plan. Key elements of a Strategic Plan to accommodate alternative fuel transit vehicles will include:

  — Formal development/adaptation of a plan to select a particular alternative fuel (including a delineation of the objectives of the transit agency).

  — Establishment of a vehicle purchase and retirement schedule.

  — Development of vehicle specifications that will mitigate required changes in existing mechanic training, parts inventory and maintenance operations, (i.e., optimize the fit with existing fleet).

  — Provisions for modifying the maintenance facility to accommodate alternative fuels.

  — Refueling logistical plans, including need for temporary fueling stations or off-site/contracted refueling operations.

  — Plans for retrofitting or rebuilding existing engines to meet pending rebuild standards in California.

  — Development of a safety and training program for maintenance personnel, operators and supervising staff.

  — Plan for introducing new fuel technology to bus riders and the community.

  — Development of capital and operating budgets including a sensitivity analysis in the event that maintenance or fuel costs are higher than anticipated.

  While the development of a Strategic Plan has always been a helpful management tool, its usefulness and necessity is even more pronounced given a change to alternative fuel vehicles.

With the move towards alternative fuels there exists the potential for a substantial loss of standardization among vehicle designs, refueling procedures, maintenance training and overall operating procedures. To date such standardization has helped to keep costs down and also reduces the potential for accidents or injury. The transit industry in California must take a proactive position regarding the development of new standards for alternative fuels.

At present, it appears that many safety and training issues pertaining to the use of alternative fuels are in a state of flux and are subject to interpretation by the individual transit operator as well as the local fire marshal. The industry would be well served by the clear identification and adoption of procedures, equipment and facility modifications needed to accommodate alternative fuels. We are already aware of decidedly different approaches being taken by different transit properties regarding modifications of ventilation, electrical and fire protection systems in and around maintenance repair bays. Caltrans is in a good position to assist the transit industry in California with the development of a variety of standards related to the use and handling of alternative fuel vehicles.

Selected Observations Regarding Fuel Alternatives

Methanol. Methanol's primary advantage is that it is a liquid and therefore storage, handling, and vehicle refueling can be accomplished in much the same fashion as diesel fuel. Total fuel storage weight (for equivalent range) is about 1,000 lbs. less than for CNG, thus improving maximum load capacity. With proper sizing of equipment, refueling times are essentially the same as for diesel. Methanol buses also appear to be slightly less expensive than CNG buses — about 5 to 10 percent less on average. Finally, the DDC methanol engine equipped with a catalytic converter has demonstrated extremely low emission levels. Particulate levels similar to CNG engines have been achieved (in the 0.05 g/bhp-hr range for both engines) and NOx levels of 2.5 g/bhp-hr have been achieved.

Methanol's primary disadvantage is likely to be high operating costs (compared to CNG) due to anticipated future methanol fuel prices and characteristic fuel consumption. At $0.45 per gallon for methanol and $0.40 per therm for natural gas, the annual fuel bill for a 200-bus methanol fleet will be about $1 million per year higher than for a similar CNG fleet.

However, for small transit properties, operating vehicles that accumulate relatively low annual mileage, the fuel cost penalty associated with methanol will be minimized. Such properties may select methanol based on relative ease of implementation, comparatively low vehicle weight, and low initial vehicle purchase price versus other alternatives.

Also, the capital costs for establishing a CNG or LNG refueling facility are comparatively high for small properties since the cost cannot be spread over many vehicles. Methanol's low facility conversion costs should make it comparatively attractive for smaller transit properties.

Compressed Natural Gas. The disadvantages of a compressed natural gas bus include slightly higher initial vehicle cost, greater vehicle weight, and higher refueling station costs. However, as noted, natural gas costs are considerably lower than methanol on an equivalent gallon basis and CNG vehicles will thus yield lower operating costs. CNG buses will likely fair well at transit properties where average bus loadings are moderate and are thus able to more readily accommodate the added weight of the CNG storage system. CNG vehicles are also advantaged at transit properties with routes requiring only moderate vehicle range. If a long operating range is not mandated, then fuel storage capacity can be reduced, thus reducing vehicle weight.

Liquefied Natural Gas. The development of production intent LNG vehicular fuel storage and engine technology is just beginning. LNG, however, can offer advantages as a storage medium over CNG — because it is a liquid it can be transferred and stored in a fashion similar to other liquid fuels (although cryogenic tanks must be used for storage). Perhaps more importantly, LNG may offer benefits both in terms of emissions and fuel costs. Because it is a liquid, and therefore almost pure methane, engine calibration should be simplified — and emissions controlled within tighter limits. Finally, because LNG can be purchased from suppliers who purchase the feed stock directly from the wellhead owner (or who own the wellhead themselves), the utility companies can be by-passed. Our preliminary review of spot LNG prices suggest that lower energy costs may be possible compared to compressed natural gas (prices will be highly dependent on location and transportation costs for the LNG). In the long run, LNG vehicles may offer the lowest operating costs of any clean fuel alternatives due to vehicle weight savings and refueling advantages over CNG, as well as competitive fuel pricing.

Liquefied Petroleum Gas. LPG has a number of properties that make it an attractive fuel for transit. LPG straddles the boundary between liquid and gaseous states, and as a result offers the advantages of both. LPG is non-toxic like CNG, and offers similar capability for low emission combustion with a very low rate of deposit formation, giving the potential for very long engine life. Yet LPG's property of liquefying at moderate pressures allows it to be stored and dispensed in a manner similar to the true liquid fuels, avoiding CNG's weight penalty. LPG also has a greater energy density than LNG, and does not have to be cryogenically refrigerated.

In addition, unlike natural gas and methanol, LPG is a well established motor vehicle fuel with an extensive refueling infrastructure in California. Fuel cost with LPG is somewhat higher than that of CNG, and much lower than that of methanol.

Development of LPG as an alternative fuel has been hindered by the motor vehicle manufacturers' view that supplies are inherently limited, so that the fuel could only occupy a very narrow market niche. This assessment is unfounded. Current LPG availability is sufficient for it to become a major fleet fuel. Being a constituent of natural gas, its future availability will increase as natural gas production increases. Also, a substantial increase in LPG demand, relative to that for gasoline, would lead petroleum refiners to alter their processes to increase the yield of LPG.

Because of the tendency of LPG vapor to pond and form combustible fuel/air mixtures if released indoors, LPG is not suitable for indoor fueling. This is not a major hurdle for transportation agencies in California, who largely refuel outdoors.

The greatest impediment to greater use of LPG by transportation agencies is the absence of a certified heavy-duty bus engine. Natural gas engines being developed by Cummins and DDC could be adapted to LPG via simple recalibration of their fuel systems---much less engineering would be needed than was required for adapting diesel engines to methanol and natural gas. However, these manufacturers are unwilling to absorb the engineering and certification costs without greater assurance of a market. This is an instance of the classic "chicken and egg problem" that has hindered the commercialization of alternative fuels. As was the case with methanol and natural gas, cost sharing by the LPG industry and public agencies promoting fuel diversification would greatly help in making LPG bus engines commercially available.

Alternative Fuels and Vehicle Weight. Passenger cars have shown impressive weight reductions and fuel efficiency gains during the last decade. Other forms of passenger transportation, such as aircraft and trains, have become more energy efficient over time. Urban buses are a conspicuous exception. Bus weight has increased substantially in recent years, accompanied by deteriorating fuel efficiency.

Conversion to alternative fuels threatens to cause additional weight gains due to increased tank weight or fuel mass; Heavier buses require more power for undiminished performance. This increases fuel consumption, resulting in greater emission of air pollutants/mile, and increasing operating costs. In addition, hidden costs are imposed by heavier vehicles:

- Peak passenger capacity decreases, which may necessitate increasing fleet size to avoid reduced service levels. This is a potentially large cost.
- Tire wear, brake wear and road wear are accelerated.
- Vehicle safety may be compromised because of higher brake and tire loading, and poorer handling characteristics.

As conversion to alternative fuels proceeds, bus manufacturers and transportation agencies who specify bus designs need to emphasize minimizing bus weight. This can be accomplished through greater use of lightweight, high strength materials, innovative structural design, and avoiding the specification of unnecessary features that increase weight.