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Safety Assessment of DME Fuel

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M. Paas Consulting Ltd.
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This report reflects the views of the author and not necessarily those of the Transportation Development Centre.

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16. Abstract

The report provides a general assessment of the use of dimethyl ether (DME) as a transportation fuel for compression ignition engines. The goal was to determine issues that might impede the use of DME in this application and to identify equipment and standards requirements for the vehicle fuel system and for dispensing of DME or mixtures of DME and propane into the vehicle. Fuel, vehicle fuel system, and dispensing issues that will require further analysis were also identified.

It was concluded that the safety concerns are similar to those for other liquefied gases that are heavier than air and flammable. DME is benign, has low toxicity, and is non-carcinogenic. Emission testing has shown substantial reductions in particulate and NOx emissions.

The DME vehicle fuel system operates at much higher pressures than found in propane fuel systems. These higher pressures have created leaking problems due to the low viscosity of DME. Lubricity also appears to be an issue leading to premature wear of components. DME dispensing will be very similar to propane dispensing. There are no standards covering the design or installation of vehicle or dispensing equipment using DME. One of the biggest concerns is that DME attacks most of the common elastomers and many of the parts in both the vehicle and dispensing system rely on elastomers for seals and seats. It is felt that these technical problems are not insurmountable.

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16. Résumé

Analyse générale de l'utilisation du diméthyléther (DME) comme carburant de substitution pour les moteurs à allumage par compression dans les véhicules de transport. Le but visé était de déterminer les obstacles à cette utilisation, les équipements nécessaires et les besoins en normalisation concernant les circuits d'alimentation et les pompes de distribution en DME pur ou mélangé avec du propane. Les aspects nécessitant de plus amples recherches ont également été identifiés.

La recherche montre que, du point de vue de la sécurité, l'utilisation du DME soulève les mêmes questions que pour tout autre gaz inflammable et plus lourd que l'air. Le DME s'est révélé sans danger, faiblement toxique et non carcinogène. Du point de vue des émissions polluantes, il produit beaucoup moins d'imbrûlés et de NO_x.

La pression d'alimentation beaucoup plus élevée que pour le propane et la faible viscosité du DME augmentent les risques de fuite. Son pouvoir lubrifiant médiocre entraîne l'usure précoce des composants du moteur. Du point de vue de la distribution, le DME se présente à peu près comme le propane. Il n'existe pas de norme applicable à la conception de moteurs au DME, à son installation dans un véhicule ou aux pompes de distribution. Un obstacle majeur vient du pouvoir du DME d'attaquer la plupart des élastomères connus dont sont faits les joints d'étanchéité dans le circuit d'alimentation et les pompes de distribution en DME. Mais, estime-t-on, des solutions techniques sauront être trouvées à tous ces problèmes.

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Executive Summary

The Canadian federal government has initiated studies and research into the use of dimethyl ether (DME) as an alternative to diesel fuel in compression ignition engines. These efforts are the result of concerns regarding the capability of diesel fuel in meeting future emission regulations. At issue are the particulate and NOx engine emissions. DME is being viewed as a potential solution.

Natural Resources Canada are supporting research into DME fuel system and engine development work. Transport Canada, Transportation Development Centre, Safety and Security are complementing the engine development work with this report into the safety, health, and environmental aspects of DME to determine issues with the use of the fuel, the vehicle fuel system and the dispensing system.

Extensive interviews with producers and suppliers of DME, engine and fuel system research organizations, government officials, standards writing organizations, equipment manufacturers, and oil companies provided information regarding DME and some of the issues that might be encountered. A literature search also yielded valuable data regarding previous studies into the health and environmental aspects of DME as well as current research into engine and fuel system development.

The analysis of the safety, health, and environmental aspects of DME confirmed its clean air emissions qualities. The reports indicate that DME offers reductions in particulates and NOx emissions. Particulates are virtually eliminated. Extensive research has been conducted previously into the use of DME as an aerosol. Those studies indicated that DME is of low toxicity and is non-carcinogenic; in addition, there are no known effects regarding teratogencity. It is, of course, extremely flammable and has wide flammability limits. It is a liquefied gas under pressure and is colorless and odorless. Mixtures of DME and propane are possible.

There are a number of companies working on DME vehicle fuel systems and engine research. These companies are hesitant to share information regarding fuel system development in order to protect commercial interests and proprietary rights. However, SAE reports have provided some insight into the issues regarding fuel system and engine development. The injector pressure is much lower than diesel but much higher than that found in current liquid propane systems used in spark ignited engines. The technical issues concerning fuel system design arise from poor fuel viscosity, poor lubricity and incompatibility with most elastomers. DME has a lower vapour pressure than propane and therefore propane tanks can be used. This would also facilitate mixtures of DME and propane. As expected there are no standards regarding DME fuel systems.

A limited number of bulk DME facilities exist in Canada. Bulk quantities are required for use in the aerosol packaging business. There are no specific national standards in Canada covering DME bulk installations or components other than the tank. A major manufacturer and supplier of DME uses propane standards as a model for its installations with the appropriate electrical equipment to suit DME. Typically, equipment suppliers

use their standard propane equipment and find alternative materials for elastomers to suit DME. As a result of a lower energy content in the fuel, either more frequent fuel deliveries or larger storage would be required to serve the same number of vehicles. In all likelihood, site traffic would also increase.

No major hurdles were identified in the use of DME as a fuel for compression ignition engines. Additional studies and research will be required in all the areas prior to arriving at a commercial product. It is recommended that work be started to find a suitable odorant for use in leak detection.

Sommaire

Le gouvernement du Canada a lancé des études sur l'utilisation du diméthyléther (DME) comme carburant de remplacement du diesel dans les moteurs à allumage par compression. Des doutes ayant été exprimés quant à l'aptitude du carburant diesel à satisfaire aux réglementations concernant la pollution atmosphérique, notamment les émissions d'imbrûlés et de NOx, le DME est une des solutions envisagées pour régler ce problème.

Ressources naturelles Canada a financé la recherche sur le développement technique d'un moteur brûlant du DME et sur le circuit d'alimentation correspondant. Pour leur part, Transports Canada et le Centre de développement des transports (Groupe Sécurité et Sûreté) appuient la recherche sur le volet développement technique en publiant les résultats de la présente étude qui a analysé l'impact du DME sur la sécurité, la santé et l'environnement et déterminé les questions soulevées par ce carburant, le circuit d'alimentation et les pompes de distribution.

L'information relative à toutes ces questions a été obtenue par le biais d'interviews auprès des producteurs et des fournisseurs de DME, d'institutions de recherche sur les moteurs et les carburants, des pouvoirs publics, des organismes de normalisation, des équipementiers et de sociétés pétrolières. Elle a été complétée par une recherche documentaire sur les études antérieures dans les domaines de la santé et de l'environnement ainsi que sur les études plus récentes portant sur le développement du moteur et son circuit d'alimentation.

Toutes les analyses faites ont confirmé l'innocuité du DME qui réduit les émissions de NOx et qui ne produit presque pas d'imbrûlés. Des recherches antérieures exhaustives sur le DME utilisé comme aérosol, il est ressorti que ce carburant est faiblement toxique, qu'il est non carcinogène, et qu'on ne lui connaît aucun pouvoir tératogène. Par contre, il est extrêmement inflammable avec une plage d'inflammabilité étendue. Sous forme de gaz liquéfié sous pression, il n'a ni couleur ni odeur. Enfin, on peut l'utiliser mélangé à du propane.

Plusieurs sociétés s'intéressent au développement d'un moteur brûlant du DME et du circuit d'alimentation correspondant. Elles ne diffusent que peu d'information sur l'avancement de leurs travaux afin de protéger leurs intérêts économiques ainsi que les droits de propriété intellectuelle. Mais, dans les rapports qu'elle publie, la SAE en donne certains aperçus, notamment que la pression d'injection est beaucoup plus faible que pour le carburant diesel, mais beaucoup plus élevée que pour le propane liquide injecté dans des moteurs à allumage commandé. Les difficultés techniques posées par le circuit d'alimentation proviennent d'une faible viscosité, d'un pouvoir lubrifiant médiocre et de l'incompatibilité avec la plupart des élastomères. La tension de vapeur du DME gazeux étant plus faible que celle du propane, il devient possible de le stocker dans les réservoirs de propane, et cela facilite l'utilisation de mélanges DME-propane. On savait déjà qu'il n'existe pas de norme concernant les circuits d'alimentation en DME.

Au Canada, il existe un nombre limité d'installations de stockage du DME que l'industrie des aérosols utilise en grosses quantités. Aucune norme canadienne ne s'applique directement aux installations de stockage de DME ou aux éléments constitutifs autres que les réservoirs. Un producteur et fournisseur en gros de DME applique aux installations de stockage de ce gaz les normes concernant le propane, mais avec des équipements électriques adaptés au DME. Règle générale, les équipementiers se servent pour ce gaz des mêmes équipements que pour le propane, mais avec des élastomères compatibles. Considérant le pouvoir calorifique plus faible du DME, il faudra soit augmenter la fréquence des approvisionnements, soit augmenter la capacité des réservoirs si l'on souhaite pouvoir approvisionner le même nombre de véhicules. En toute probabilité, la circulation vers et depuis l'installation de stockage augmentera, elle aussi.

On n'a rien observé de grave qui puisse compromettre l'utilisation du DME dans les moteurs à compression, mais des recherches plus poussées couvrant tous les aspects de cette utilisation seront nécessaires avant d'en arriver à un produit pouvant être mis sur le marché. De plus, il est recommandé de trouver un agent odorisant approprié pouvant aider à détecter les fuites.

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Glossary of Abbreviations, Acronyms, Symbols, and Special Terms

^{o}C	Degree Celsius
CGA	Canadian Gas Association
CI	Compression ignition
CMVSS	Canada Motor Vehicle Safety Standards
CSA	Canadian Standards Association
DME	Dimethyl ether
GVWR	Gross vehicle weight rating
J	Joule
kg	Kilogram
kPa	Kilo pascal
L	Litre
LPG	Liquefied petroleum gas
m	Metre
MSDS	Material Safety Data Sheet
MJ	Mega joule
NFPA	National Fire Protection Association
NO_x	Oxides of nitrogen
OEM	Original equipment manufacturer
psi	Pounds per square inch
psig	Pounds per square inch gauge pressure
UL	Underwriters Laboratory
USWG	United States water gallon capacity
>	Greater than
<	Less than

1 INTRODUCTION

1.1 Background

The Canadian federal government has initiated studies and research into the use of dimethyl ether (DME) as an alternative to diesel fuel in compression ignition (CI) engines. This is as a result of concerns regarding the capability and cost of meeting future emission standards with diesel fuel and CI engines. Emission standards are being tightened to improve air quality and reduce the impact that emissions have on health and the environment.

Transport Canada and Natural Resources Canada have taken an active interest in the use of DME. Natural Resources Canada are supporting DME research into fuel system design, CI engine development work, fuel mixtures, and production of DME. Transport Canada are complementing this work with their interest in the safety, health, and environmental aspects of the use of DME.

DME is not a naturally occurring product but rather manufactured. Production is currently limited and would have to be increased substantially to meet the demands of its use as a vehicle fuel. DME is produced using methanol as the feedstock, but processes are being investigated which would provide direct synthesis from natural gas [1]. This could reduce the cost of DME. Canada has an abundant supply of natural gas and is well positioned to be the major producer of DME.

DME is rather benign and is used as a propellant in aerosol packaging. Prior to its use in that application, studies were done to determine the health and environmental aspects.

DME is an attractive alternative fuel for compression ignition engines because it has a high cetane value.

There are also considerations for the use of mixtures of DME and propane in CI engines. Propane has a low cetane value and cannot be used by itself in CI engines. It has been used with diesel fuel in parts of Europe to reduce visible smoke from CI engines. Instead of mixing it directly with diesel, the gaseous propane is blended into the incoming engine air in a fumigation process. Canada is also a major producer of propane.

1.2 Project Objectives and Tasks

The purpose of the project was to conduct a preliminary assessment of the overall safety issues regarding the fuel, the vehicle fuel system, and the dispensing into the vehicle. The project was broken down into four tasks;

Task 1 - Compilation of Information on DME
Compile basic information on DME fuel properties using propane as a benchmark and identify safety issues including fuel compatibility with the engine fuel system and ground storage/dispensing system related to use of DME fuel alone or blended with propane. Assess the benefits and negative aspects of DME from environmental and health perspectives.

Task 2 - Fuel System Requirements
Identify the type of equipment or components that are appropriate for use with DME fuel and assess the safety and regulatory issues that must be addressed.

Task 3 - Fuel Dispensing System Requirements
Identify the type of dispensing system that would be appropriate for use with DME fuel and assess the safety and regulatory issues that must be addressed

Task 4 - Report
Prepare a final report detailing the results of the investigation and containing recommendations on further research necessary to bring about the introduction of DME to the market as a viable alternative automotive fuel.

2 APPROACH & METHODOLOGY

It was determined that the quickest method for obtaining information about DME was to contact the companies manufacturing and supplying DME, DME equipment manufacturers, standards writing associations, and companies and organizations doing research into its use as a fuel for CI engines. This provided a starting point and yielded valuable information. Refer to Appendix A for a list of companies and organizations contacted.

Most of the general information on fuel properties was consistent. There were wide variations to specific values for a few properties - auto-ignition temperature and flammability limits.

The companies doing research into fuel system design were hesitant in providing specific information about their injection systems because there are commercial and patent issues at stake. The problems that they faced were consistent.

There are a limited number of bulk DME storage facilities in Canada and the U.S. Information provided indicated that the standards followed in the design and installation were company standards and that these followed propane or LPG standards. There is no experience to date on dispensing into vehicles.

The telephone interviews also provided leads for reports, trade publications, material safety data sheets, and journal articles that were very useful. References are made to these throughout the report.

3 DIMETHYL ETHER FUEL PROPERTIES

Dimethyl ether is also know as DME, methyl ether, and a number of different brand names that are used in the aerosol propellant industry by the manufacturers of DME. The chemical formula is $(CH_3)_2O$. Its molar mass is 0.046069 kg/mole.

The properties of DME impact the safety, health, environmental and operational aspects of its handling and use.

3.1 Safety

Detection

It is a colorless gas and liquid with a slight ethereal odor. Although it has a unique odor, it is claimed that there can be variations to this and therefore an odorant will be required to ensure adequate control and leak detection.

Density

The relative vapour density at 20^{o}C of DME is 1.59. It is heavier than air (air = 1) and therefore will settle or gravitate to low lying areas. One litre of liquid will vaporize to produce 374 L of gas (when expanded to 15^{o}C and 100 kPa).

The specific gravity of the liquid is 0.668. The liquid expands and contracts with temperature. At its boiling point of -25^{o}C the density is 735 kg/m^3. At 50^{o}C the density is 615 kg/m^3 The expansion of liquid with temperature will be critical to determine maximum filling densities of both dispensing storage vessels as well as vehicle tanks. This information will also be useful for providing temperature correction for volumetric measuring of the liquid as it is metered into the dispensing storage as well as metering into the vehicle tank.

Combustion

Its lower flammability limit in air is 3.4 percent. The two most frequent values used for upper flammability limits are 18 percent and 27 percent in air. The two values used for auto-ignition temperature are 235°C and 350°C. Its flash point is -41^{o}C. It burns with a visible flame. Under most conditions combustion requires a source of ignition and a flammable mixture of DME and air. If those conditions exist, the chemical reaction that takes place is the release of heat and the formation of other gases. If incomplete combustion takes place, it is possible to get excessive amounts of carbon monoxide which is a poisonous gas in relatively low concentrations.

Pressures

DME exists as both a gas and a liquid at normal temperatures. Its boiling point is -25°C at normal atmospheric pressure. In order for it to exist as a liquid above that temperature requires that the liquid be contained under pressure. Figure 1 shows the vapour pressures for both DME and propane as saturated liquids for a range of temperatures.

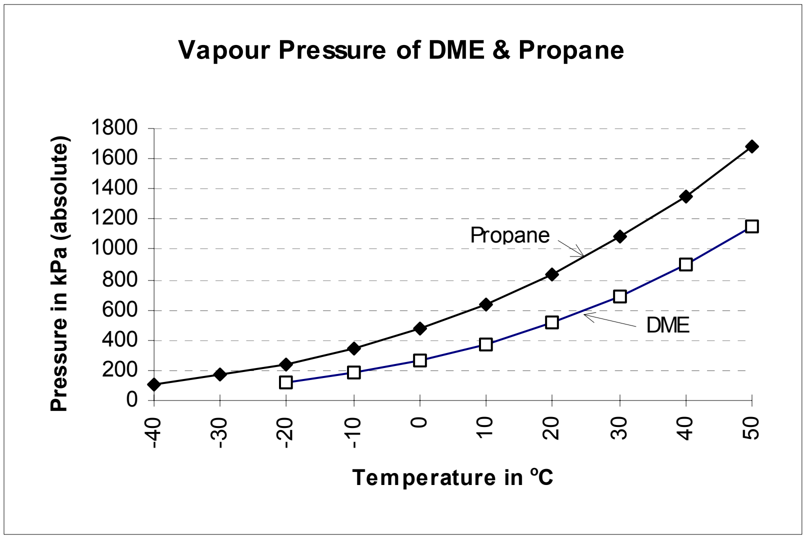

Figure 1 Vapour Pressure of DME and Propane

Heat of Vaporization

Care must be taken in the handling of the liquid. The liquid vaporizes quickly and removes heat from those areas which it contacts in the vaporization process. If it contacts exposed skin, there is the potential for "freeze burns". The heat of vaporization at 20°C is 412 kJ/kg.

3.2 Health

Inhalation Toxicity

Dimethyl ether produces an anesthetic or narcotic effect with inhalation of the vapours. Concentrations of 5-20 percent [2] by volume can cause irritation, incoordination, shortness of breath, drowsiness, intoxication, blurring of vision, headaches, dizziness, excitation, and unconsciousness [3, 4, 5]. These appear to be short-term effects caused by short-term exposure.

DME in higher concentrations, in excess of 20 percent, can increase the risk of cardiac irregularities and possibly cardiac arrest [6, 10]. In high concentrations DME replaces breathing air and acts as a simple asphyxiant. This is a result of the displacement of and lack of oxygen.

Depending upon the reference, the level of toxicity varies from non toxic to a low order of acute and chronic toxicity [2, 6, 7, 8, 9].

Skin Contact

Exposure to the skin or eyes to high concentrations of vapour or liquid can cause irritation or dermatitis [4, 5]. If the exposure is to the eyes it causes inflammation of the ocular mucous membranes [4].

In addition, contact with the vaporizing liquid can cause frostbite. This is characterized by a change in color of the skin to white or gray and possibly followed by blistering of the affected area.

There does not appear to be any evidence that DME is absorbed through the skin at normal atmospheric pressures.

Carcinogenicity

Any information that is available indicates that there are no known effects [6, 8].

Teratogencity & Mutagencity

Teratogencity is the ability to cause fetal malformations and mutagencity is the ability to alter genes or chromosomes. Any information that is available, indicates that there are no known effects [6, 7, 8].

3.3 Environmental

Exhaust and Evaporative Emissions

The reason that there is an interest in DME as an alternative to diesel is that it has the potential to reduce harmful tailpipe emissions. A number of studies have indicated that it has to the potential to meet new ULEV standards without the need for expensive exhaust after treatment [13, 14]. Particulate formation is almost eliminated [13, 14, 15].

Formaldehyde emissions are reported to be low [14, 15], but testing was not done using constant volume sampling apparatus. Regardless, the results appear to be well within established standards. The hydrocarbon emissions are methane and unburnt DME. Both have low photochemical reactivity [15].

There may also be added advantages in cold weather startup conditions with engines fueled by DME. There are special assists required for cold weather starting of a diesel engine due to poor initial combustion. In the limited DME testing that has been done the engine started at temperatures of -24°C without special assists [15].

DME released into the atmosphere has a half life of hours in the lower troposphere and days in the upper troposphere and decomposes into carbon dioxide and water [8, 9, 12].

Soil Contamination

As DME is a pressurized fuel stored in closed systems, it is difficult to have spills of DME. In addition, as DME is a vapour at temperatures above -25°C and at atmospheric pressure it will vaporize and not pose a hazard to soil.

Water Contamination

Although DME is soluble in water, the likelihood of a spill of DME into water is low due to the fuel being stored in a closed system. Regardless, it evaporates over a period of hours [8].

Noise

There is a reduction in the noise levels from a compression-ignition engine when fueled with DME. Reports place it at under 80 decibels and at the level of gasoline spark-ignited engines [15, 16].

3.4 Operational

Cetane Number

DME has a cetane number in excess of 55. The range for diesel is 40 to 55. Propane's value is less than 10. The higher the cetane number the shorter the ignition delay and the better the ignition quality.

Net Heating Values

The net heating value for DME is 28.43 MJ/kg. Assuming the same thermal efficiency of the CI engine it will require approximately 50 percent more fuel on a mass basis and 89 percent more fuel on a volumetric basis to go the same distance as a vehicle or engine operated on diesel.

Compressibility

Like other gases and liquids both the vapour and liquid are compressible. The vapour will behave according to the saturated vapour-liquid relationship. The liquid is compressible and increasing the pressure from 100 kPa to 11 000 kPa at a temperature of 50^{o}C decreases the volume by a factor of 20 percent.

Viscosity

Information is limited on liquid viscosity. The viscosity falls between propane and butane - propane at 0.10 centipoise, DME at 0.15, and butane at 0.18 [15]. Poor viscosity complicates the design of fuel injectors, solenoids, and pump and meter components as a result of leakage of DME past the moving parts within the components.

Lubricity

Poor lubricity has also been identified as an issue [11, 15]. Poor lubricity accelerates wear and leads to an unacceptable short life for components.

Compatibility with Materials

DME is non-corrosive and can be used with most common metals although one report lists DME/water/methanol mixtures to be corrosive [11].

Explosive reactions may also take place in the presence of aluminum hydrides, chromic anhydrides, lithium tetrahydroaluminate, nitric acid, peroxides, oxidizers, ozone, and oxygen.

There is conflicting information on the formation of peroxides in the presence of air. This could be an issue with regards to storage tanks. Tanks which have been previously in DME service and left open for prolonged periods may form peroxides which when put back in service and exposed to friction, impact, or heating may explode [4]. A number of reports indicate that the formation of peroxides is minimal, if at all, or unlikely [8, 9, 12].

Most elastomers are attacked by DME due to its high solvency. Teflon shows resistance to DME.

Electroconductivity

DME has low electroconductivity. The flow of product may generate a buildup of electrostatic charge. This will have to be taken into consideration in the design of the dispensing facilities.

Solubility

DME vapours are soluble in water. The solubility changes with pressure and temperature. At 100 kPa and 18°C water can hold 7 percent by weight. At 500 kPa and 23.5°C it can hold 35 percent by weight.

CO_2 is highly soluble in DME. It should not be used as a purge or pressure medium.

Other Basic Properties

See Appendix B for a list of properties and a comparison to diesel and propane.

3.5 DME Fuel Specification

Fuel quality affects a number of different items. In addition to the safety, health, and environmental aspects, it also affects the cost of production of the fuel, the complete distribution infrastructure, and the vehicle in which it is being used. The research that has been done on DME has been to determine engine emissions and engine design using chemical and technical grades of DME [14, 15]. In some cases lubricants were added. The technical grades are various mixtures of DME, methanol, and water. The research has shown that both chemical and technical grades of DME can reduce particulates and NO_x.

Investigations are also underway to determine the impact of mixtures of DME and propane. Propane has a low cetane value and as such can not be used by itself in a CI engine. As DME has a higher cetane value than diesel, it is felt that propane, in limited quantities, can be mixed with DME without sacrificing ignition quality and thermal efficiency and improving the cost effectiveness and the energy content of the fuel.

It is possible to improve on some of the shortcomings of DME with the use of other chemicals or additives. Areas that need investigating are low energy content, poor lubricity, and lack of odorant.

As is the case for gasoline, diesel, and propane, it will be necessary to develop a fuel grade specification for DME. Preferably this will be a National Standard and cover minimum and maximum compositions, testing methods, and general requirements.

4 VEHICLE FUEL SYSTEM

4.1 General Information

Research

There are a number of companies and organizations doing research on DME and its use in CI engines. The results of the work look promising [11, 13, 14, 15, 16, 17]. DME may have applications in both aftermarket conversion of the fuel system to DME as well as new vehicles and engines [14, 17].

Markets

The suitability and practicality of its use on engines and vehicles already in service will depend upon the cost of the equipment and installation to change the vehicle to operate on DME, the price difference in the fuels, and the emissions benefits. Experience with propane and natural gas vehicles indicates that users need an economic incentive to switch their vehicles to an alternative fuel. With a large enough incentive they are prepared to put up with some inconveniences.

Approximately 50 000 trucks and buses with diesel engines are sold in Canada each year. Forty-nine percent of those are under 4 500 kilograms. Class 7 (11 800 kg to 15 000 kg GVWR) and Class 8 (15 000 kg and up GVWR) vehicles represent an additional 49 percent. Smaller vehicles may find it difficult to store enough fuel without compromising range. Larger vehicles have more space available for mounting the storage tank or tanks. With larger vehicles there may be an issue in mounting the tanks outside the main chassis rails. This is a common practice on aftermarket conversions to propane on medium duty vehicles.

Similarities to Propane

As both propane and DME are liquid fuels stored under pressure, it will be useful to review some statistics for propane as an alternative transportation fuel. There are approximately 140 000 vehicles operating on propane in Canada. Estimates are that 60 percent of the vehicles are light duty pickups, 20 percent light duty vans, 10 percent cars, and 10 percent medium duty trucks and buses. Many of these vehicles are in commercial or fleet service. A large number of school buses are powered by propane. Almost all these vehicles have been converted in the aftermarket.

Approximately 4 000 000 vehicles worldwide run on LPG. There are in excess of 7 000 vehicles operating on liquid LPG injection in Europe. LPG has been used in city buses from many years in Vienna and there are a number of European cities with demonstration programs on LPG buses. The safety record for LPG is excellent.

4.2 Vehicle Fuel System Components

The basic components are:

- fill connection

- tank
- tank pump module
- liquid lines
- injector pump
- injectors

Regardless of whether it is an aftermarket conversion or an OEM installation, the function of the components will be similar.

4.3 Safety Regulations and Standards

Federal

Federal regulations govern the testing and certification of new vehicles. The Canadian federal government standards for fuel system integrity are CMVSS 301, 301.1 and 301.2. Standard 301 applies to any fuel with a boiling point above 0°C, a GVWR of 4 500 kg or less, and all school buses regardless of weight. CMVSS 301.1 applies to all vehicles powered by LPG regardless of weight. CMVSS 301.2 applies to all vehicles powered by CNG regardless of weight. Both 301.1 and 301.2 give manufacturers the option of meeting certain requirements in the CAN/CGA-B149 codes or conducting crash tests as part of the certification process. Manufacturers build, test, and certify their vehicle fuel systems according to these standards.

As DME has a boiling point below 0°C, it does not fall within the CMVSS 301.

CSA also produces a standard - D250 School Buses. Within that standard are requirements for fuel system design such as minimum fuel capacity, location of tank or tanks, and positioning of tank relative to frame and cowl.

Provincial

Provincial regulations apply to vehicles already in service. There are currently no regulations covering the aftermarket conversion of the fuel system to DME. In the case of propane, provincial regulations set the conditions for the design, testing, certification, and installation of aftermarket conversion components. CAN/CGA-B149.5 Installation Code For Propane Fuel Systems And Tanks on Highway Vehicles is adopted either in its entirety, or parts of, as the cornerstone for provincial regulations. This standard also references other standards many of which are listed in Table 1.

In addition, many of the provinces also regulate the facilities which install and service aftermarket conversions to propane. In those provinces, the installation shops are required to meet certain conditions before they can perform conversions.

Table 1 Propane Standards and Equipment Pressure Ratings

Item	Propane Standards	Pressure Requirements
Installation	. CAN/CGA-B149.5 Installation Code For Propane Fuel Systems And Tanks on Highway Vehicles	. Tank tested at 140 psig (1 000 kPa) . All assembled piping, tubing, & hose tested at 140 psig (1 000 kPa)
Tank	. CAN/CSA B51 Boiler, Pressure Vessels, and Pressure Piping Code . CAN/CGA-B149.5 Installation Code For Propane Fuel Systems And Tanks on Highway Vehicles	. Design pressure of 250 psig (1 750 kPa) or 312.5 psig (2 150 kPa)
Tank Relief Valve	. UL 132 Safety Relief Valves for Anhydrous and L-P Gas	. 250 psig (1 750 kPa) or 312.5 psig (2 150 kPa)
Line Filter	. UL 331 Strainers For Flammable Liquids and Anhydrous Ammonia	
Liquid Lines - Hose	. CAN/CGA-8.1 Elastomeric Composite Hose and Hose Couplings for Conducting Propane and Natural Gas	. Minimum working pressure 350 psi (2 400 kPa)
Liquid Lines - Tubing	. ASTM Specification A539 Electric-resistance Welded Coiled Steel Tubing for Gas and Oil Lines . SAE J527 Brazed Double Wall Low Carbon Steel Tubing . ASTM B75 Specification for Seamless Copper Tube	. Minimum of 250 psig (1 725 kPa)
Line Relief Valve	. UL 132 Safety Relief Valves for Anhydrous and L-P Gas	. Start to discharge of 375 psig (2 500 kPa) to not more than 500 psig (3 500 kPa)
Automatic Shut-off Valve	. CAN/CGA-12.2 Propane Fuel System Components for Use on Highway Vehicles	
Solenoid Valves	. CSA C22.2 No.139 Electrically Operated Valves	
Regulator (tank pressure containing parts)	. CAN/CGA-12.2 Propane Fuel System Components for Use on Highway Vehicles	. Maximum working pressure of not less than 250 psig (1 725 kPa) . Strength test at 5 times maximum working pressure
Liquid Level Gauges	. UL 565 Liquid-Level Gauges and Indicators for Anhydrous Ammonia & LP-Gas	. Working pressure 375 psig (2 600 kPa) . Strength test 1 250 psig (8 600 kpa)

4.4 Potential Issues

Fuel System Pressures

Although there will be similarities in some of the components to propane vehicle fuel systems the pressure at which the liquid will be introduced into the diesel engine will be much higher. Refer to Table 2 for a comparsion of fuel system pressures between propane and DME.

Table 2 Comparison of Propane and DME Fuel System Pressures

Type of Fuel System	Pressure from Tank	Pressure from Injector Pump or Manifold Inlet
Propane Vapour	Tank pressure to vaporizer	Slight positive pressure
Propane Liquid Injection	Tank pressure plus up to 500 kPa	Tank pressure plus 500 kPa
DME	Up to 3 000 kPa	Up to 22 000 kPa

Material Compatibility

Many of the elastomers that are used on propane components will not be acceptable for use with DME or DME mixtures. Standards will be required which address this issue to minimize the risk of leaking fuel. This will apply to all valves, hoses, and any component that uses elastomers.

Electrical Conductivity

DME is a very poor conductor of electricity and is susceptible to building up a static electrical charge as a result of flow or vaporization of the DME. Although this doesn't appear to be a safety issue in that it is a closed system and therefore unlikely that an ignitable mixture could develop it might still be advisable to provide routing of any charge away from the fill connection and other areas where there might be the presence of vapours. This can be done by providing electrical grounding between the fill connection and the vehicle tank to the vehicle chassis.

Engine Temperatures

The auto-ignition temperature of DME (235^{o}C or 350^{o}C depending upon the source of information) is above the temperatures that can be reached in a typical underhood compartment of a diesel engine. The worse case for temperatures for a diesel engine is with a rear mounted engine (no ram air) and in the proximity of the turbocharger during a hot soak condition. It is possible to reach temperatures close to 175^{o}C. There is little information published on the engine temperatures of a DME fueled engine.

Additional Volume and Weight of DME

Table 3 provides important fuel properties for determining the volume of fuel and the weight of fuel required to go a certain distance. Assuming the same thermal efficiency, it will require an additional 89 percent more fuel than diesel by volume to go the same distance and it will add an additional 50 percent of the diesel tank and fuel weight to the weight of the vehicle. If a blend of DME and propane is used these percentages will decrease. This difference in energy content will also impact the size of components on the vehicle including valves, lines, pumps, and injectors.

Table 3 Comparison of Density and Heating Values

Property	DME	Diesel	Propane
Density in kg/L	0.668	0.84	0.51
Net Heating Value in MJ/kg	28.43	42.7	47.25
Net Heating Value in MJ/L	19.0	35.9	24.1

Vehicle Fill Connection

It will be necessary to come up with a unique fill fitting for DME or DME mixtures to eliminate the risk of filling propane powered vehicles and vice versa The recognized fitting for propane vehicles is a 1 ¾ inch ACME screw connection. It is used throughout Canada, the U.S., and Mexico.

The DME fitting will need to be unique to this application, easy to use, have North American acceptance, low dead fill space, provide security through a gas tight seal or seals, and be capable of high flow rates. The low dead fill space is to minimize release of DME from the connection of the nozzle to the vehicle after filling has been completed. Amendments to the Motor Vehicle Safety Regulations are being proposed for propane vehicles to limit this dead space to 2.0 cm^3. This pertains to emissions and air quality rather than safety.

Tank & Tank Relief Valve Pressures

Propane is a higher vapour pressure fuel and therefore requires a higher tank and relief valve design pressure. The B149.5 Standard for propane requires a tank and tank relief valve pressure rating of 1 750 kPa (250 psig). This vapour pressure would be reached at a temperature of 54°C. The vapour pressure of DME at that temperature is approximately 1 210 kPa (175 psig). For mixtures of DME and propane it would be necessary to determine the maximum amount of each component in order to determine the design pressure of the vessel.

Tank Filling Volume

Liquid DME, like liquid propane, expands and contracts with changes in temperature (refer to Figure 2). For propane, B149.5 requires the maximum fill volume not to exceed 80 percent of the tank volume. This then accommodates any expansion in liquid volume which might take place as a result of increases in temperature. A vehicle tank filled to the 80 percent tank volume with propane at -25°C would have to be raised by 83°C in order for the entire tank volume to be filled. As liquid DME expands at approximately the same rate, the same level (i.e. 80 percent) is suitable for DME or mixtures of DME and propane.

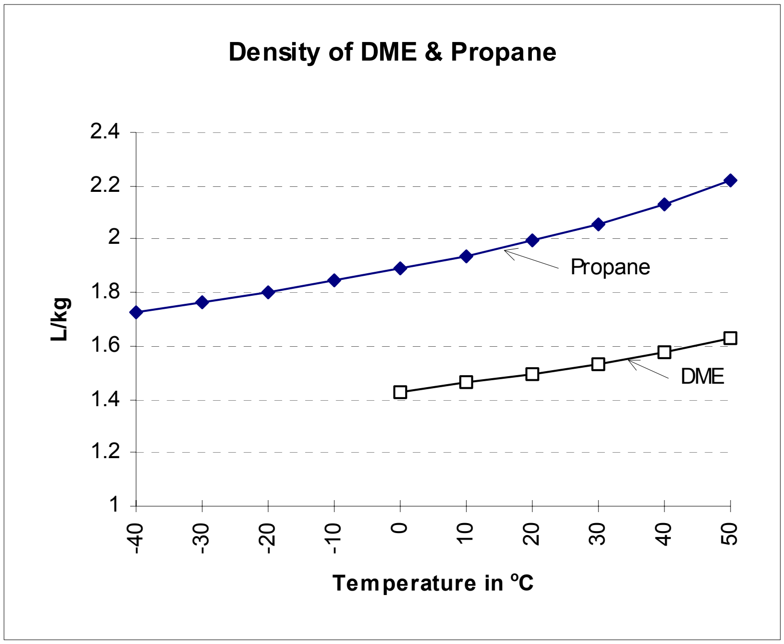

Figure 2 Specific Volume of Liquid DME and Propane

Tank Valves

Many of the manufacturers that are supplying tank valves to the DME industry are using valves manufactured for propane and substituting other materials for the elastomers that are used in propane service. As there are no standards for DME components, there is no requirement for certification.

Tank Withdrawal Valve & Excess Flow Valve

In the propane vehicle system an excess flow valve is required by code. It is typically a part of the liquid withdrawal service valve and located at the inlet of this valve. Excess flow valves are sized to permit adequate fuel flow to the engine but to shut off in the case of a line rupture. Proper sizing is critical. They are spring loaded devices which are activated if the pressure drop through the valve is greater than the spring pressure holding the valve open. They may not be completely effective under all conditions - if there is only a partial rupture vs. a complete rupture or if there is minimal tank pressure forcing the liquid through the valve even though there is a complete rupture. The impact of these shortcomings are minimized by having the withdrawal valve as an electrically operated solenoid valve. When the engine is not running the valve is closed.

Liquid Lines and Fittings

Fuel line working pressures are higher than those on propane systems as a result of the use of a fuel pump. Pump pressures are in the range of 1 200 kPa to 3 000 kPa [14, 16]. It will be necessary to provide lines with a minimum working pressure greater than the discharge pressure of the pump.

Tank Pump/Injector Pump/Injectors

Viscosity, lubricity, and material compatibility are all issues which could eventually lead to leaking of DME. It will be necessary to develop standards which minimize the likelihood of this occurring.

5 DISPENSING OF DME

5.1 Fueling Applications/Infrastructure

DME Vehicle Applications

The majority of vehicles that are sold with diesel engines fit into two categories - those that are under 4 500 kg GVWR and those over 11 800 kg GVWR. The vehicles in the first category range up to one ton vans, pickup trucks, or chassis-cab arrangements that are built on the same type of chassis as the van and pickup. Because of their smaller size, these vehicles are not restricted to certain fuel dispensing sites as may be the case for larger vehicles where manoeuvrability is a problem. The vehicles in the larger GVWR category are more likely to fuel at cardlock, keylock, and commercial types of outlets due to their size and the higher flow rates of the pumps and meters to facilitate faster fueling.

Fuel Dispensing Stations

There are a number of different types of stations where fuel can be accessed. They range from:

- the corner retail gasoline station which serves the private motorist as well as commercial vehicles
- truckstops which cater to the larger diesel trucks
- cardlock and keylock which again cater to commercial vehicles
- on-site fueling for vehicles owned by the company where the fueling site is located.

Although the number of stations is in a constant state of flux, Table 4 provides a snapshot of station numbers by fuel type and mode of operation.

Table 4 Numbers of Fueling Stations

Retail Fuel Outlet by Fuel Type	Total Number
Retail Gasoline Outlets	14 194
Retail Diesel Outlets	4 811
Cardlock Locations	873
Keylock Locations	271
Retail Propane Locations (estimate)	3 500
Retail Natural Gas Locations	125

Many sites serve more than one type of fuel. For those particular sites, space to add other fuels may be limited due to clearances required between the different types of fuels, property lines, buildings, and possibly even the aggregate amount of fuel at the location. Many sites are self serve and to have DME available at those sites means that DME must also be self serve.

Those retail locations that sell diesel fuel could be potential locations for installing DME dispensing systems. They will have the space required to permit access for the types of diesel vehicles that they currently serve and they may have the space to install the storage tank for DME. Cardlock and keylock self serve fueling are common in the diesel fuel market. High speed dispensing is the norm at these sites and flow rates up to 150 L/minute are standard. On-site fueling is also popular in the diesel fuel market.

Propane Dispensing

As DME and propane are receiving considerations to be used as a mixed or blended fuel, it will be helpful to review some of the history regarding propane dispensing. Propane dispensing sites have been common in Canada since the early 1980s. There are currently in excess of 3 500 retail dispensing outlets for propane. On-site fueling is also very popular.

Propane is dispensed at gasoline service stations in all types of locations - city centres, commercial, industrial and residential areas. Frequently these same locations also fill portable propane cylinders. Although self serve dispensing is not permitted in the general sense, the industry is moving in that direction. A number of retail sites are also self serve cardlock facilities. Self serve fueling is permitted at these locations as they are restricted as to who can access the fuel. Those interested in fueling their own vehicles must undertake training and certification in the handling of propane.

The typical size of storage tank used for dispensing of propane is 2 000 USWG (approximately 6 000 L of usable capacity). The tank is mounted above ground and can either be of the vertical or horizontal type. There are very few underground tank installations in Canada although in other parts of the world they are quite common. The typical vehicle fill rates are in the order of 40 to 50 L per minute. On-site fueling may be higher - up to 100 L/minute. The volume of propane used in the vehicle market is approximately 1 billion L per year.

There are approximately 22 000 LPG dispensing sites worldwide.

5.2 DME Dispensing System

The dispensing systems for both DME and propane require the following components:

- storage tank
- pump
- valves, fittings, piping
- meter
- hose and nozzle

See Appendix C for a typical schematic of a propane dispensing system.

5.3 Standards and Regulations for Dispensing

National Standards have been developed for propane equipment and the handling of propane. CAN/CGA-B149.2 Propane Installation Code covers the design and installation of propane dispensing systems. It was prepared by the Canadian Gas Association and approved by the Standards Council of Canada as a National Standard. This standard is the cornerstone for many of the provincial regulations on propane dispensing.
There are also municipal regulations that must be adhered to. These include zoning and other land use permits as well as business licences.

Table 5 Propane Dispensing Standards and Suitability for DME

System Component	Standards used for Propane	Suitability for DME
Tank	. CAN/CSA B51 Boiler, Pressure Vessels, and Pressure Piping Code . CAN/CGA-B149.2 Propane Installation Code	Yes -DME has a lower vapour pressure
Pump	. UL 51 Power-Operated Pumps for Anhydrous Ammonia and LP-Gas	Yes - with materials compatible to DME
Valves	. UL 132 Safety Relief Valves for Anhydrous Ammonia and LP Gas . UL 565 Liquid-Level Gauges and Indicators for Anhydrous Ammonia and LP Gas . UL 125 Valves for Anhydrous Ammonia and LP Gas (Other Than Safety Relief) . UL 331 Strainers for Flammable Fluids and Anhydrous Ammonia	Yes - with materials that are compatible with DME
Piping	. ASTM A53 Specification for Pipe, Steel, Black, and Hot-Dipped, Zinc coated Welded and Seamless . ANSI Standard B16.3 Malleable-Iron Threaded Fittings	Yes
Meter	. UL 25 Meters for Flammable Liquid and LP Gas	Yes - with materials that are compatible with DME
Dispenser	. CAN/CGA 12.4 Dispensing Devices for Propane Fuel for Highway Vehicles	Yes - with materials that are compatible with DME
Hose	. CAN/CGA 1-8.1 Elastomeric Composite Hose and Hose Couplings for conducting Propane and Natural Gas or CAN 1-8.3 Thermoplastic Hose and Hose Couplings for Conducting Propane and Natural Gas.	Yes - with materials that are compatible with DME
Electrical	. CSA C22.1 Canadian Electrical Code Part 1 Safety Standards for Electrical Installations	Yes - Group C vs. D

As shown in Table 5, a number of different standards are used in the design, testing and certification of items within the propane system. Some are applicable “as is” to DME.

Many of the manufacturers that are supplying pumps and valves for DME are using components manufactured for propane and substituting other materials for the elastomers that are used in propane service. As there is no certification process for DME components these components are not certified after these changes have been made.

It will be necessary to develop new standards or modify existing standards that apply to propane to ensure the safe handling and dispensing of DME.

5.4 Potential Issues

As outlined in the section on vehicle fuel systems (Section 4), propane serves a different vehicle market than that which is expected for DME. The main market for propane is the light-duty vehicle market. Although DME can also serve this market, it may find its greatest use in the medium and heavy-duty vehicle markets. Larger storage tanks and higher flow rates than those typically used in propane dispensing will be required.

Due to differences in energy content between diesel and DME, it is expected that either the vehicle tanks (DME) will hold more fuel in terms of volume or the site activity will increase as a result of more fueling stops to the site. In addition, the site storage will have to be larger than that which would be used to handle the same number of diesel vehicles or the frequency of delivery to the site would have to increase if the site storage were kept at the same size. The dispensing capacity (litres/minute) will also be critical.

As was the case in the vehicle components many of the elastomers that are used on propane components will not be acceptable for use with DME or DME mixtures. Standards will be required which address this issue to minimize the risk of leaking fuel. This will apply to all valves, hoses, and any components that use elastomers.

DME is a poor conductor of electricity and is susceptible to building up a static electrical charge as a result of flow or vaporization of the DME. It will be necessary to provide adequate grounding for the tank and all piping. This also applies to the transport delivering fuel to the storage tank during the offloading process.

Tables 6 to 11 identify potential issues with the equipment that will be used in the dispensing of DME.

Storage Tank

DME has a lower vapour pressure than propane (see Figure 1) and therefore it is possible to use tanks with a lower minimum design working pressure than the 1 750 kPa (250 psig) required by CAN/CGA B149.2.

Table 6 Issues with DME Storage Tanks

Item/Function	Potential Issues
Site storage tank	. CAN/CSA B51 - Minimum design working pressure . Liquid fill volume . Site clearances . Tank static electricity grounding . Man-way seals - compatible materials

Liquid DME, like liquid propane, expands and contracts with changes in temperature. CAN/CGA B149.2 dictates maximum propane filling density of a tank by liquid volume. The filling density is based upon the temperature of the liquid, the size of the tank being filled, and the mechanism used to gauge the fill level. These levels then accommodate any expansion in volume which might take place as a result of increases in temperature of the liquid. As liquid DME expands at approximately the same rate as liquid propane (see Figure 2), the same level measurement is suitable for DME or mixtures of DME and propane.

Tank Valves

Table 7 Issues with Tank Valves Used in DME Service

Item/Function	Potential Issues
Tank inlet valve	. May require unique inlet thread on valve . Compatibility of elastomers
Liquid level gauge	. Determination of level settings . Compatibility of elastomers
Excess flow valve	. May not prove effective under all conditions . Compatibility of elastomers
Emergency shut off	. Compatibility of elastomers
Tank pressure relief valve	. Pressure relief settings . Compatibility of elastomers

There may be dispensing sites which include separate propane and DME dispensing systems. To guard against misfilling of tanks it may be necessary to have a different tank inlet valve than that for propane.

Excess flow valves are installed to provide protection in case of line ruptures. They are spring-loaded devices which are activated if the pressure drop through the valve is greater than the spring pressure holding the valve open. Proper sizing is critical. They may not be effective under all conditions. Two such examples are in the case of a partial rupture vs. a complete line rupture and in the case of extremely cold temperatures when there is very little tank pressure and the pressure drop through the valve may not be enough to close the valve even with a complete line rupture.

The same conditions that apply to the tank design pressure also apply to the tank relief valve.

Pump and Motor Assembly

Table 8 Issues with Pump Assembly in DME Service

Item/Function	Potential Issues
Motor	. Electrical classification of the motor
Pump	. Compatibility of elastomers in pump . Maximum discharge pressure of pump
Bypass Valve - circulate liquid back to tank above certain set pressure	. Compatibility of elastomers . Pressure setting

UL 51 limits the maximum discharge pressure to 24 100 kPa gauge (350 psig). This pressure then forms the basis for the design of the downstream components. Similar requirements are needed for DME.

Piping/Excess Flow Valves/Hydrostatic Relief Valves/Shutoff Valves

Table 9 Issues with Pipe and Pipe Valves in DME Service

Item/Function	Potential Issues
Pipe	. Pressure rating for line . Screwed or welded fittings
Excess flow valves	. Partial rupture vs. complete rupture of line . Performance with pump off and low tank pressure . Compatibility of elastomers
Hydrostatic relief valves	. Pressure rating based upon maximum pump discharge pressure . Compatibility of elastomers
Shutoff valves	. Pressure rating . Compatibility of elastomers

Dispenser/Meter

Table 10 Issues with the Dispenser/Meter in DME Service

Item/Function	Potential Issues
Measurement of volume of product being dispensed	. Pressure rating . For retail trade - Weights and Measures Regulations . Electrical classifications within dispenser & surrounding area . Compatibility of elastomers

There is little or no experience in North American with volumetric metering of DME.

Dispensing Hose, Hose Breakaway Coupling & Nozzle

Table 11 Issues with the Dispensing Hose System

Item/Function	Potential Issues
Hose	. Pressure rating . Compatibility of materials
Breakaway coupler	. Compatibility of elastomers
Dispensing nozzle	. Differentiation from propane nozzle outlet . Compatibility of elastomers

The hose and nozzle are the two items which are subject to the most abuse during use. The dispensing nozzle (propane experience) is also one of the components most prone to leaking.

Site Clearances

CAN/CGA-B149.2 provides minimum clearance distances with regards to location of tanks, piping, and dispensers as they relate to property lines, buildings, sources of combustion, other tanks of propane and other flammable liquids, electrical lines, railway lines, and equipment protection.

There is no reason to expect that any of these distances should increase for DME.

Electrical Requirements

According to the designations outlined in CSA 22.1 Canadian Electrical Code, DME and propane would fall under Class 1, hazardous locations. CEC indicates that propane falls within their group D category. Although DME is not specifically listed in CEC, NFPA #70 National Electrical Code lists it as Group C, and International Electrotechnical Commission publications provide information which would indicate that DME falls within Group C based upon its maximum experimental safe gap.

The Canadian Electrical Code provides clearance distances for Class 1 Division 1 and Division 2 locations for propane facilities. CAN/CGA-B149.2 does likewise.

Canadian Experience with DME Facilities

There are very few DME bulk storage facilities in Canada. The primary use of DME is a propellant in the aerosol industry. Discussions with industry representatives indicate that there are approximately 10 installations. DME is also sold in cylinders by a number of industrial and specialty gas companies.

6 CONCLUSIONS

6.1 DME Fuel Properties

DME provides an opportunity to substantially reduce particulate and NO_x tailpipe emissions when used in compression ignition engines. It has low photochemical reactivity, produces low formaldehyde, and decomposes within hours to form carbon dioxide and water.

It is relatively benign. It has low toxicity and is non-carcinogenic. It produces an anesthetic effect when inhaled and can act as an asphyxiant if enough oxygen has been displaced.

DME is a liquefied gas and flammable. As with all fuels it should be treated with a great deal of respect. An odorant will need to be added to aid in the detection of leaks.

DME and propane mixtures are possible. The amount of propane that can be added will be a function of the engine ignition quality of the mixture and of the engine exhaust emissions output. This is yet to be determined.

DME has very poor viscosity and lubricity. This affects the design of vehicle components such as fuel injectors, solenoids, and pumps and dispensing components such as meters and pumps.

6.2 Vehicle Fuel System

The injection of DME into the engine will take place at much higher pressures than propane injection into a spark-ignited engine but at much lower pressures than diesel injection. Testing has confirmed DME injection pressures of 22 000 kPa whereas diesel can exceed 120 000 kPa.

There is no standard for DME component specification or certification. There are many similarities in the issues faced with propane and the standards for propane could be used as models for DME standards or modified to include DME.

In order to have the same range from the vehicle it will be necessary to increase the capacity of fuel storage by 89 percent by volume beyond the diesel capacity.

The filling level of the DME tank is the same as a propane vehicle tank - 80 percent. Propane tanks can be used for DME. They have a higher working pressure than those required for DME.

The elastomers that are used in propane components will not be suitable for DME.. There are a number of perflouroelastomers that are being used in DME service. Teflon can also be used but it may not give the same life as the perflouroelastomers.

6.3 Dispensing System

The type of equipment used for DME dispensing will be similar to propane.

There is no standard for DME component specification or certification. There are many similarities in the issues faced with propane and the standards for propane could be used as models for DME standards or modified to include DME.

High-speed refueling or dispensing at flowrates of up to 150 L per minute will be required in order to provide the same flowrates as in diesel service.

The elastomers that are used in propane components will not be suitable for DME. There are a number of perflouroelastomers that are being used in DME service. Teflon can also be used but it may not give the same life as the perflouroelastomers.

A new outlet fitting on the dispenser nozzle will be required to prevent inadvertent filling of propane powered vehicles with DME.

The filling level of the storage tank is the same as propane - 85 percent. Propane tanks can be used for DME. They have a higher working pressure than those required for DME.

7 RECOMMENDATIONS FOR FURTHER RESEARCH

7.1 DME Fuel Properties

The following items have been identified as requiring further work:

- develop a suitable odorant to provide leak detection
- address lubricity issues
- investigate the formation of peroxides in vehicle and dispensing tanks
- investigate whether corrosion is possible with DME/methanol/water mixtures
- develop a fuel specification
- perform cold weather emissions testing
- confirm auto-ignition temperature
- confirm flammability limits
- investigate blends of DME and butane
- more detailed emission speciation

7.2 Vehicle Fuel System

The following items have been identified as requiring further work:

- develop a new vehicle fill connection
- initiate changes to CMVSS for DME fuel system integrity
- develop equipment and installation standards (National Standards) for aftermarket conversions
- investigate alternative vehicle tank design and manufacturing processes to optimize capacity in limited spaces
- market analysis to determine which vehicles and engines are best candidates for conversion or OEM

7.3 Dispensing System

The following items have been identified as requiring further work:

- select or develop a new dispensing nozzle outlet
- verify that propane dispensing hoses are compatible with DME
- develop equipment and installation standards (National Standards) for dispensing systems
- develop suitable dispensing meters and register for DME
- initiate Weights and Measures standards/approvals for DME meters
- confirm Group C rating and electrical clearance distances

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Appendix A

List of Organizations and Companies Contacted

Avanced Engine Technology Ltd., Nepean, Ontario
AVL Powertrain Engineering, Inc., Novi, Michigan
BC Research Inc., Vancouver, British Columbia
Blackmer Pump, Grand Rapids, Michigan
Canadian Association of Fire Chiefs, Ottawa, Ontario
Canadian Liquid Air Ltd., Winnipeg, Manitoba, and Montreal, Quebec
Canadian Standards Association, Toronto, Ontario, and Edmonton, Alberta
Chrysler Canada, Windsor, Ontario
Concordia University, Montreal, Quebec
Cummins Engine Company, Inc., Columbus, Indiana
Dupont Co. Canada, Toronto, Ontario
Dupont Company, Flourochemicals, Wilmington, Delaware
Engineering Controls International, Inc., Elon College, North Carolina
Environmental Protection Agency, Ann Arbor, Michigan
Haldor Topsoe A/S, Lyngby, Denmark
Kraus Alternative Fuels, Winnipeg, Manitoba
Manitoba Hydro, Winnipeg, Manitoba
Matheson Gas Products Canada, Edmonton, Alberta
Michigan Technology University, Houghton, Michigan
National Fire Protection Association, Quincy, Maryland
National Renewable Energy Laboratory, Golden, Colorado
Natural Gas Odorizing, Inc., Baytown, Texas
Natural Resources Canada, Ottawa, Ontario
P.D McLaren, Burnaby, British Columbia
Petro-Canada Products, Calgary, Alberta
Phillips Chemical Co., Specialty Chemicals Group, Bartlesville, Oklahoma
Ramco Electrical Consulting, Calgary, Alberta
Shell Canada Products Ltd., Calgary, Alberta
Sleeger Engineering Inc., London, Ontario
Society of Automotive Engineers, Warrendale, Pennsylvania
Standards Council of Canada, Ottawa, Ontario
Statoil A/S, Copenhagen, Denmark
TNO Road Vehicles Research Institute, Delft, Holland
Transport Canada, Ottawa, Ontario, and Montreal, Quebec

Appendix B

Comparison of Properties of DME, Diesel, and Propane

Property	DME	Diesel	Propane
Chemical Formula	$(CH_3)_2O$		C_3H_8
Molar Mass - kg/mol	0.04607		0.0441
Stoichiometric Air/Fuel Ratio	9	14.6	15.6
Cetane Number	>>55	40-55	<10
Flammability Limits - percent in Air (V/V)	3.4-27[1]	0.6-6.5	2.4-9.5
Net Heating Value - kJ/kg	28.43	42.7	47.25
Auto-ignition Temperature - ^{o}C	235[2]	250	468
Flash Point - ^{o}C	-41	45 to 60	-104
Liquid Density - kg/L	0.6683	0.84	0.51
Relative Vapour Density (air=1)	1.59		1.52
Boiling Point - ^{o}C	-24.8	180-370	-42.1
Heat of Vaporization - kJ/kg	412	250	345
Vapour Pressure @ 20^{o}C - kPa	512		835
Odour	Slight		None
Odorant Added	To Be Determined		Ethyl Mercaptan
Color of Liquid	Colorless		Colorless

Sources of Information

Matheson Gas Data Book 6th Edition, 1980
DEA Handbook DME 99.99 Aerosol Propellant, January 1997
CAN/CGA-B149.2-M95 Propane Installation Code

[1] A number of sources listed the higher flammability limit as 18%
[2] A number of sources listed the auto-ignition temperature as 350 ^{o}C

Appendix C

Typical Propane Dispensing System