Challenges for Integration of Alternative Fuels in the Transit Industry

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The implementation of alternative-fuel, heavy-duty engines is promoted under the Clean Air Act of 1990. The move toward alternative fuels finds impetus from the emission-reducing properties of alternative fuels and the need to reduce dependence on foreign petroleum supplies. The widespread use of alternative fuels faces three major integration challenges: (*a*) the leading alternative fuels have handling requirements that are different from petroleum fuels, and some are hazardous; (*b*) some have low energy densities and, at current prices, are more expensive per diesel fuel-equivalent unit of energy; and (*c*) the United States lacks an adequate ready supply of alternative fuels, as well as a high-volume, nationwide distribution network.

An overview of the physical and handling properties, the health hazards, and some of the supply issues related to the most widely used alternative fuels is provided. Four leading alternative fuels are discussed using experience derived from experimentation in the transit bus industry. Results generated in the transit bus industry have been used to analyze the use of alternative fuels in a "real-time" production environment. The transit bus industry provides the best source of empirical data on fleetwide implementation of alternative transportation fuels technology. Issues that confronted the transit operators and the experiences of some 40 different trials involving more than 200 coaches (in service in early 1991) in the United States and Canada were obtained (*1*).

Differences between properties of alternative and conventional (e.g., gasoline and diesel) fuels, and precautions that should be taken to guard against risks of handling alternative fuels and maintaining alternative-fuel engines, are identified. It is not suggested that alternative fuels present greater risks than conventional fuels, simply different risks.

The paper also counters some misconceptions concerning the hazards of integrating alternative fuels into transit fleets. Clearly, alternative fuels, and for that matter conventional fuels, present significant health and safety challenges. Experience through alternative-fuel vehicle demonstrations indicates that with proper training, facility design, and adequate precautions, alternative fuels can be handled safely by operations, service, and maintenance personnel.

Current Environmental Protection Agency (EPA) tail pipe emissions rules and the Clean Air Act of 1990 (as amended) are pressing transit managers to embrace alternative-fuel engine technology. In many cases, legislation has encouraged the introduction of alternative-fuel buses into transit fleets. The information presented should help transit managers select specific technology and prepare the work force and should help maintenance facilities safely operate alternative-fuel vehicles. The paper is not a complete overview of each technology. A thorough investigation into the costs and benefits is encouraged before implementation of alternative-fuel vehicles.

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CLEAN AIR ACT REQUIREMENTS

The Clean Air Act of 1970, which set forth clean air goals and emission standards for the nation, has been amended several times. Nonetheless, the United States has been unable to reduce ambient air pollution levels as the act requires. Extensions of deadlines for meeting air quality standards were granted repeatedly but expired in 1988. Finally, P.L. 101-549, which amends the 1977 Clean Air Act (P.L. 95-95), was signed into law on November 15, 1990. The most recent law is commonly called the Clean Air Act of 1990.

The new Clean Air Act sets standards for stationary and mobile sources of pollution and establishes incentives for emissions reduction. The sections of the act are as follows: Title I, Ambient Air Quality (smog); Title II, Motor Vehicles; Title III, Air Toxics (hazardous air pollutants); Title IV, Acid Rain (utility power plants); Title V, Permits (stationary or area source); Title VI, Stratospheric Ozone; Title VII, Federal and State Enforcement; Titles VIII-X, Miscellaneous; and Title XI, Job Loss Benefits. A detailed synopsis appears in the *Congressional Quarterly* (*2*) (the act itself is more than 300 pages).

Title II requires EPA to set forth, by January 1, 1992, emissions standards for urban buses for model year 1994 and thereafter. The standards may be based on and reflect industry costs, safety issues, and lead time factors, but they must require compliance with heavy-duty truck emissions standards for the same model year. In 1994, bus emissions of particulate matter (PM) may not exceed 50 percent of the 1994 truck standards. The EPA administrator may require that all buses placed into service in urban areas with populations exceeding 750,000 (1980) that have not met PM standards use alternative fuels. Title II specifies methanol, ethanol, propane, natural gas, or any comparably low-polluting fuel.

Compared with earlier EPA rules, the new act allows a slightly higher level of PM emissions for model year 1991 and 1992: 0.25 grams per brake-horsepower-hour (g/bhp-hr), decreasing to 0.10 g/bhp-hr in 1993 and beyond. The 0.10 level represents an 83 percent reduction in particulate emissions from 1988–1990 standards.

EPA has been charged with implementation and enforcement of the act and will be formulating and proposing amendments and administrative rules through 1991 and beyond. New heavy-duty truck standards, generally for vehicles with gross vehicle weight between 8,500 and 26,000 lb, on which bus standards will be based, are shown in Table 1.

Continuing in effect are EPA rules for transit buses and heavy trucks requiring a reduction in nitrogen oxides (NO_x) from 10.7 g/bhp-hr in 1989 to 5.0 g/bhp-hr in 1991. Trucks have until 1994 to meet the particulate standards, and in 1994 bus and truck standards may converge (*3*).

Standards for hydrocarbon emissions (1.3 g/bhp-hr) and carbon monoxide (15.5 g/bhp-hr) were made effective in 1987 and remain in force. By and large, these standards have been met.

Under authority found in enabling legislation, EPA also regulates vehicle exhaust and evaporative emissions as well as emissions from refueling of tanks and vehicles. National Ambient Air Quality Standards (NAAQS) have been established under EPA's regulatory authority. To reduce ozone concentrations in metropolitan areas, NO_x emissions standards were included in the NAAQS (40 CFR 80 and 40 CFR 86).

The heavy-duty truck fleet will be required to meet a phased-in reduction of hydrocarbon, carbon oxide, and NO_x emissions through 1998, with intermediate standards in 1994.

The new legislation directs the EPA administrator to set standards for carbon oxide emissions at cold temperatures, evaporative emissions, on-board vapor recovery systems, and reformulated and oxygenated fuel use and credits in nonattainment areas. The act sets fuel volatility standards, allowing an exception for gasohol. It also sets a maximum sulfur content for diesel fuel. (Gasohol is 10 percent ethanol and 90 percent unleaded gasoline. Diesel fuel sulfur content by 1993 must have a Cetane index below 40.)

LEADING ALTERNATIVE AND CLEAN-BURNING FUEL CANDIDATES

Current diesel engine technology cannot meet the EPA tail pipe emissions standard. The early deadline for buses has placed pressure on transit industry and equipment manufacturers to seek clean-burning alternative fuels.

It is clear that no single alternative fuel will emerge soon as the favorite, especially in the transit bus industry. Experimentation and engine testing necessarily have led to many candidates. The leading fuels that will meet the 1991 bus emissions standards or the 1994 truck emissions standards include methanol, compressed natural gas (CNG), ethanol, and liquefied petroleum gas (LPG). Reformulated gasoline and "clean diesel" fuel should also be included as possible clean-burning fuels. Although the main ingredient of reformulated fuel is a conventional fuel, reformulated fuels are clearly different from conventional fuels and have many desirable attributes. The feasibility of other alternative fuels, such as solar power, electricity, or hydrogen fuel, has not been demonstrated in the field, and so these fuels were excluded from this analysis.

UMTA has compiled a list of past, present, and likely future applications for capital assistance by transit agencies under its Alternative Fuels Initiative program. Applications since 1988 and "likely" future applications bring the total alternative vehicles under this program to 808 (*4*). Sixty-two percent of the past and expected applications are for CNG-powered buses, 13 percent are for LPG-powered buses, 13 percent are for ethanol-powered buses, and 5 percent for methanol-powered buses. The remaining applications included other technologies, particulate traps, and liquefied natural gas, or were undecided.

Methanol

Methanol, an alcohol fuel, is also known as methyl alcohol, wood alcohol, or carbinol. An oxygenated hydrocarbon, its molecular formula is CH_3OH. It is a clear, colorless liquid with a characteristic odor. It is derived from natural gas processing, gasification of coal, or wood-based refuse and other biomass sources. The conversion of coal and biomass to methanol is roughly twice as expensive as conversion from natural gas. Therefore, commercially available methanol is almost entirely derived from natural gas. The methanol-fueled heavy-duty engine is the only technology that has demonstrated its ability to meet the 1991 transit emission standards for both particulates and NO_x (*3*).

CNG

CNG is a clean-burning gaseous fuel that can significantly reduce hydrocarbon, NO_x, and carbon monoxide emissions from diesel levels. The gas is highly compressed when used as a fuel, to between 2,400 and 3,000 psi, to increase the available energy. This accounts for the necessity of strong, heavy (thickness of 0.25 to 0.5 in.) on-board steel or aluminum tanks.

CNG engines can meet the 1991 particulate emission standards. In fact, according to American Gas Association tests, CNG engines emit no PM. It is, however, proving difficult for CNG engines to meet the NO_x emission standards. CNG engines eliminate evaporative reactive hydrocarbons, and in three of four studies, current CNG technology exceeds EPA standards for exhaust reactive hydrocarbons. There appears

TABLE 1 HEAVY TRUCK EMISSION STANDARDS (BUSES MAY NOT EXCEED 50 PERCENT OF THESE LEVELS)

Hydrocarbons	0.39 g/mi	(1994-95: 0.49 g/mi)
Carbon Oxides	5 g/mi	(1994-95: 6.2 g/mi)
Nitrogen Oxides	1.1 g/mi	(1994-95: 1.38 g/mi)
Nitrogen Oxides	4 g/bhp-hr.	(1998)

Note: 50% of trucks must comply by model year 1996, rising to 100% thereafter.

to be general agreement that hydrocarbons from exhaust will be well below EPA levels with advanced technology CNG engines now in development. Carbon monoxide emissions from CNG engines are more than 50 percent below those of gasoline engines (*5*).

Ethanol

Ethanol, an alcohol fuel, is also known as ethyl alcohol, grain alcohol, or just alcohol. An oxygenated hydrocarbon, its molecular formula is C_2H_5OH. It is water clear and has a neutral odor. Appearance and odor could be modified by adding nonhazardous components. Ethanol is produced through the fermentation of simple sugars or through other chemical and catalytic reactions. Most fuel ethanol in current use is fermentation ethanol, produced as a by-product of corn or wheat milling processes (*6*).

Ethanol engines produce only half the carbon monoxide of gasoline, significantly reduce PM, and emit no harmful hydrocarbons. There is contradictory evidence in emissions studies. One recent EPA study found an increase in hydrocarbon and NO_x emissions as a result of increased ethanol use (*7*).

Most ethanol used in fuel is in gasohol, which is sold in 42 states and accounts for about 9 percent of the total gasoline market (*8*). Though performance reports on gasohol use in automobiles are mixed, it is clear that with proper engine design and adjustment, ethanol blends, as well as neat ethanol, are appropriate, clean-burning fuels. Ethanol prices and supplies depend on the grain market and to a certain extent on the location of the wholesale and retail outlet. Nearly 1 billion gal of ethanol is used with gasoline in gasohol blends each year (*9*).

LPG

LPG is a gaseous fuel that may include propane gas, butane gas, or a mixture of the two. LPGs can be extracted from oil fields or derived as by-products of the petroleum refining process, specifically in refining and cleaning up natural gas. LPG is gaseous under normal atmospheric conditions, but it may become a liquid when compressed or refrigerated. It is then reconverted to a vapor for burning in the engine.

LPG has been used as an internal combustion fuel since the mid-1920s. National standards for containers and pertinent equipment were first published in 1940 and have been continuously updated (*10*).

Reformulated Fuels

Fuel reformulation may include altering the composition of gasoline or diesel fuel to reduce sulfur and particulate content. There is significant potential for "clean" diesel fuel and for expanding the scope and performance of fuel mixtures, such as gasohol and M85. These alternatives are under study by petroleum companies and engine manufacturers. One large oil company predicts that clean diesel fuel will be readily available in time to meet the 1994 tail pipe standards for heavy trucks (A. Krodel, unpublished data, 1990).

Ethanol also has a role to play in the composition of reformulated gasoline. Octane levels in any reformulated gasoline must be kept high. Octane is a measure of the fuel's resistance to premature ignition, which causes spark-ignited engines to knock. Oil companies typically add oxygenates to fuels to raise octane levels. They are currently unable to meet Clean Air Act standards while keeping fuel octane ratings high using 100 percent petroleum-based ingredients. They can use a non-petroleum-based oxygenate in the form of ethanol, or ethyl tertiary butyl ether (ETBE). The other common oxygenate is methyl tertiary butyl ether (MTBE), a petrochemical made from methanol (*8*).

HANDLING PROPERTIES, HAZARDS, AND AVAILABILITY OF ALTERNATIVE FUELS

The handling characteristics of alternative fuels differ significantly from those of diesel fuel or gasoline, which is a major obstacle to their implementation. Clearly, conventional fuels have presented many safety problems, but they have been overcome in the last 130 years of petroleum experience. The automotive and petroleum industries developed appropriate infrastructure and safety precautions to deal with the dangers of conventional fuels (*11*). The leading alternative fuels, on the other hand, present different and challenging risks. Many of the differences in the handling properties of alternative fuels are due to their chemistry and physical properties.

Because gasoline and diesel fuel are molecular mixtures, their specific physical properties vary. For example, the boiling temperature of gasoline ranges from 80°F to 437°F. For diesel fuel the range is 370°F to 700°F. Diesel fuel contains approximately 18,000 Btu/lb and 130,000 Btu/gal, whereas gasoline contains about 18,000 Btu/lb and 115,000 Btu/gal (gasoline is less dense and, therefore, has fewer Btu per gallon than diesel fuel) (A. Krodel, unpublished data, 1990). Ethanol and methanol, on the other hand, are pure chemicals with fixed physical properties. The differences in chemistry and physical properties account for the different risks associated with transferring, dispensing, and handling alternative fuels.

Alternative fuel users also face the problem of supply. Availability largely depends on the manufacturing and distribution systems for fuels. Most transit systems do not depend on public commercial fueling sites, because they maintain their own refueling facilities. Use of even the leading alternative fuels is not widespread in fleet operations, so fuel supplies and vendors are, to varying degrees, limited.

Conventional fuels are available throughout the United States through a widespread system of pipelines, terminals, and delivery vehicles. The existing petroleum fuel distribution system delivers 110 billion gal of gasoline and 20 billion gal of diesel fuel for motor vehicle operation in the United States each year (A. Krodel, unpublished data, 1990). The conventional fuel distribution system does not lend itself to the distribution of alternative fuels. Alcohol fuels are corrosive and mix with water. Gaseous alternative fuels are not compatible with the existing liquid fuel distribution system. In addition, limited amounts of alternative fuels are available.

The following subsections discuss the handling properties, hazards, and availability for each of the leading alternative fuels. Each of the alternative fuels requires enhanced ventilation of maintenance workplaces compared with conventional fuels. The type and location of ventilation necessary varies with the fuel (some fuels produce vapors that settle in low places, whereas others are lighter than air). The last subsection deals with training requirements for mechanics and vehicle operators so that they can deal with the hazards and improve handling safety.

Methanol

Handling Properties and Hazards

Methanol is considered a fire hazard when exposed to sparks, heat, or flames. Ignition sources for methanol include sparks from shop equipment and even sparks from static electricity. Methanol vapor has a density 1.1 times that of air, so it settles in low-lying areas, such as maintenance pits. Work areas should be appropriately ventilated with mechanical systems to avoid concentrations of methanol fumes. At the same time, methanol is much less likely than gasoline to ignite in open air. In well-ventilated or open-air areas, the low volatility of methanol makes fires less likely (P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

The flash point of a flammable liquid is the lowest temperature at which sufficient vapors may form above a pool of that liquid to permit its ignition. The flash point of methanol is 52°F. Therefore, the flammability of outdoor methanol spills changes with the seasons; flammability is not a problem on cold winter days.

A pure methanol fire has low flame luminosity, making it difficult (at night) or impossible (in daylight) to see or even to estimate the size of the fire. This led to the development of the M85 blend. With M85, the flame is visible in broad daylight.

Disposable work rags and methanol-contaminated absorptive material may present a fire hazard and are regulated wastes. Unless laboratory test results indicate otherwise, they should be assumed to be hazardous (Resource Conservation and Recovery Act, 40 CFR 261.31 and 261.32). They must be stored in EPA-approved fire-resistant covered containers until transport, using the EPA Uniform Hazardous Waste Manifest, to an EPA-permitted disposal facility [29 CFR 1926.252(e)]. Reusable cloth rags sent to commercial laundries are apparently "unregulated," although transit operators should carefully consider the liability and ethical issues associated with laundering these rags (Iowa Waste Reduction Center, University of Northern Iowa, 1991).

A prime fire hazard of methanol-fueled vehicles may be ruptured fuel tanks resulting from vehicle collisions. To date, two such collisions and spills have been reported; neither caught fire. Methanol vehicle operators may want to consider carrying an on-board supply of vermiculite or other absorptive material, as well as an on-board fire extinguisher.

Methanol is considered to be a moderate explosion hazard. A mixture of methanol fuel vapor and air will auto-ignite at 725°F. Liquid methanol ignites if exposed to hot surfaces, such as hot engine exhaust manifolds and components exceeding 430°F (*12*).

Methanol storage and dispensing facilities present unique but not insurmountable challenges. Methanol is incompatible with and may react vigorously with strong oxidizing agents, such as nitrates, perchlorates, and sulfuric acid. In a maintenance facility, common oxidizing agents include battery acid in automotive batteries and (zinc) chromate primers. Chromium (chromate) plating baths, lawn fertilizers (nitrates), and common powdered lime are other examples of incompatible oxidizing materials. Therefore, methanol must be stored and dispensed in separate facilities.

Fiberglass, glass-lined, or stainless steel vessels, piping, and fittings must be used for methanol. Methanol is a solvent, and it may attack and corrode plastic, rubber, and coatings found in traditional fuel storage and dispensing equipment. It may react with or corrode aluminum metals, such as steel-aluminum fuel nozzles, generating hydrogen gas. Methanol may attack terneplate linings of fuel tanks, aluminum or zinc fuel pump and carburetor castings, and fuel line and fuel pump elastomers (*13*).

The threat of explosion and fire in fuel tanks is more significant for methanol than other fuels. Fuel tank explosion of methanol vapor-air mixtures is possible with air temperatures between 45°F and 110°F. In a "closed-air" environment, gasoline vapors are considered too rich to burn, and diesel fuel vapors are considered too lean to burn. The methanol fuel-air mixture in closed-air tanks is within its ignition limits. To explode, the mixture must first be exposed to an ignition source. Methanol in a closed tank should be considered an explosion hazard (*12*).

Storage tanks often include floating covers, or tanks with inert atmospheres that address the problem of surface accumulation of vapors. Both on-board fuel tanks and stationary fuel storage tanks may accumulate excess vapors, necessitating vapor recovery and return systems for all fuel transfers (*14*; P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

Methanol delivery systems that include a submersible pump are not appropriate because the pump becomes an ignition source. Therefore, facility space should be allocated for a traditional stand-alone pumping system (P. G. Saklas, unpublished data, 1989).

Vapors from methanol are toxic. A person who can smell methanol has probably been exposed to an unhealthy level. A brief whiff, however, is not considered harmful. The maximum airborne limit for methanol vapor, set forth by the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA), is 200 ppm.

Methanol is a defatting agent. As such, exposed skin may become cracked and dry. Absorption may occur through the skin. Symptoms are similar to those of inhalation. The fuel is especially harmful to the mucous membranes. Methanol is a severe eye irritant, and continued exposure may cause eye lesions. In cases of dermal contact through the clothing, contaminated clothing should be removed immediately and the skin should be washed with soap and flushed with water for 15 min. Methanol is readily absorbed into the skin at a rate of about 0.2 $mg/cm^2/min$. Immersion of one's hand in methanol for 4 hr would permit sufficient absorption to cause death (P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

Clinical research to date has provided little information on methanol toxicity resulting from chronic, low-level outdoor exposure or exposure in well-ventilated areas (*13*). There are some standards set for chronic exposure. The American Council of Governmental Industrial Hygienists (ACGIH) in 1985 and the National Institute for Occupational Safety and Health (NIOSH) in 1976 established ambient air concentration threshold values for methanol vapor. The ACGIH threshold limit value (TLV) is 260 mg/m^3 time-weighted average (TWA) over 8 hr. Its 15-min TLV is 310 mg/m^3. NIOSH recommends a TWA standard of 260 mg/m^3 and a 15-min ceiling of 800 ppm.

The research on acute exposure to methanol is more complete. Toxicity from larger doses of methanol taken over a short time follows a well-known pattern. Symptoms include nausea, headaches, blurred vision, and an initial mild depression of the central nervous system. An asymptomatic period of several hours to several days usually follows. The latent period then gives way to physical symptoms, including metabolic acidosis and visual impairment or blindness. In severe cases, coma and death may follow (*15*).

Methanol is toxic if ingested or accidentally swallowed. Small amounts can intoxicate and cause blindness. The usual fatal dose is 3 to 4 teaspoonfuls. Methanol poisoning is treatable with prompt medical attention.

Long-term low-level exposure to methanol is not considered to pose chronic health problems. Methanol occurs naturally in the body at a level of about 0.5 mg/kg of body weight. It is also present in a daily diet of fruits, vegetables, alcoholic beverages, and aspartame, the diet soft drink sweetener (P. Machiele, paper presented to American Institute of Chemical Engineers, 1989).

Shop areas and refueling stations must have eye wash facilities and safety showers (*14*). It may be necessary to have a rest room or dressing room for workers handling methanol to ensure that contaminated clothing does not go home with the crew. Costs for installation of an eye wash and emergency shower (excluding drain facilities) have been estimated at $1,500 (*16*).

Spilled or leaking methanol may not be flushed to the public water treatment facility because of the potential for fire and explosion in the sewer lines and its structurally corrosive nature [40 CFR 403.5(b)]. Specially designed dedicated floor drains are advised for methanol shop and refueling areas. Traditional oil separators cannot be used, because methanol is miscible with water. Even mixtures of one part methanol to five parts water are flammable (*12*).

A by-product of methanol combustion is formaldehyde, which can cause a burning sensation in the eyes, nose, and throat. The highest concentrations of formaldehyde in methanol exhaust have been found during the first 8 min after start-up of a vehicle. This occurs because the catalyst is neither warmed up nor fully effective. It is, therefore, essential to cold-start methanol engines outdoors or in mechanically well-ventilated areas (*13*). There are currently no EPA standards for formaldehyde exposure (*17*).

Although methanol presents severe health hazards, when handled appropriately, it does not represent a significant safety threat. In 4 years of experience with methanol-powered buses purchased through UMTA's Methanol Bus Demonstration Program, no incidents have been reported in which transit workers were harmed (*18*).

Availability

Methanol has about 57,000 Btu/gal, or 43 percent of the energy content of diesel fuel. In January 1990 wholesale methanol fuel at Gulf Coast markets in the United States sold at between 36 and 38 cents per gallon (*19*). The price has decreased since 1988, when the cost ranged from 55 to 60 cents per gallon. Research indicates that at 55 cents per gallon, the methanol-equivalent of the energy in a gallon of diesel fuel would cost $1.22 (*20*).

Currently the annual world supply of methanol is roughly 7 billion gal (A. Krodel, unpublished data, 1990). The feedstock used to produce methanol is natural gas. Although the conversion process results in an energy-dense liquid, the process is only about 60 percent efficient (40 percent of the energy is lost during the conversion). Methanol can be produced from coal gasification and biomass, but their conversion to methanol is approximately twice as costly as the conversion of natural gas.

The manufacture of methanol could be increased, but there is no incentive to measurably expand supplies. Because methanol has less than half the energy density of conventional fuels, twice as many gallons of methanol would have to be produced as the amount of petroleum replaced.

Distribution and delivery systems for methanol present two challenges: methanol is corrosive and requires special storage and delivery equipment, such as dedicated tank trucks; and its toxicity requires special precautions and training for users and for those who service methanol vehicles.

CNG

Handling Properties and Hazards

Natural gas has been used as a vehicle fuel in the United States since the late 1960s. According to the Natural Gas Vehicle Coalition, there are currently between 250 and 300 CNG refueling sites across the nation, with about two dozen open to the public. Most refueling stations are open only to utility companies or private fleets.

Because of residential and industrial use of natural gas, it has its own distribution systems and supply network. The supply and distribution system of natural gas is superior to that of the other leading alternative fuels. Mechanics and operators are accustomed to its physical properties and risks. The most significant drawbacks of natural gas are (*a*) its low boiling point and (*b*) the requirement that to generate enough energy per volume of storage, it must be highly compressed (2,000 to 3,500 psi). Compression requires a great deal of gas, powerful, high-voltage compressors, and bulky vehicle tanks.

CNG ignites at temperatures between 1,200°F and 1,300°F, about twice as high as gasoline, so it is more difficult to ignite than gasoline. The higher heat at ignition presents problems in dissipating heat from CNG-powered heavy-duty engines. Natural gas will ignite only in a limited gas-to-oxygen mixture range of 5 to 15 percent (*21*). Because there is a moderate explosion risk with CNG, care should be taken to isolate and eliminate potential ignition sources. Natural gas is lighter than air, and any leaks disperse upward. This makes proper ceiling ventilation essential in vehicle maintenance shops.

According to National Fire Protection Association standards, gas compressors, dispensing equipment, and storage containers may be located inside or outside buildings. Most refueling activities are performed outdoors to prevent fire or explosion. It is unclear whether insurance underwriters, fire officials, and building code departments will allow indoor fueling of CNG equipment. A building separate from other activities (e.g., maintenance) should be used for indoor refueling facilities. In addition, specially constructed blowout wall panels are recommended for relief in the event of an explosion. Fire protection systems must be installed with densities and flow rates adequate for high-hazard uses (internal memorandum, New Jersey Transit Bus Operations, April 20, 1989).

The CNG facility must have an independent mechanical ventilation system, gas detection system, and explosion venting system. For fast-fill, high-horsepower compressors, the noise level is significant. Soundproofing, as well as high-voltage electrical service, are, therefore, necessary. In some locations, significant improvements by utility companies may be necessary to increase underground gas pipeline capacity (*22*).

Availability

The retail price for natural gas varies by location, from about 41 cents to 70 cents per therm. One therm is equal to 100,000 Btu, or roughly three-fourths the energy content of 1 gal of diesel fuel (*13*).

Natural gas is in plentiful supply, and most urban areas already have a distribution network. The primary drawback is that it occupies 1,000 times the volume of its energy equivalent in gasoline, thus creating the need for compressing natural gas in heavy tanks. On the average, the tanks plus the fuel in a CNG-fueled vehicle account for 36 percent of vehicle weight, compared with 11 percent for the average gasoline-fueled vehicle (*23*).

It is estimated that there are 30,000 to 40,000 CNG vehicles on the road today in the United States and some 700,000 worldwide (*24*). Most CNG vehicles in the United States are members of fleets. This is partially because of the expensive compressors, CNG storage tanks, and high-capacity gas supply lines required with fast-fill systems and the lengthy refueling with less expensive slow-fill systems. Fast-fill systems can refill roughly as quickly as for a refill of diesel fuel. Slow-fill systems are usually designed to refill vehicles when they are not being used (e.g., overnight).

Ethanol

Handling Properties and Hazards

Much like the other fuels, ethanol presents a fire hazard if handled improperly. The explosion hazard of ethanol when exposed to flames is rated moderate. Although ethanol is less volatile than gasoline, it is considered to be more explosive. Like methanol, vapors that form above a pool of ethanol are potentially explosive. Therefore, it must be stored in specially vented containers (*6*).

Repeated overexposure to ethanol will cause redness and irritation of the skin. Ethanol is not considered to be hazardous to the skin, but it is considered an eye hazard. Inhalation of small amounts of ethanol vapors is not considered to be toxic.

Excessive ingestion of ethanol is dangerous and requires gastric lavage, followed by saline catharsis and medical care. As an intoxicating beverage, ethanol presents a special supervisory challenge. Supplies of ethanol must be carefully monitored, and great care should be taken to determine that employees are not intoxicated on the job.

Small amounts of ethanol spills or leaks may be flushed with water. Large amounts should be contained and collected for incineration.

Availability

Grain-producing states from Indiana to western Nebraska have ample supplies of ethanol fuel. The supply and distribution channels in the New England, Southern, and Far West states are considered moderate.

Ethanol is produced from the distillation of grain products. The most commonly used grains are wheat, corn, and milo (grain sorghum). Alcohol is not manufactured or distilled directly from grain. Rather, there are at least two important extractive products that are manufactured before the distillation of alcohol.

First, the grain is milled and the protein is extracted. In the case of wheat, this produces vital wheat gluten, a high-protein food additive. This product is then sold, and the wheat starch remains. The starch is processed, the premium wheat starch is sold for human consumption, and other starch is sold for industrial purposes. The processing "leftovers" are then sent to a distillery, where alcohol is produced.

Once the alcohol is produced, it is refined. The purest grade is known as grain neutral spirits. This is the product used in the beverage industry and for chemical ethyl alcohol. The fuel-ethanol grade is just slightly lower in purity.

Companies selling both beverage-grade premium ethanol and fuel ethanol may use the fuel-ethanol market as an inventory-clearing tool. In this way, ethanol inventories can be controlled without dumping large quantities onto the higher-priced beverage alcohol markets, thereby risking a supply-sensitive price decline (interview with H. Hinton, May 7, 1990).

Ethanol has only about 76,000 Btu/gal, or 58 percent of the Btu energy per gallon of diesel fuel. In May 1990 fuel ethanol (200 proof) prices to retailers were $1.24 to $1.25 per gallon, FOB terminal, in the Omaha area. Wholesalers paid $1.13 to $1.14 per gallon, FOB terminal, for ethanol directly from an Atchison, Kansas, plant (price quotes from Midwest Grain Products).

The price of ethanol varies significantly on the basis of geographical region and subsidy levels. The wholesale price of 200-proof ethanol in January 1990 was between $1.10 and $1.36 per gallon (*25*). Ethanol has sold for as much as $3 per gallon (*13*).

Almost 1 billion gal of ethanol is currently used as motor fuel and in reformulated fuel (gasohol). Ethanol has slightly more than half the energy density of conventional fuels (i.e., gasoline and diesel fuel). Thus, to replace conventional fuels would require slightly less than twice the volume of ethanol. Producing substantially more ethanol will tremendously tax the agricultural sector. For example, it is estimated that to double United States ethanol fuel production (to roughly 1.82

billion gal) would require an additional 715 million bushels of corn annually (*26*). In 1985 the entire corn crop of Iowa, which produces more corn than any other state, was only 1,707 million bushels (*27*). Ethanol production cannot be directly related to corn production, because ethanol is only one of the products from grain processing, and additional grain by-products would be used to produce other goods. This indicates that the use of ethanol as a motor fuel for any significant share of the demand for transportation energy would overwhelm the agricultural sector.

LPG

Handling Properties and Hazards

Heavy fuel tanks are required to contain this moderately compressed gas. LPG fuel systems are pressurized to about 250 psi, often 175 psi. Many fuel tanks, however, are built with ¼-in. steel, to a 1,000-psi specification. This makes them much more capable of withstanding a collision than typical gasoline or diesel tanks.

There is also a combustion hazard with the use of LPG, which can be minimized by eliminating ignition sources and performing refueling and maintenance activities outdoors where possible. Direct heat applied to storage or vehicle fuel tanks is dangerous, because temperature changes may cause pressure changes inside the tanks, with a potential for explosion.

Many organizations that handle propane use portable explosion meters that detect unacceptable levels of ambient propane. Many fire departments have not invested in explosion meters. It is recommended that fleet operators making extensive use of propane fuel purchase their own meters.

In gaseous form, propane is heavier than air, so it tends to settle in trenches or maintenance pits, exacerbating the explosion hazard there.

For safety reasons, most propane tanks are designed to be filled to about 85 percent of capacity. As long as the sealed pumping system operates without leaks, the risk of explosion is low.

Propane boils at $-44°F$. There is a burn risk when opening valves to bleed off excess propane remaining in the line after refueling or fuel transfer. The amount remaining in the line is typically about 1 tablespoon. Heavy insulated neoprene gloves should be required for persons engaged in fuel transfer activities.

Small amounts of propane leaking into the air disperse. It is recommended that all maintenance areas be well ventilated. Propane is not known to be toxic.

Technical regulations and recommendations for the safe use of LPG have been well developed over time. A discussion of standards for containers, installations, valves, cylinders, vaporizers, piping, and other items may be found elsewhere (*28*).

Availability

The principal vehicle fuel application of LPG is propane gas. Propane sells for 30 to 40 cents per gallon at the wholesale level and 40 to 50 cents per gallon retail. Many prices are quoted at Conway, Texas. For terminal delivery, another 4 cents per gallon should be added for pipeline and truck transport cost (interview with Campbell Oil Co., 1990). The typical 91,000-Btu/gal propane offers between 71 and 83 percent of the energy content of diesel fuel.

LPG is a by-product of petroleum refining. Although LPG has desirable properties for reducing vehicle emissions, its use does not reduce the dependence of transportation on petroleum-based fuels.

There are approximately 330,000 LPG-fueled vehicles in the United States and more than 2.5 million worldwide (*29*). The LPG transportation fuel market in the United States could grow to 2.85 million to 3.6 million vehicles by 2004 (*29*). Because it is a by-product of petroleum production, increases in production of LPG are governed by the refining of other petroleum products. LPG can be easily transferred to vehicles at rates rivaling the refueling of conventionally fueled vehicles, at 12 to 15 gal/min.

Workplace Training Programs

Effective training programs are essential to the success of an alternative-fuel program. Training should encompass all aspects of any alternative fuel in use, including a general description of the fuel, examples of its uses both in engine applications and elsewhere, and its toxicity and hazards. Relating case studies on toxic ingestion, skin absorption, fire hazards, and explosion risks may be helpful.

Training in hazardous materials or wastes should be conducted pursuant to the 1983 OSHA Hazard Communication Rule, also known as the "Right To Know" law, as amended (29 CFR 1926.59). Many states have similar rules. The law requires the development and maintenance of a written hazard communication program in workplaces. Steps to be taken include developing a list of hazardous substances, placing proper labels on containers, keeping Material Safety Data Sheets for employee use, and establishing training programs for protective measures. Specific protective eye wear, head gear, and respiratory protection devices are outlined (29 CFR 1926.100 through 1926.103).

Alternative-fuel pumping devices take longer to fill the vehicle's tank than gasoline or diesel fuel. For gaseous fuels, fast-fill equipment may reduce fueling time. Refueling takes longer for methanol and ethanol because they have less energy content per unit volume than diesel fuel. With additional safety and fuel security devices in operation at the time of fueling, crews should expect a different pace of work.

Some transit authorities, such as the New York City Transit Authority, issue certificates of fitness to employees trained in and authorized to handle alternative fuels. Certificates are earned through successful completion of a practical training program. This ensures an emphasis on learning and safety awareness on the job.

Other specialized training that should be considered for maintenance, refueling attendants, and drivers includes fire-fighting techniques, use of protective clothing and equipment, and fuel inventory practices.

CONCLUSIONS

Each of the leading alternative fuels has significant impediments to widespread implementation. Because of supply, handling, and distribution problems and costs, alternative fuels are likely to be integrated in and have their greatest impact on transit fleets and other self-fueling fleets. Many of the anticipated drawbacks, especially health hazards, have not been a significant impediment to use by fleet operators. Experiments to date, however, are probably not indicative of ordinary use. They suggest that, given the correct precautions and worker training, it is possible to overcome the challenges to fleet integration and work safely with different and hazardous fuels such as methanol in the transit industry.

ACKNOWLEDGMENT

The research reported in this paper was supported through a grant to Iowa State University from the University Research and Training Program, Urban Mass Transportation Administration. The authors are grateful for the opportunity to conduct research through the University Research and Training Program.

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Publication of this paper sponsored by Committee on Transit Bus Maintenance.