TP 13949E

Evaluation of Vehicle Fuel Safety Regulations and Test Methods for New Fuels and Technologies

Prepared for

Transportation Development Centre

Transport Canada

by

Charonic Canada Inc.

in conjunction with

Powertech Labs Inc.

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16. Abstract

This report analyses the regulatory environment and safety implications for the use of new vehicle fuels and their associated fuel system technologies. It includes a review of the properties of new fuels and information about their use in light-, medium- and heavy-duty vehicles, focussing on natural gas and hydrogen as the most likely options for the future. The report also contains a discussion of requirements for vehicle fuel systems under the Canadian Motor Vehicle Safety Regulations and compares these with requirements in the United States and Europe. Related codes of practice and test procedures are also examined, especially the B149.5 Installation Code for Propane Fuel Systems and Tanks on Highway Vehicles and the B109 Natural Gas for Vehicles Installation Code.

Fuel safety issues are summarized and analysed, and conclusions are drawn regarding suggested strategies for Transport Canada to develop regulations and test methods that would provide equivalent levels of safety between new vehicle fuels and traditional fuels. Recommendations are made regarding restructuring regulations to reflect categories of fuel properties, continuing and expanding the use of consensus and reference to other publications, participating in consultations concerning new and developing technologies, and establishing requirements in additional areas not covered by current regulations.

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16. Résumé

Ce rapport analyse le cadre réglementaire à mettre en place pour régir l'utilisation et garantir la sûreté des nouveaux carburants pour véhicules et des technologies d'alimentation connexes. Il examine les propriétés des nouveaux carburants et fournit des données sur leur utilisation dans les véhicules légers, moyens et lourds. Il s'intéresse tout particulièrement au gaz naturel et à l'hydrogène, ces carburants étant considérés comme les candidats favoris pour remplacer les carburants classiques. Le rapport rappelle en outre les exigences relatives aux systèmes d'alimentation des véhicules contenues dans le *Règlement sur la sécurité des véhicules automobiles* du Canada et compare ces exigences à celles en vigueur aux États-Unis et en Europe. Il se penche également sur les codes de pratique et les protocoles d'essai, notamment la norme B149.5, *Code d'installation des réservoirs et des systèmes d'alimentation en propane sur les véhicules routiers* et la norme B109, *Code d'installation au gaz naturel pour véhicules*.

Après une analyse des enjeux relatifs à la sûreté des carburants, les chercheurs suggèrent à Transports Canada des façons d'élaborer des règlements et des méthodes d'essai qui feront en sorte que les nouveaux carburants offriront des niveaux de sûreté équivalents à ceux offerts par les carburants classiques. Voici quelques-unes des recommandations contenues dans le rapport : réaménager la réglementation de manière à y regrouper les carburants possédant des propriétés communes; continuer à favoriser le recours à des normes consensuelles et à inclure dans les textes réglementaires des renvois à d'autres publications; mener des consultations sur les technologies nouvelles et émergentes; établir des exigences touchant des domaines non couverts par la réglementation actuelle.

17. Mots clés Carburants de substitution, nouveaux carburants, sûreté des carburants pour véhicules, véhicules au gaz naturel, véhicules à l'hydrogène, règlement de sécurité, GNC, GNL, GPL	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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Executive Summary

There has been considerable interest and investment in alternative and renewable fuels in Canada and in other countries throughout the world. Canadian organizations are currently developing technology for hydrogen and natural gas, and it is expected that vehicles using these “new fuels” will be developed and marketed within the next few years.

Transport Canada identified the need to evaluate the safety aspects of new fuels and fuel system technologies, and to devise appropriate strategies for the development of regulations that provide equivalent levels of safety between new fuels and traditional fuels. In the project initiated to address these issues, Charonic Canada Inc., in conjunction with Powertech Labs, was requested to review the properties of liquefied natural gas (LNG) and other fuels, such as hydrogen, and compare the safety implications of their use to conventional and current gaseous fuels, such as liquefied petroleum gas (LPG) and compressed natural gas (CNG).

The new fuels and technologies for both light- and heavy-duty vehicles were reviewed to determine how Canada might structure regulations and test methods to ensure that these fuels and technologies meet the same safety levels as traditional fuels.

As well, current industrial test procedures were reviewed and evaluated to consider how Canada should establish procedures for preparing and testing vehicles. Current provincial regulations were also reviewed and consultations were held with provincial regulatory agencies and manufacturers to determine their current strategies for ensuring safe vehicle testing, repair and disposal.

The information was assessed and recommendations were made regarding the structure of regulations, the use of consensus and other standards, participation and consultation, and areas of coverage. The major recommendations are stated below.

Structure of Regulations

To provide adequate safety coverage for new fuels and technologies (including hydrogen, CNG, LNG or other possible fuels or fuel mixtures), it is recommended that Transport Canada:

- Restructure its fuel safety regulations to reflect fuel properties rather than establish a new regulation for each fuel.
- Move issues and procedures that pertain to all fuels to one main section and establish sub-regulations (i.e., 301.1, etc.) to address issues applicable to specific fuel types.
- State the intent for each requirement in a preamble, then list acceptable procedures for demonstrating the required level of safety.
- Introduce explicit language that requires multi-fuelled vehicles to meet the requirements of each fuel type.

Use of Consensus and Other Standards

With the rapid pace of technological development, it is unlikely that Transport Canada will be able to maintain in-house expertise to develop detailed regulations on all aspects of new fuels and technologies. It is recommended that Transport Canada:

- Continue and expand the use of reference publications in its regulations and test methods.
- Refer to the latest edition of a standard where a standard is published by a recognized agency with an established development and review procedure equivalent to that required by the Standards Council of Canada for Canadian Standards.
- Continue to allow the use of assembly codes and standards as an alternative to crash testing vehicles.

Participation and Consultation

In new or rapidly developing technology areas, it is recommended that Transport Canada:

- Ensure that it is a participant in the development and/or the approval of new standards that pertain to new fuels or fuel technologies.
- Initiate public consultations with vehicle manufacturers and importers of vehicles using new fuels, regarding audit procedures designed to ensure compliance with Canadian regulations.
- In conjunction with other national regulatory agencies, consider sponsoring sessions on regulatory issues at major conferences on the development of hydrogen- or LNG-fuelled vehicles.

Areas of Coverage

In areas not covered by present regulations, Transport Canada should consider establishing requirements on the following topics:

- Fuel system components that are designed to fail in crashes to protect the fuel storage system.
- Independent evaluation of fuel system components used in “built-to-code” vehicles.
- Limits on the amount of fuel that may be accumulated external to the fuel storage system.
- Minimum requirements for all types fuel storage tanks.
- Impact resistance for fuel storage systems mounted in saddle position on heavy-duty vehicles.

Transport Canada should initiate consultations with the provinces and territories with respect to issues that pertain to areas under provincial jurisdiction but are fixed at the time of manufacture. Two identified areas where national standards would be beneficial are:

1) Unique fuelling connectors for each fuel.
2) De-fuelling procedures to be followed for vehicle testing, maintenance and disposal.

Sommaire

Les carburants de substitution et les carburants renouvelables suscitent un intérêt et des investissements considérables au Canada et partout ailleurs dans le monde. Des sociétés canadiennes travaillent présentement au développement de technologies devant appuyer l'utilisation de l'hydrogène et du gaz naturel, et il faut s'attendre à voir apparaître sur les routes, d'ici quelques années, des véhicules qui seront mus par ces «nouveaux carburants».

Pour Transports Canada, il reste à évaluer la composante sécurité des nouveaux carburants et technologies connexes, et à établir des stratégies de réglementation qui feront en sorte que les nouveaux carburants offriront des niveaux de sûreté équivalents à ceux offerts par les carburants classiques. Voilà l'origine du présent projet. Son exécution a été confiée conjointement à Charonic Canada Inc. et à Powertech Labs. Le mandat des chercheurs consistait à examiner les propriétés du gaz naturel liquéfié (GNL) et d'autres carburants, dont l'hydrogène, et de comparer les risques qu'ils représentent par rapport aux carburants classiques et aux carburants gazeux actuellement sur le marché, comme le gaz de pétrole liquéfié (GPL) et le gaz naturel comprimé (GNC).

Les chercheurs ont passé en revue les nouveaux carburants et technologies destinés aux véhicules légers et aux véhicules lourds afin de voir comment le Canada pourrait aménager ses règlements et ses méthodes d'essai de façon que les nouveaux carburants et technologies soient aussi sûrs que les carburants classiques.

Ils ont ensuite évalué les protocoles d'essai en usage dans l'industrie, afin d'examiner comment le Canada devrait s'y prendre pour encadrer la préparation et l'essai des véhicules. Ils ont également dépouillé les règlements provinciaux en vigueur et tenu des consultations avec les organismes de réglementation des provinces et les constructeurs automobiles, afin de connaître les mesures qu'ils prennent pour garantir la sûreté des essais, de la réparation et de la mise au rebut des véhicules.

À la lumière de l'information recueillie, des recommandations ont été formulées concernant l'aménagement de la réglementation, le recours à des normes consensuelles et autres, la participation et la consultation, et les nouveaux domaines devant être couverts par la réglementation. Les principales recommandations sont présentées ci-après.

Aménagement de la réglementation

Pour couvrir adéquatement l'aspect sécuritaire des nouveaux carburants et technologies (y compris l'hydrogène, le GNC, le GNL ou d'autres carburants ou mélanges de carburants éventuels), il est recommandé que Transports Canada :

- réaménage sa réglementation sur la sûreté des carburants de façon à regrouper les carburants selon leurs propriétés, plutôt que d'établir une réglementation distincte pour chaque carburant;
- regroupe dans de grands articles de loi les questions et procédures communes à tous les carburants et élabore des paragraphes distincts (301.1, etc.) pour traiter des sujets applicables à des types particuliers de carburants;
- énonce l'intention de chaque exigence dans un préambule, puis énumère les méthodes jugées acceptables pour démontrer que le degré de sûreté exigé est atteint;
- établisse explicitement que les véhicules à carburants multiples sont assujettis à toutes les exigences relatives à chaque type de carburant.

Recours aux normes consensuelles et autres

Compte tenu du rythme rapide auquel évolue la technologie, il est peu probable que Transports Canada soit en mesure de maintenir à l'interne l'expertise nécessaire pour élaborer en détail des règlements couvrant tous les aspects des nouveaux carburants et technologies. Il est donc recommandé que Transports Canada :

- continue à inclure dans ses textes réglementaires des renvois à des publications et des méthodes d'essai émanant d'autres organismes, et accentue même le recours à de tels renvois;
- cite la dernière édition d'une norme, dans le cas où une norme pertinente existe et qu'elle est publiée par un organisme reconnu, doté d'une procédure d'élaboration et d'examen bien établie, équivalente à celle qui est exigée par le Conseil des normes du Canada pour les normes canadiennes;
- continue d'autoriser l'utilisation de codes et de normes de montage plutôt que d'exiger des essais de choc des véhicules.

Participation et consultation

Pour ce qui touche les nouvelles technologies ou les technologies émergentes, il est recommandé que Transports Canada :

- prenne part à l'élaboration et/ou l'approbation des nouvelles normes ayant trait aux nouveaux carburants ou aux nouvelles technologies touchant les carburants;
- lance des consultations publiques avec les constructeurs et importateurs de véhicules utilisant de nouveaux carburants, pour l'établissement de méthodes de vérification destinées à garantir la conformité des véhicules à la réglementation canadienne;
- envisage de parrainer, de concert avec les organismes de réglementation d'autres pays, des séances sur l'aspect réglementaire des nouveaux

carburants, lors des grandes conférences sur le développement de véhicules à l'hydrogène ou au GNL.

Portée de la réglementation

Transports Canada devrait envisager d'établir des règlements couvrant les questions suivantes :

- Que les composants des systèmes d'alimentation en carburant soient conçus pour devenir inopérants en cas d'accident, de façon à assurer la protection du système de stockage du carburant.
- Que les composants des systèmes d'alimentation en carburant des véhicules «construits conformément au code» soient soumis à une évaluation indépendante.
- Que des limites soient imposées à la quantité de carburant pouvant être accumulée à l'extérieur du système de stockage du carburant.
- Que des exigences minimales soient établies pour tous les types de réservoirs de carburant.
- Que des normes de résistance au choc soient élaborées pour les systèmes de stockage de carburant montés latéralement sous le châssis des véhicules lourds.

Transports Canada devrait entreprendre des consultations avec les provinces et les territoires sur les questions qui relèvent du champ de compétence des provinces mais qu'il importe de régler au moment de la fabrication des véhicules. Voici, enfin, deux secteurs dans lesquels ils serait avantageux de disposer de normes nationales :

1) Prises de remplissage spécialisées pour chaque carburant.
2) Procédures de reprise du carburant lors des essais, de la réparation et de la mise au rebut des véhicules.

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Glossary of Acronyms

AGA	American Gas Association
ANSI	American National Standards Institute
BLEVE	Boiling Liquid Expanding Vapour Explosion
CFR	US Code of Federal Regulations
CGA	Compressed Gas Association
CMVSR	Canadian Motor Vehicle Safety Regulations
CNG	Compressed Natural Gas
CSA	Canadian Standards Association
ECE	Economic Commission for Europe
ISO	International Organization for Standardization
FMVSS	US Federal Motor Vehicle Safety Standards
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NFPA	National Fire Protection Association
NGV	Natural gas (fuelled) vehicle
NHTSA	US National Highway Traffic Safety Authority
PRD	Pressure Relief Device
SAE	Society of Automotive Engineers

1. Introduction

In the early days of the development of fuel-powered transportation, many fuels were tried, with various degrees of success. Diesel's work with pulverized coal dust,[1] Ford's belief in ethanol,[2] and the fact that there were more electric than internal combustion vehicles in Ontario at one time demonstrates the ingenuity and open-mindedness of the transportation industry.

With the advent of cheap and readily available crude oil after World War II, the focus became refining and improving gasoline as the spark ignition fuel and diesel as the compression ignition fuel. These fuels have been continuously reformulated and improved to reflect changing economics and the requirements of increasingly sophisticated engine systems.

1.1 New Fuels Being Considered for Use

Starting in 1978, several oil price shocks shattered the complacency of this perspective and stimulated renewed interest in alternative and renewable fuels. Since then, there has been considerable interest and investment in both alternative and renewable fuels. The term "alternative" was coined to designate fuels derived from natural gas, or synthetic fuels such as methanol or Fischer-Tropsch diesel[3] produced from coal. The term "renewable fuels" is used for fuel produced from biological origins. Examples include ethanol produced by the fermentation of grains, methanol from wood wastes, or biodiesel from oil seeds.

Hydrogen is properly an energy carrier and as such can be either an alternative or a renewable fuel, depending on the source of the fuel. Due to hydrogen's unique properties, it has the potential for being used with technologies that may significantly reduce both carbon dioxide and local pollutants that produce urban smog.

Liquified natural gas (LNG) is a cryogenic fuel used in heavy-duty lean burn engines and its use is expected to grow as those technologies improve.

A number of synthetic fuels such as dimethyl ether are also being discussed, although these are not currently being used in Canada.

Alternative and renewable fuels have achieved a considerable degree of penetration into niche markets, but no fuel has yet proved to be a significant challenge to the established (but evolving) conventional fuels in the global marketplace. Despite the continued popularity and success of conventional fuels, there is a consensus that the supply of these fuels is limited – the disagreement lies in the timing of the transition to other fuels. Opinions on this transitional timeframe vary from a few years to several centuries.

Canada has a strong interest and position in both hydrogen and LNG vehicle technologies and it is expected that vehicles using these fuels will be developed and used in the country in the next few years.

It is anticipated that the focus of new fuels will be on hydrogen for light-duty and heavier-duty vehicles, such as transit buses, that return to a central location each day. At present, LNG is being proposed for diesel substitution in medium- and heavy-duty vehicles.

1.2 Properties of Fuels

The design of the fuel storage and handling systems on a vehicle is dictated by the properties of the fuel and differs significantly from fuel to fuel. The choice of fuel does not necessarily result in any increase or decrease in hazard. However, any crash that releases any fuel may create a hazard to persons in the vehicle, bypassers and rescue personnel, and the release of new fuels may have unfamiliar effects. For example, the noise from venting pressurized gas lines or the frost and vapour plume from cryogenic liquid spills are not particularly hazardous in themselves, but may cause panic and result in inappropriate responses because they are unfamiliar situations.

A summary of important property values for conventional and new fuels is shown in Table 1. The molecular weight given in the table is either that of the predominant component of the fuel or, in the case of gasoline and diesel, a typical value. As shown in the gas density row, hydrogen and natural gas are lighter than air and will tend to dissipate rapidly. Any propane vented will also be a gas but it will tend to pool at ground level, creating a hazard similar to that of liquid fuels with high vapour pressure.

The heat of combustion and the ignition energy measure the heat that will be liberated and the energy required to cause that ignition. In reality, vehicles will carry enough fuel so that the potential energy release will be similar and, in a crash situation, the available ignition sources will be sufficient to ignite any of the catalogued fuels. The exception may be diesel fuel. Diesel fuel is considerably more difficult to ignite because of its higher ignition temperature compared to the other fuels listed.

Flammability limits are important in enclosed spaces when vapours may reach sufficient concentration to ignite or, in the worst situation, cause deflagration. This is unlikely to occur on a vehicle used on highways but may be of concern when vehicles are used or stored in enclosed spaces. The concentrations shown are for air at room temperature and one atmosphere pressure. The upper flammability limit percentage of fuel for stoichiometric combustion in air at room temperature can dictate the worst situation.

Although there are inherent hazards to consider in the case of each fuel specified, careful risk assessment of both conventional and non-conventional new fuels is important in designing and considering new technologies. Understanding fuel properties is an important part of this process.

Table 1 Selected Properties of Selected Fuels[4]

Property	Hydrogen	Methane[a]	Methanol	Propane[b]	Dimethyl ether	Ethanol	Gasoline[c]	Diesel[d]
Molecular weight of pure fuel	2.02	16.04	32.04	44.11	46.05	46.05	~110	~150
Boiling Point at 1 atmosphere (°C)	-253	-162	65	-42	-22	78	-	-
Density of gas at NTP	0.09	0.72	1.50	1.52	1.6	1.6	~6.00	~7.00
Density of liquid at room temperature (g/L)	-	-	790	510	670	789	~740	~835
Density of liquid at boiling point (g/L)	70	420	-	-	-	-	-	-
Critical pressure (bar)	0.13	0.46	7.9	0.42	3.69	-	-	-
Critical temperature (°C)	-240	-82	240	97	127	-	-	-
Heat of combustion (MJ/kg)	120	56	22	50	28.8	38.5	48	45
Ignition energy in (mJ/g)	20	300	200	250	290		250	-
Lower flammability limit in air at room temperature and one atmosphere (%)	4%	5%	6%	2%	3%	3%	1%	1%
Upper flammability limits in air at room temperature and one atmosphere (%)	75%	15%	36%	10%	18%	25%	8%	7%

[a] The properties of commercial natural gas in Canada will vary slightly from these values.

[b] The properties of commercial liquefied petroleum gas (LPG) or auto-propane will vary from these values depending on the source of supply.

[c] Gasoline is a complex mixture of hydrocarbons and additives and the values shown will be approximate.

[d] Diesel is a complex mixture of hydrocarbons and additives and the values shown will be approximate.

1.3 Light-Duty Vehicles

As noted earlier, many fuels and engine technologies have been proposed and used during the past 100 years of motorized vehicles. In the 1970s and 1980s, a perceived shortage of oil led to the development of natural gas-based fuels (compressed natural gas (CNG) and LPG), bio-fuels (principally ethanol), coal-derived fuels and, based on the precept of electricity being a renewable resource, electric vehicles. Encouraged by government policies, natural gas-based fuels have become popular in some market segments in a number of geographic areas, and ethanol was for a period a significant fuel in Brazil.[5] Ethanol is now a common additive to gasolines in the United States.

In the 1980s and 1990s a second wave of new fuel vehicles was developed based on air quality considerations. The simpler combustion characteristics of the alternative fuels developed during the 1970s and 1980s allowed vehicles using these fuels to achieve much lower emissions than those fuelled by conventional gasolines and diesel fuels.

In the 1990s, improvements to both conventional fuel formulations and to vehicle pollution control systems had narrowed the absolute gap (although not necessarily the ratio) in emissions between new and conventional fuels. However, during the 1990s an increasing body of evidence suggested that the increase in greenhouse gases was having a noticeable and significant effect on the world's climate. As a major source of greenhouse gases, the transportation industry has again come under pressure to modify the amount and type of fuel being consumed.

These issues have converged over the past 30 years, leading to hydrogen and natural gas being considered as serious candidates to replace conventional fuels. During this period, many permutations and combinations of fuels and technologies have been considered and evaluated in the transportation industry, but there are three concepts that need to be considered from a regulatory viewpoint:

1) The consequences of a "loss of vacuum" incident in a vehicle using a cryogenic fuel such as LNG, or venting from such a vehicle that is parked for an extended period of time.
2) Situations in which significant quantities of fuel are contained or accumulated outside the fuel tank that holds the original fuel. This may occur in fuel cell vehicles equipped with a fuel processing system that reforms fuels such as methanol or gasoline to hydrogen that is used by the fuel cell.
3) Systems that remove a liquid from a fuel tank and accumulate this as a high-pressure gas for injection into the engine. Examples include liquid propane and LNG withdrawal systems.

Although these technologies will be implemented differently on light-duty and heavy-duty vehicles, it does not appear that a different regulatory approach will be required for the different types of vehicles.

The decrease in cost of and increase in reliability of sensors, together with the increasing power of in-vehicle computers, can be expected to increase the complexity of fuel storage systems. While this should lower the number of loss-of-fuel incidents, it will also increase the complexity of auditing compliance with fuel safety regulations. Currently, fuel lock-offs for gasoline and natural gas vehicles (NGVs) whereby the fuel storage tanks are isolated in the event of a crash that is sufficiently severe to trigger the air bags are being introduced into the market.

Hydrogen is the most likely candidate of the new fuels for use in light-duty vehicles. While compressed hydrogen gas appears to be the fuel most widely discussed in Canada and the US, the US Department of Energy 2003 budget submission to Congress[6] cites a lack of fuelling technology infrastructure and states that it is focussing on the on-board generation of hydrogen from fossil fuels as the most likely option in the near term.

1.4 Medium- and Heavy-Duty Vehicles

Natural gas is the only new fuel being considered as an alternative to conventional diesel fuel for medium- and heavy-duty vehicles. Because of natural gas's low cetane number, two approaches have been taken: pilot ignition using diesel fuel, and conversion to spark ignition.

Early work in Canada[7] failed to achieve simultaneous emission and power targets, but has been further developed by Clean Air Partners,[8] which has marketed dual-fuel/natural gas engines through Caterpillar for Class 7 and 8 trucks. These vehicles typically retain one or more of the original diesel fuel tanks, and additional fuel tanks for CNG (for short-range operation) or for LNG (for long-range operation) are added either as saddle tanks or behind the cab. Although this technology has achieved limited market success, a new system is being developed by Westport[9] that uses a micro-pilot diesel/high-pressure natural gas system. Vehicles using this system would require a smaller diesel fuel tank and an LNG fuel system with a high-pressure fuel vaporizer.

The alternative approach developed by Cummins[10] and John Deere[11] uses a spark ignition system. Since the required fuel pressure is comparatively low (5 to 10 bar), the fuel for these vehicles may be either CNG or LNG.

The majority of medium- or heavy-duty vehicles in service that have been built and operated using hydrogen as a fuel are buses. The predominant means to store the fuel is 200 or 240 bar cylinders similar to those used for storing natural gas. To achieve the required operating range, storage cylinders of up to 900 bar have been proposed.

2. Regulatory Environment

The safety of motorized vehicles has been an issue for governments since their introduction. Early restrictions, such as the often-quoted requirement for a pedestrian with a red flag to warn of an approaching vehicle, have been replaced with a sophisticated set of regulations that address modern vehicle technology and driving conditions.

Initially welcomed as a solution to the pollution and wastes produced from horse-drawn carriages, motorized vehicles have introduced a new set of environmental issues and constraints. Urban smog, carcinogens, and more recently global climate change have spurred new regulations. Fuels and technologies have been and continue to be developed to address these concerns. The automotive and fuel supply industries continue to experiment with new and reformulated fuels to respond to new issues, often in partnership with governments.

The responsibility for vehicle safety in Canada is divided between the federal government and the provinces. The federal government sets regulations for the manufacture of vehicles, but once a vehicle has been sold, the provinces have the responsibility for maintenance and vehicle modifications. Federal and provincial responsibilities are discussed in more detail in Section 3.

The United States and Western Europe have similar regulatory frameworks to Canada's. This is discussed in further detail in sections 2.1 through 2.3.

2.1 Canada

In Canada, the federal government has jurisdiction over the manufacture and importation of motor vehicles, with the power to require manufacturers or importers to remedy faults on vehicles that are found to be in contravention of any federal regulation. The Canadian Motor Vehicle Safety Act[12] provides for and requires that the Governor General of Canada in Council make regulations for carrying out the purposes and provisions of the Act.

Canada has established three sets of regulations and test methods related to fuel technology:

- CMVSR 301 *Fuel System Integrity*[13] for conventional liquid hydrocarbon fuels (gasoline and diesel);
- CMVSR 301.1 *LPG Fuel System Integrity*[14] for propane; and
- CMVSR 301.2 *CNG Fuel System Integrity*[15] for natural gas.

The three regulations and test methods reflect the different properties of the fuels they regulate and are intended to provide an equivalent level of safety for vehicles powered by those fuels. A summary of the requirements is given in Table 2. Although multi-fuelled vehicles are not specifically addressed in the regulations, industry practice has been to ensure that each fuel system meets the requirements for that fuel.

Table 2 Canadian Motor Vehicle Safety Regulation Requirements

Regulation	Title	Summary of Requirements
301	Fuel System Integrity	Spill less than 140 g of test fluid in the 5 minutes after crash.
301.1	LPG Fuel System Integrity	No leakage of test fluid in the 30 minutes after crash. Temperature compensated pressure in fuel container drops less than 10 bar in 60 minutes after crash. Fuel tank(s) to remain attached to vehicle.
301.2	CNG Fuel System Integrity	Temperature compensated pressure in fuel system drops less than 5% in the 30 minutes after crash. Fuel tank(s) to remain attached to vehicle.

CMVSR 301 is a performance requirement and, unlike the US and Economic Commission for Europe (ECE) regulations, Canada has no requirements for the design and testing of liquid-fuel containers or fuel system components. The Canadian "crash test" approach is straightforward, but a crash test does not allow evaluation of all the situations that may occur during and after an accident. In some situations crash testing may prove to be a major hurdle to innovation, as evaluating a fuel tank in situ (with the cylinder on board the vehicle) by this technique is expensive.

While Canadian regulations do provide assurances against fuel leakage from the tested tank during and after the performance of the test, they do not provide any assurances against failure if the fuel storage system is subjected to excessive heat or fire, or if the vehicle is mis-fuelled.

The 2001 *Canadian Regulations Amending the Motor Vehicle Safety Regulations (Fuel System Integrity Requirements)*[16] apply the same crash test requirement for LPG vehicles, but offer an alternative certification system. The regulations state that as an alternative to crash testing, a vehicle, other than a school bus, that is equipped with a fuel system that uses LPG as a source of energy for its propulsion must comply with:

(a) The National Standard of Canada *CAN/CGA-12.2, Propane Fuel System Components for Use on Highway Vehicles,*[17] and

(b) The National Standard of Canada CAN/CGA-B149.5, Section 4 *Installation Code for Propane Fuel Systems and Tanks on Highway Vehicles.*[18]

With regard to CNG vehicles, the 2001 regulations state that as an alternative to crash testing, a vehicle, other than a school bus, that is equipped with a fuel system that uses CNG as a source of energy for its propulsion may comply with

Section 4 of the current version of Canadian Standards Association Standard *CSA B109, Natural Gas for Vehicles Installation Code.*[19]

In addition, the regulations require that CNG cylinder designs comply with either:

(a) The Canadian Standards Association Standard CSA B51 Part 2*, High-Pressure Cylinders for the Onboard Storage of Natural Gas as a Fuel for Automotive Vehicles;*[20] or

(b) The American National Standard ANSI/AGA – NGV2 *Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers.*[21]

2.2 United States

The United States National Highway Traffic Safety Administration (NHTSA) has a legislative mandate under Title 49 of the *United States Code* to issue road and vehicle safety standards. Manufacturers of motor vehicles and equipment must conform and certify compliance with these. The preamble to these documents states that the requirements shall be specified in such a manner that the public is protected against unreasonable risk of crashes occurring as a result of the design, construction, or performance of motor vehicles, and is also protected against unreasonable risk of death or injury in the event that crashes do occur. [22]

There are two Parts of the regulations that are applicable to this study: Part 393, *Parts and Accessories Necessary for Safe Operation,*[23] and Part 571 *Federal Motor Vehicle Safety Standards.*[24]

Part 393 states that employers and employees of companies involved in interstate commerce shall comply and be conversant with the requirements and specifications of Part 393. Conventional fuel safety is addressed in Sections 393.65 *All Fuel Systems,* [25] 393.67 *Liquid Fuel Tanks*,[26] and 571.301 *Fuel System Integrity.*[27] LPG fuel system safety is discussed in Section 393.69 *Liquefied Petroleum Gas Systems.*[28]

Section 393.69 of the regulations requires that a fuel system that uses LPG as a fuel for the operation of a motor vehicle or for the operation of auxiliary equipment installed on a motor vehicle must conform to NFPA 58, *Standards for the Storage and Handling of Liquefied Petroleum Gases.*[29] The code specifies that a fuel system providing fuel for:

(a) propulsion of the motor vehicle must conform to Division IV of the Standards.

(b) the operation of auxiliary equipment must conform to Division VII of the Standards.

NFPA 58 is a lengthy and comprehensive document. Vehicle systems for propulsion are addressed in six pages in Chapter 8 *Engine Fuel Systems*. This chapter in turn references various standards issued by the American Society for Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), and the American National Standards Institute (ANSI).

Part 571 contains the safety standards for motor vehicles and motor vehicle equipment. CNG fuel system safety is addressed in Sections 571.303 *Fuel System Integrity of Compressed Natural Gas Vehicles*[30] and 571.304 *Compressed Natural Gas Fuel Container Technology.*[31]

Section 303 contains the requirements for crash testing CNG vehicles. The fuel spillage measurements are modified from those in the liquid fuels test to require that the fuel spillage be monitored by measuring the temperature compensated pressure drop in the fuel system.

Section 304 contains the requirements for fuel storage containers. Three tests are required: burst pressure, pressure cycling, and bonfire tests. There are no environmental, sustained pressure, or non-ambient temperature tests required. The latter tests have been introduced into the industry codes to address specific known failures.

2.3 The Economic Commission for Europe

The ECE *Inland Transport Committee for Harmonization of Vehicle Regulations* has established uniform technical prescriptions for wheeled vehicles, and equipment and parts that can be fitted and/or used on wheeled vehicles. In particular, Part I of ECE Regulation No. 34, *Uniform Provisions Concerning the Approval of Vehicles with Regard to the Prevention of Fire Risks,* [32] deals with the approval of a vehicle regarding its fuel tanks and is similar in scope to the United States 49 CFR Standard Part 393. Part II deals with the approval of a vehicle with regard to the prevention of fire risks in the event of a collision, similar in scope to the United States 49 CFR Standard Part 571.

The ECE has established separate regulations to cover LPG-powered vehicles, electric vehicles, and CNG-powered vehicles. These three documents encompass much of the same areas as the Canadian and American counterpart regulations.

ECE Regulation No. 67, *Uniform Provisions Concerning the Approval of Specific Equipment of Motor Vehicles Using Liquefied Petroleum Gases in their Propulsion System,*[33] is a comprehensive document that, with its 20 annexes, stretches to 146 pages. Section 6 *Specifications Regarding the Various Components of the LPG Equipment* and Section 9 *Conformity of Production* deal with the technical requirements, although Section 9 refers to the annexes for many of the mandatory control tests.

ECE Regulation No. 100, *Uniform Provisions Concerning the Approval of Battery Electric Vehicles with Regard to Specific Requirements for the Construction and Functional Safety,*[34] provides comprehensive coverage of battery-powered electric vehicles.

ECE Regulation No. 110[35] is a comprehensive document concerning natural gas-fuelled vehicles. It comprises two sections: Section I. *Uniform Provisions Concerning the Approval of Specific Components of Motor Vehicles Using*

Compressed Natural Gas (CNG) in their Propulsion System, and Section II. *Uniform Provisions Concerning the Approval of Vehicles with Regard to the Installation of Specific Components of an Approved Type for the Use of Compressed Natural Gas (CNG) in their Propulsion System.* In general terms, Section I provides the same coverage as the CSA natural gas vehicle component standards, and Section II provides similar coverage to the CSA vehicle installation code. Annex 3 Section 6 repeats the coverage given in CSA B51 Part 2, ANSI NGV2 and ISO 11439,[36] and Annex 4 provides similar coverage to the harmonized CGA 12.3/ANSI/AGA NGV 3.1[37] and CSA 12.5. ANSI/IAS NGV 4.1[38] standards. This is similar to the coverage of ISO 15500 Parts 1 through 19.[39]

Table 3 lists existing regulations and how they address requirements and testing for liquid fuels, LPG fuel, and CNG fuel.

Table 3 Summary of Requirements for Vehicle Fuel Systems

Regulation	Liquid Fuels	LPG	CNG
ECE Regulation No. 34	Internal pressure test, plus special tests on plastic tanks.		
ECE Regulation No. 67		Comprehensive specifications for the design and testing of fuel tanks and systems.	
ECE Regulation No. 100	Crash tests of vehicles.		
ECE Regulation No. 110			Comprehensive specifications for the design and testing of fuel tanks and systems.
US FMVSS Section 393.65 and Section 393.67	Pressure resistance, overfill protection, venting system, drop tests, fill pipes, etc.		
US FMVSS Section 393.65 and Section 393.69		Comprehensive specifications for the design and testing of fuel tanks and systems, by reference to NFPA standards.	
US FMVSS Section 571.301	Crash tests of vehicles.		
US FMVSS Section 571.303			Crash tests for CNG and bi-fuelled vehicles.

Regulation	Liquid Fuels	LPG	CNG
US FMVSS Section 571.304			Pressure cycling, hydrostatic burst test and bonfire test on fuel containers.
CMVSR 301	Crash tests of vehicles.		
CMVSR 301.1		Alternative method requires comprehensive testing of components under Canadian national standard and installation in accordance with national code.	
CMVSR 301.2			Comprehensive testing of fuel tanks required, by reference to cylinder standards. Alternative method requires comprehensive testing of components under Canadian national standard and installation in accordance with national code.

3. Review of Existing Canadian Practices

3.1 Canadian Federal Test Methods

The Canadian federal test methods for light-duty vehicles and school buses require that a vehicle be subject to a simulated crash. Reflecting the commonality of vehicles sold across North America, the Canadian procedures appear to be identical to those currently used in the United States. The proposed changes to FMVSS Part 301 in the United States would require an offset rear crash test procedure. This procedure specifies that 70 percent of the rear of the vehicle would be impacted by a 1,368 kg deformable barrier at 80 km/h (50 mph). In addition, the amount of fuel spillage occurring in the Federal Motor Vehicle Safety Standard (FMVSS) Section 214[40] test would be considered. It is anticipated that the arguments made in the United States will convince Canadian regulators to adopt similar changes.

ECE Regulation No. 34 requires a 48 to 53 km/h frontal fixed barrier impact test and a 35 to 38 km/h rear moving flat barrier impact test. The flat barrier weighs 1,100 kg (± 20 kg). As an alternative, a pendulum can be used as the impactor. This regulation does not require a rollover test but does require a hydraulic internal-pressure test for all liquid-fuel tanks, and additional tests for impact resistance, mechanical strength, and fire resistance for plastic tanks.

There are differences between Canadian test methods and those in force in the United States and the European Community, and although marginal systems may be affected in these tests (i.e., they may pass in one set but fail in another), it is considered unlikely that the choice of one set of tests over another would systematically disadvantage any one fuel. The discharge of fuel remains the biggest safety and environmental concern for all the fuels considered as part of this study.

In addition to federal test methods there are two Canadian installation codes that are currently referenced by and pertinent to federal regulations. As well, there are current test procedures followed for light- and heavy-duty vehicles. Consideration of hydrogen installation standards has also been on the Canadian regulatory agenda.

3.2 B149.5 LPG Vehicle Code

The CAN/CSA B149.5 *Installation Code for Propane Fuel Systems and Tanks on Highway Vehicles* covers the selection and installation of propane (LPG) fuel system components and fuel tanks used on highway vehicles for the provision of motive power. The code states that it shall apply equally to and include any fuel that is comprised predominantly of propane, propylene, butanes, butylenes or mixtures thereof.

The code specifically exempts motor vehicles that are manufactured with a propane fuel system that meets the requirements of the Canadian Motor Vehicle Safety Standard 301. The latter wording is curious, but is almost certainly intended to exempt vehicles that have been (self) certified under the provisions of the Canadian Motor Vehicle Safety Act. However, Safety Standard 301.1 explicitly allows the code to be used in the manufacture of LPG powered vehicle as follows:

> (3) Instead of complying with subsections (1) and (2), a vehicle, other than a school bus, that is equipped with a fuel system that uses LPG as a source of energy for its propulsion may comply with
>
> (*a*) the version of National Standard of Canada CAN/CGA-12.2, *Propane Fuel System Components for Use on Highway Vehicles*, that is in effect 24 months before the date of manufacture of the vehicle, as shown on the vehicle compliance label, or a more recent version of that Standard, despite any statement to the contrary in that Standard; and
>
> (*b*) section 4, *Installation of Propane Fuel Systems and Tanks on Highway Vehicles*, of the version of National Standard of Canada CAN/CGA-B149.5, *Installation Code for Propane Fuel Systems and Tanks on Highway Vehicles*, that is in effect 24 months before the date of manufacture of the vehicle, as shown on the vehicle compliance label, or a more recent version of that Standard, except that the following requirements do not apply:
> (i) any requirement to obtain an approval from an authority having jurisdiction or an inspection authority of a province or territory, and
> (ii) any requirement for the inspection or requalification of a fuel system or tank after the main assembly of the vehicle has been completed.[41]

This code is adopted (with some modification) by provincial regulatory authorities across Canada.

3.3 B109 CNG Vehicle Code

The CSA B109 *Natural Gas for Vehicles Installation Code* states that it applies to the installation, servicing, and repair of natural gas fuel systems on self-propelled vehicles for the provision of motive power. Specifically excluded from the scope are:

- Stationary engines.
- Mobile equipment using natural gas as a fuel for other than propulsion.
- LNG vaporizers and LNG fuel storage systems.
- Electronic components of a fuel management system.
- Storage or utilization of natural gas on boats or trains.

The Canadian Motor Vehicle Safety Standard 301.2 explicitly allows the code to be used in the manufacture of natural gas-powered vehicles as follows:

(3) Instead of complying with subsection (1), a vehicle, other than a school bus, that is equipped with a fuel system that uses CNG as a source of energy for its propulsion may comply with section 4 of the version of Canadian Standards Association Standard CSA B109, *Natural Gas for Vehicles Installation Code*, that is in effect 24 months before the date of manufacture of the vehicle, as shown on the vehicle compliance label, or a more recent version of that Standard, except that the following requirements do not apply:
(*a*) any requirement to obtain an approval from, or to act under the supervision of, an authority having jurisdiction or the boiler and pressure vessel inspection authority of a province or territory; and
(*b*) any requirement respecting inspection, service or repair after the main assembly of the vehicle has been completed.[42]

Provincial regulatory authorities across Canada have also adopted this code (with some modification).

3.4 Current Industry Light-Duty Vehicle Test Procedures

Current industry test procedures are based on extensive evaluation of components and then overall evaluation of the assembled sub-system or vehicle. While procedures that are applicable to new conventional fuels and technologies are published as industry standards, usually as documents published by the Society of Automotive Engineers (SAE), automotive companies are reluctant to discuss procedures for new vehicles and technologies. There appear to be two reasons for this reluctance.

The first reason is that companies instruct employees not to disclose data that may give competitors a commercial advantage. Since engineering staff are not necessarily in a position to know the commercial implications of their work, they are reluctant to provide information without getting official clearance.

Second, there is a reluctance to supply information about work-in-progress, as there is concern that the information may be picked up and included in a requirement. This could make it difficult to revise or abandon projects. Complicated test procedures that are undertaken in the early stages of development are often revised or consolidated as the technology approaches commercialization. This has been the case in the development of an environmental test procedure for natural gas storage containers. A simple test procedure was found to correlate better with field data than an earlier complex procedure that attempted to simulate in-service experience.

Consultations were held with:

General Motors of Canada Ltd.	Bill Ball
Chrysler Corporation	Larry Robertson
Ford Motor Company	Tom Barker

3.5 Current Industry Heavy-Duty Vehicle Test Procedures

Current industry procedures for evaluating fuel tanks for heavy-duty vehicles are based on the requirements for side-mounted liquid tanks found in Title 49 CFR 393.67 *Liquid Fuel Tanks* and Section 5.3.4 of SAE J703 *Fuel Systems - Truck and Truck Tractors.*[43] These procedures have provided a level of safety acceptable to authorities in the United States.

Consultations were held with:

Orion Bus Industries	Stan Gornick
Westport Innovations Inc.	Charlie Ker
Xcellsis	Janusz Blaszczyk

3.6 Hydrogen-Fuelled Vehicle Installation Code

In 2001, CSA International contacted developers of hydrogen-fuelled vehicles and equipment suppliers and found that there is currently little interest in developing a Canadian installation code for hydrogen-fuelled vehicles.[44] This may reflect the participation of major automotive manufactures in the development of these types of vehicles.

3.7 Current Provincial Regulations

Discussions were held with regulatory staff from British Columbia, Alberta and Ontario. Staff in all three provinces indicated no desire to expand the current provincial responsibilities, but rather expressed concern that they may be requested to provide evaluations or approvals for systems for which they have no expertise. Provincial authorities are currently responsible for regulating vehicle conversions, general maintenance, repairs to fuel systems, and the disposal of vehicles.

With the exception of the converted vehicles operated by Powertech Labs Inc., no light-duty vehicles fuelled by hydrogen or LNG were in operation in Canada in 2001.

4. Fuel Safety Issues

Different types of damage to the fuel storage system may occur, the most serious being the failure of the fuel storage container itself. Pressurized containers for new fuels are likely to be more robust than those for conventional liquid fuel systems, and should not be adversely affected by differences in regulations.

Another cause of fuel release is related to the failure of the piping, hoses and valves external to the fuel tank. These external systems are often more complex than those associated with traditional fuels and, in some vehicles, are considered sacrificial provided that the fuel in the fuel tank is safely contained. Since these systems extend throughout the vehicle, they are more likely to be affected by variations in crash test procedures. This fact should be recognized in any new regulations.

Vehicles that use new fuels may have fuel-processing sub-systems that are not required in conventionally fuelled vehicles. Known examples include hydrogen and LNG systems that pressurize an accumulator, where the fuel is vaporized for use in the engine, and proposed fuel-reforming systems, where a fuel such as methanol or gasoline is chemically processed to hydrogen for use in fuel cells. In these types of systems the amount of fuel that is "in transit" from the fuel tank to the engine may be significant if the vehicle were to be involved in a crash or other hazard. It is not obvious how these systems should be addressed in regulations and test procedures, as they are experimental at this time.

While there have been relatively few safety problems with new fuels, there have been serious incidents with the introduction of both LPG and CNG that are attributable to the failure of either equipment or procedures.

Conventional fuel system safety is an ongoing concern in many countries and is often a contested issue in the litigation-prone United States. Responding to a number of well-publicized crash-and-fire incidents, in 1995 the US NHTSA published an advance notice of proposed rulemaking, announcing its plans to consider upgrading Standard No. 301, *Fuel System Integrity.*[45] Specifically, NHTSA announced plans to consider research and rulemaking activities to:

- define performance criteria for fuel system components, directed at reducing the occurrence and spread of vehicle fires;
- modify the existing Standard No. 301 crash test procedures and performance criteria to better simulate the events that lead to serious injury and fatalities in fires; and
- define the role of environmental and ageing factors such as corrosion and vibration as they affect fuel system integrity, and, if appropriate, specify performance criteria related to this area.

The results of the preliminary regulatory evaluation were published in November 2000[46] and the US Department of Transportation has issued a notice of a proposal to upgrade the rear impact test in the FMVSS on fuel system integrity.[47] This document proposes replacing the full rear impact test procedure with an offset rear impact test procedure using a deformable and lighter barrier at 80 km/h.

Despite the involvement of vehicle manufacturers in non-conventional fuels (fuels other than gasoline or diesel), there were no submissions on these fuels and how their properties might result in safety differences. However, both Charonic Canada and Powertech Labs are aware of safety concerns that have arisen from the use of LPG and CNG, and we anticipate that these will continue and increase when new fuels are introduced unless relevant safety standards are adopted and enforced. Some instances have been published by the US Department of Transportation.[48]

Based on our knowledge of LPG and CNG fuel system failures and incidents, we have identified five areas that should be taken into consideration in developing a strategy for advanced fuels: vehicle fires, incorrect fuelling, fuel storage systems, fuel system components, and testing.

4.1 Vehicle Fires

Vehicle fires can and do occur. These fires may be related to a collision or may result from other causes, such as arson, or from fires that spread from adjacent vehicles or buildings. Serious incidents have occurred during vehicle fires when pressurized fuel storage systems have been fitted with inadequate pressure relief devices (PRDs) and venting systems. For example, during a shuttle bus fire at Denver Airport in 2000 (caused by leaking hydraulic fluid under the vehicle), the vent line from the PRDs on the vehicle was inadequate, allowing gas to escape under the vehicle and feed the fire.

4.2 Incorrect Fuelling

Vehicle operators, when presented with choices, demonstrate a poor ability to recognize which fuel a vehicle requires, and may even go to heroic lengths to fill vehicles with an incorrect fuel. Two serious incidents occurred in Germany in 2000 when “adaptor” fittings were used to connect a natural gas dispensing hose to a propane-fuelled vehicle, causing the fuel container to rupture.

4.3 Fuel Storage Systems

The manufacture and installation of pressurized fuel containers are sophisticated operations that should only be undertaken by knowledgeable persons. Failures have occurred in the LPG and CNG industries primarily due to the prematurely shortened service life of fuel storage systems caused by poor selection of materials and poor installation designs. These problems were experienced in the United States in 1994 with converted GM Sierra pickup trucks.

4.4 Fuel System Components

Components with a well-established record of safe use may not be available for fuel systems associated with new fuels. This leads to a greater likelihood of improper selection of items and subsequent in-service failures. While most failures have resulted in driveability problems, in some more serious cases fuel leakage has occurred.

4.5 Testing

From time to time it is necessary to remove fuel from vehicles for testing or other work, and incidents have occurred when inadequate provision has been made for this eventuality, or when improper procedures have been followed. Risks associated with these operations relate to fuel accumulating outside the protective barrier of the fuel storage assembly. A number of incidents of this type have been reported in both Canada and the United States. The most serious incident occurred at a testing facility in Blainville, Quebec, in 2000.

5. Conclusions

Strategies for meeting the safety concerns related to new fuels and new fuel technologies are best undertaken by classifying fuel types and their inherent risks. Once these are identified, new and revised regulations, test methods and test method procedures can be established that will satisfy the demand for addressing fuel safety.

5.1 Classification of Fuel Types

As shown in Table 4, all fuels fall into three general categories based on their physical properties. This classification is consistent with that proposed in the clear language amendments to the *Transportation of Dangerous Goods Regulations*[49] and international usage under the *Recommendations on the Transport of Dangerous Goods Model Regulations.*[50] In all situations it is assumed that the fuel will be flammable and that sources of ignition are present in the event of a vehicle crash.

Table 4 Classifications of Fuels by Physical Properties

Category	Fuel Type	Examples
A	Fuels with a vapour pressure of less than 1 atmosphere at 20°C.	Diesel fuel Gasolines Methanol and blends Ethanol and blends
B	Fuels with a vapour pressure equal to or greater than 1 atmosphere at 20 °C and which may form a liquid phase on the vehicle.	Propane and LPGs Dimethyl ether Liquid natural gas Liquid hydrogen
C	Gaseous fuels that do not form a liquid phase on the vehicle.	Methane and natural gas Ethane Hydrogen Adsorbed gases

Category "A" Fuels - Although the materials used in the construction of the fuel tanks may vary, there does not appear to be any reason why fuel systems for fuels that remain a liquid at normal operating temperatures cannot be evaluated in a similar fashion to conventional gasoline or diesel fuel.

Non-traditional fuel tanks and fuels with vapour pressure curves that differ from conventional fuels could be evaluated using tests similar to those specified in ECE Regulation No. 34 for plastic fuel tanks.

Category "B" Fuels - The fuels in category B have many features in common, but there are significant differences between fuels such as LPG and cryogenic systems. In cryogenic systems, significant hazards result from the destruction of the insulation layers that surround the fuel tanks in a "loss of vacuum" incident.

As is recognized in the existing LPG regulations and test methods, both liquids and vapours will be present and the fuel systems may have complex vaporization and pressure regulation systems external to the fuel tank. Cryogenic systems may operate at near atmospheric or moderate pressures (10 bar).

The fuels may have large coefficients of thermal expansion compared to container materials and require "stop fill" systems to prevent tank rupture in the event that a vehicle is filled cold and then stored in a warm environment. If stored in a sealed container and subject to a fire, these fuels have a high BLEVE[51] potential. Therefore, the fuel storage systems are usually fitted with a vented pressure relief system. The design of the relief system will be dependent on the fuel, the anticipated thermal input, and whether it must function in both the gas and liquid phases (as in the case of vehicle rollover).

Category "C" Fuels - These fuels are typically lighter than air, although expanding gas plumes may be chilled and temporarily have a higher density. The gases are typically stored in cylinders rated at 200 to 300 bar and considerable mechanical energy is contained in the compressed gas. Pressures of up to 700 bar are being considered for hydrogen. Because of the high pressure of the stored gas, fuel containers are extremely strong but must be resistant to environmental degradation and be fitted with a thermally activated pressure relief system.

5.2 Strategy for Regulation Development

It appears that there are a number of approaches that should be considered to build on the existing regulatory framework and develop a federal fuel safety strategy that covers new fuels. The conclusions that follow incorporate methods to address the safety issues discussed in Section 4 of this report.

Classification of Fuels – In future, Transport Canada should consider revising CMVSR 301 to recognize the three general categories of fuels and their physical properties, as discussed in the previous section. A suggested restructuring is shown in Table 5.

The advantage of this approach is that all fuels would automatically be covered, even if new fuel blends or combinations are proposed or used. While it may be argued that the release of fuels of different types leads to different hazards, this argument is not convincing. The intent of these tests is to ensure that the amount of fuel released does not add to the hazard that has been created after an incident, and the amount of fuel specified in the above tests is small, regardless of the fuel used.

Table 5 Suggested Structure of Fuel Safety Regulations

Standard	Title	Addresses
301 All Fuels	Requirements for all fuel systems.	Motherhood statements. Excludes solid fuels. Connectors.
301.1 Liquid Fuels	Fuels with a vapour pressure of less than 1 atmosphere at 20°C.	Fuel spillage after each impact shall not exceed (*a*) 28 g from the moment of impact until motion of the vehicle ceases; (*b*) a total of 142 g during the 5-minute period after motion of the vehicle ceases; or (*c*) 28 g during any 1-minute interval for the subsequent 25-minute period.
301.2 Liquefied and Refrigerated Gaseous Fuels	Fuels with a vapour pressure equal to or greater than 1 atmosphere at 20°C and which may form a liquid phase on the vehicle.	Pressure drop in fuel container drops less than 10 bar in 60 minutes after crash. Fuel tank(s) to remain attached to vehicle.
301.3 Gaseous Fuels	Gaseous fuels that do not form a liquid phase on the vehicle.	Temperature compensated pressure drop in fuel system drops less than 5% in 30 minutes after crash. Fuel tank(s) to remain attached to vehicle.

Unique Connectors to Prevent Mis-fuelling – Mis-fuelling can create an immediate hazard at the point of refuelling or it can create hazards later if a vehicle malfunctions. This problem may be alleviated by a requirement for unique connectors at the point of fuel transfer. Given the international nature of the automotive industry and the fact that vehicles travel across country boundaries, this would require that agreements be reached with other countries and with the major vehicle producers and fuel suppliers.

Canada could consider sponsoring a protocol through the International Organization for Standardization (ISO) or the United Nations that would allow the development and recognition of connector standards. Since industry has made major progress in developing standards for specific fuels, it would not be difficult to develop a framework to recognize these and ensure that any new fuel connector standard meets a set of minimum requirements.

If such a protocol were established, it could be adopted by reference in Canadian regulations.

Use of Sacrificial Fuel System Components – The use of hydrogen and LNG may exacerbate issues that have already arisen with both natural gas and conventional fuels. Since the most serious consequence is a sudden lost of fuel from the fuel storage container (or containment system), manufacturers have developed systems that lock off the fuel container from the rest of the vehicle in the event of a crash or other incident. Some of these systems are designed so that the connections between the fuel lines and the fuel container shear off to prevent stresses from being transmitted to the fuel container.

This approach can mitigate the more serious loss-of-fuel incidents. However, the fuel contained in the lines to the engine may be sufficient to fail vehicles under the current CMVSR Section 301*.*

This problem could become more severe with LNG and hydrogen-fuelled vehicles. One of the options for high-pressure natural gas-fuelled engines is to pressurize the LNG to 300 bar, then vaporize the liquid at pressure in the engine compartment to provide the engine fuel. While this may not be in technical violation of any current regulation, it is obviously a source of hazard that should be limited.

Hydrogen-fuelled vehicles that make the hydrogen through reforming of a convention fossil fuel can present similar problems. While the fuel storage system for the conventional fuel is comparatively easy to address, the fuel contained in the reformer system and a secondary buffer system to fuel the engine while the reformer is powering up may be considerable.

Canada should consider making provision in future regulations to recognize and limit the amount of fuel that may be present outside the main fuel container(s). If the amount can be demonstrated to be small, then this could be excluded from the test procedures. Larger amounts of fuel should be considered as part of the fuel containment system.

Standards for Pressurized Fuel Containers – Although there are international standards for conventional fuel storage containers, Canada has not established requirements for these in the current federal standards or test procedures.

However, there have been issues with pressurized fuel containers and this is explicitly addressed in the current Canadian fuel safety regulation 301.2. Canadian regulations also permit LPG-powered vehicles to be built using specified fuel storage containers. Although these specifications address a wide variety of items and contain detailed test procedures, in essence they are intended to provide that the fuel containers will survive in the automotive environment and in particular address:

- Number of fills;
- Environmental degradation;
- Sustained temperature;
- Sustained pressure;
- Impact resistance (drop tests);
- Fire tolerance; and
- Quality control in manufacturing processes.

Canada could consider making provision in its regulations that all fuel containers meet these requirements. Since there are well-established national and international standards for current fuels, and standards have been or are being developed for new fuels, these standards could be adopted by reference.

While this may be controversial for conventional fuels, it has the advantage of simplicity and allows the demonstration of equivalent safety among different countries.

Building to Meet Assembly Codes – Construction of experimental and low-volume production vehicles to meet assembly codes may be an attractive alternative to crash testing procedures. Although crash testing is simpler to administer and may be more cost-effective at higher production volumes, there appears to be no evidence that it leads to safer vehicles than building to meet codes.

It is recommended that Canada continue to allow building to meet assembly codes according to the current CMVSR 301.1 and CMVSR 301.2 fuel safety regulations for experimental and low-volume production vehicles.

Building to meet assembly codes can only be effective in maintaining safety standards if mutually agreed construction codes and component standards are available. As well, independent testing facilities for components and compliance auditing for vehicles would be required.

Tests for Saddle Tanks – Fuel tanks or tank assemblies installed on heavy-duty vehicles in positions where they may be impacted by other vehicles need to be designed to withstand a reasonable impact in an event such as the side impact of another vehicle.

The most straightforward procedures appear to be tests modelled on the requirements for side-mounted liquid tanks, found in 49 CFR 393.67 *Liquid Fuel Tanks* and Section 5.3.4 of SAE J703 *Fuel Systems - Truck and Truck Tractors*. This test procedure requires that a fuel storage cylinder be:

> filled with a quantity of inert gas having a pressure equal to 50% of the rated service pressure of the system [and] dropped 9.1 m (30 ft.) measured from the centre of gravity of the system onto an unyielding surface. The impact shall be at 45° ± 5° from the horizontal of the long axis of the tank. The tank should not impact on the fuelling receptacle or valve area. Each side-mounted fuel tank or fuel tank assembly shall be tested. Where fuel tanks are assembled into a module then the test shall be performed on the final assembly including mounting hardware, protective parts and appurtenances.

This approach has been followed in the development of SAE J2343, *Recommended Practices for LNG Powered Heavy-Duty Trucks.*[52]

It is recommended that, in future regulations, Canada consider requiring that fuel tanks or fuel tank assemblies that are located in a position where damage is likely to occur from a collision meet impact requirements based on drop tests of the fuel tank assemblies.

5.3 Strategy for Test Method Development

It appears likely that the conventional test methods will be sufficient to ensure the safety for both hydrogen- and LNG-fuelled light-duty vehicles.[53] However, new test methods will be required if fuel systems are mounted in exposed locations on heavy-duty vehicles. Given the relatively small number of heavy-duty vehicles fuelled with fuels other than diesel, vehicle manufacturers have limited experience on the behaviour of these fuel systems in crash situations.

Irrespective of the design of the vehicle and fuel system, there are some incidents that will result in loss of fuel. The consequences of fuel loss will vary by fuel type.

There are three approaches that could be taken by Transport Canada to testing the integrity of heavy-duty fuel systems:

a) Impact completed vehicles with moving sledges in a similar fashion to the testing of light-duty vehicles.

b) Mount the fuel system on a frame that has similar vehicle and mechanical characteristics to that of a vehicle and impact this assembly with moving sledges in a similar fashion to the testing of light-duty vehicles.

c) Test the fuel system assembly through drop tests in a similar fashion to the tests used by manufacturers of diesel fuel tanks.

The first option has the advantage of resembling real-life situations most closely but, in the absence of data on the frequency of various types of impact and the consequences of impacts on vehicles with different body configurations, it is doubtful that results from this type of test could be easily correlated with on-road incidents. At present these tests are only required for school buses, where the consequences of a loss-of-fuel incident are high and the vehicles are built to a standard configuration. It is expected that a move to this type of testing for all medium- and heavy-duty vehicles would be strongly resisted by manufacturers. Not only would the cost of these tests have to be amortized over a small number of vehicles, but coordinating the results over a variety of body types and configurations could present many administrative and legal difficulties.

The second option addresses the cost issue and may be more attractive to manufacturers of serially built vehicles such as transit buses or highway tractors. However, it does not address the difficulties faced by manufacturers of chassis that are fitted with a variety of body types and styles.

The third option is certainly more attractive to vehicle manufacturers. Test results can be used to develop guidelines for the location and protection of fuel system components, to be followed by both internal design staff and by vehicle body builders and up-fitters. This has been the approach developed by the SAE J2343 Committee on LNG Fuel Storage Tanks. The SAE also initiated a similar group to address CNG fuel systems and recently published J2406

Recommended Practices for CNG Powered Medium and Heavy-Duty Trucks.[54] While drafts of this document contained several proposals to require tests for fuel system integrity, the committee was unable to reach a consensus and the published document is silent on this topic.

There is extensive information on the performance of diesel fuel tanks and this could form the basis for the development of equivalent safety tests methods for other fuel storage systems. This would require an independent assessment of the equivalent energy of drop tests and, since different types of storage systems behave differently when pressurized, determination of what fill conditions should be specified in the test procedures.

5.4 Development of Procedures for Vehicle Preparation and Testing

Discussions with persons employed by vehicle manufacturers in the development of alternatively fuelled vehicles elicited few suggestions that were useful in considering the development of procedures for the preparation and testing of vehicles. The strategy used by vehicle manufacturers typically involves a detailed evaluation of components and sub-systems before they are used in vehicles. In addition, alternatively fuelled vehicles selected for crash tests are not fuelled before the crash tests. Crash testing of a vehicle selected after production would be an unusual occurrence.

De-fuelling Vehicles – All vehicle and/or fuel system manufacturers provide instructions for de-fuelling vehicles. Since the fuel systems on vehicles using new fuels are by definition non-standard, written instructions should always be obtained and followed by persons de-fuelling vehicles. However, these instructions are intended for maintenance purposes and may not always be suitable for preparation of vehicles for crash testing purposes.

A safe procedure would be to request that an authorized vehicle manufacturer remove the original fuel storage system, install a new (empty) fuel system, and not fuel the vehicle after the replacement. While this would resolve safety concerns for the test preparation procedures, the agency conducting the tests would not be able to ascertain if deterioration of the original fuel system had occurred before the test. Questions may be raised if the original and replacement systems were not identical in all respects.

An alternative procedure would be to crash test vehicles that are fuelled with their intended fuel. This has the advantages of simplicity, and results would be unambiguous. Unfortunately, existing Canadian facilities would not be able to conduct “fully-fuelled” tests and Transport Canada would have to consider contracting work to facilities in other countries. This would result in additional costs and administrative difficulties.

Instrumentation of Vehicles - While a plan to “instrument” any one vehicle during testing is possible, the variety of approaches and technologies being considered by manufacturers precludes the possibility of a simple “one-size-fits-all” recommendation.

The problem of installing instruments capable of detecting fuel leakage becomes increasingly complex when one considers that pre-packaged fuel storage sub-systems may contain multiple fuel tanks. These issues may be addressed by vehicle manufacturers using their prior knowledge of the fuel system and specially built vehicles that have appropriate sensors installed before the vehicle is complete. However, these options are not available to a regulatory agency wishing to conduct post-production audits.

6. Recommendations

A number of recommendations have been made throughout this report. The major recommendations are grouped into topics and summarized below.

6.1 Structure of Regulations

To provide adequate safety coverage for new fuels and technologies (including hydrogen, CNG, LNG or other possible fuels or fuel mixtures), it is recommended that Transport Canada:

- Restructure its fuel safety regulations to reflect fuel properties rather than establish a new regulation for each fuel.
- Move issues and procedures that pertain to all fuels to one main section and establish sub-regulations (i.e., 301.1, etc.) to address issues applicable to specific fuel types.
- State the intent for each requirement in a preamble, then list acceptable procedures for demonstrating the required level of safety.
- Introduce explicit language that requires multi-fuelled vehicles to meet the requirements of each fuel type.

6.2 Use of Consensus and Other Standards

With the rapid pace of technological development, it is unlikely that Transport Canada will be able to maintain in-house expertise to develop detailed regulations on all aspects of new fuels and technologies. It is recommended that Transport Canada:

- Continue and expand the use of reference publications in its regulations and test methods.
- Refer to the latest edition of a standard where a standard is published by a recognized agency with an established development and review procedure equivalent to that required by the Standards Council of Canada for Canadian Standards.
- Continue to allow the use of assembly codes and standards as an alternative to crash testing vehicles.

6.3 Participation and Consultation

In new or rapidly developing technology areas, it is recommended that Transport Canada:

- Ensure that it is a participant in the development and/or the approval of new standards that pertain to new fuels or fuel technologies.

- Initiate public consultations with vehicle manufacturers and importers of vehicles using new fuels, regarding audit procedures designed to ensure compliance with Canadian regulations.
- In conjunction with other national regulatory agencies, consider sponsoring sessions on regulatory issues at major conferences on the development of hydrogen- or LNG-fuelled vehicles.

6.4 Areas of Coverage

In areas not covered by present regulations, Transport Canada should consider establishing requirements on the following topics:

- Fuel system components that are designed to fail in crashes to protect the fuel storage system.
- Independent evaluation of fuel system components used in "built-to-code" vehicles.
- Limits on the amount of fuel that may be accumulated external to the fuel storage system.
- Minimum requirements for all types fuel storage tanks.
- Impact resistance for fuel storage systems mounted in saddle position on heavy-duty vehicles.

Transport Canada should initiate consultations with the provinces and territories with respect to issues that pertain to areas under provincial jurisdiction but are fixed at the time of manufacture. Two identified areas where national standards would be beneficial are:

1) Unique fuelling connectors for each fuel.
2) De-fuelling procedures to be followed for vehicle testing, maintenance and disposal.

References

1. "Diesel examined and initially considered using pulverized coal as fuel. The first prototype engine in the summer of 1893 was not functional. The second prototype (the early Diesel) did function and even managed an efficiency of 16.6% by the summer of 1894. But there was no question of actual operation. It was towards the end of 1896 and the beginning of 1897 that the third Augsburg prototype (often also known as the "first Diesel engine") became truly functional." Walter Kaiser, "Rudolf Diesel and the Second Law of Thermodynamics" in German News: The Magazine [Online Magazine], June/July 1997 and August/September 1998. www.germanembassy-india.org

2. "Vehicles fuelled by ethanol actually use E85, a blend of 85 percent ethanol and 15 percent gasoline. Ford's interest in using ethanol as an alternative fuel goes back to the days of Henry Ford. Ford planned to use ethanol as the primary fuel for his Model T, however, the less expensive gasoline emerged as the dominant fuel." Ford Motor Company, "Ethanol Vehicles" [Website Article], 2002. www.ford.com

3. The Fischer-Tropsch (F-T) catalytic conversion process can be used to synthesize diesel fuels from a variety of feedstock, including coal, natural gas and biomass. Synthetic diesel fuels can have very low sulfur and aromatic content, and excellent auto ignition characteristics.

4. Data in Table 1 is from a variety of sources. Since values from different sources are not always consistent, the authors will not assume responsibility for the use or misuse of this data. Sources consulted include V. Soots, *Hydrogen Utilization in Surface Vehicles*, Ontario Hydrogen Energy Task Force, Ontario Ministry of Transportation and Communications, September 1981; Material Safety Data Sheet (MSDS) information from the Physical and Theoretical Chemical Laboratory, Oxford University, Oxford, England, published on the internet at www.physchem.ox.ac.uk; *Properties of Fuels* and other resources of the Alternative Fuels Data Center, US Department of Energy, published on the internet at www.afdc.doe.gov; International Chemical Safety Cards, International Occupational Safety and Health Information Centre, published on the website of the International Labour Organization, www.ilo.org; *Compiler's Guide for the Preparation of International Chemical Safety Cards*, US National Institute for Occupational Safety and Health (NIOSH), published on the internet at www.cdc.gov; and others.

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8. For more information on this program and the introduction of dual-fuel Caterpillar NGV engines see: Clean Fuels Partnership, *Low Emission Vehicle Products,* [Website Advertisement], 2002. www.cleanairpartners.com

9. Further information on the technological development of NGV technologies introduced by Westport Innovations Inc. can be found at www.westport.com.

10. Cummins spark-ignited generator sets can be seen at www.cummins.com. Cummins and Westport have joined forces toward the introduction of NGV systems. More information on these ventures can be found at www.cumminswestport.com.

11. John Deere Power Systems, the National Renewable Energy Laboratory and the Southwest Research Institute have combined forces to develop fuel-efficient technology. Accounts of their work can be found in "Improved Natural Gas Engine Shows Part-Load Efficiency Gains" [Website Article], www.trucks.doe.gov and "Alternative Fuel Engines: Spark Ignited Natural Gas Engines (CNG and LNG)" [Website Article], www.ccities.doe.gov.

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15. Ibid., Section 301.2, *CNG Fuel System Integrity*.

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