TP 14016E

SCHEMA FOR DEMONSTRATING A NATURAL GAS-FUELED RAILWAY OPERATION

Prepared for
Transportation Development Centre
Transport Canada

by

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NOTICES

This report reflects the views of the author and not necessarily those of the Transportation Development Centre of Transport Canada or the sponsoring organization.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Since the report deals with the North American railway sector as a whole, units of measure are a mixture of imperial and metric units (as per current Canadian railway convention) and American units (as per current railway convention in the U.S.A.).

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16. Abstract

A schema was developed for implementing a project in Canada to demonstrate a railway operation fueled by natural gas. The motivation to consider natural gas as a fuel for diesel locomotives is that the exhaust emissions contain lower carbon dioxide (CO_2) and particulate matter (PM) as compared to using conventional diesel oil. Natural gas as a transportation fuel could help Canada attain its goal of stemming the harmful effects on the environment. The railways can contribute to this goal. The study concluded that more benefits accrued from a demonstration based on liquefied natural gas (LNG) than compressed natural gas (CNG) and on direct injection combustion than spark ignited.

Three candidate sites for a demonstration were examined, namely the regions around Vancouver, Toronto and Montreal. The Vancouver-centred region provided more potential for the realization of a demonstration because of the variety of commuter, switcher yard and regional freight operations, and the existence of an LNG production and distribution network. Toronto and Montreal are also sites for potential commuter operation demonstrations but lacked an LNG network. The recommended next step is for a sponsoring governmental agency to issue a "Call for Expressions of Interest" to the railway and natural gas sectors for the undertaking of a bankable feasibility study. What is problematic is the immediate availability of appropriate technology to convert existing locomotive prime movers to operate on natural gas without a power or fuel penalty.

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16. Résumé

Un schéma a été élaboré en vue de la réalisation, au Canada, d'un projet de démonstration d'un service ferroviaire fonctionnant au gaz naturel. La raison pour laquelle on s'intéresse au gaz naturel comme carburant pour les locomotives est que les gaz d'échappement générés contiennent moins de dioxyde de carbone (CO_2) et de particules que ceux produits par les locomotives mues au diesel classique. Ainsi, l'utilisation de véhicules de transport mus au gaz naturel peut aider le Canada à atteindre son objectif de réduire les effets nocifs de l'activité humaine sur l'environnement. En ce sens, les chemins de fer peuvent contribuer à cet objectif. Les chercheurs ont conclu qu'il est préférable de recourir, aux fins de la démonstration, à du gaz naturel liquéfié (GNL) plutôt qu'à du gaz naturel comprimé (GNC), et à des moteurs à injection directe plutôt qu'à allumage commandé.

Trois sites candidats ont été envisagés pour la tenue de la démonstration, soit les régions de Vancouver, de Toronto et de Montréal. La région de Vancouver offrait un meilleur potentiel en raison de la diversité des services ferroviaires (trains banlieue, gares de triage, transport de marchandises) et de l'existence d'un réseau de production et de distribution de GNL. Toronto et Montréal sont aussi des sites intéressants pour des démonstrations de services de trains de banlieue, mais l'approvisionnement en GNL y est difficile. Il est recommandé, pour la prochaine étape, qu'un organisme gouvernemental parrain émette un «Avis de manifestation d'intérêt» à l'endroit des secteurs ferroviaire et du gaz naturel, en vue de la réalisation d'une étude de faisabilité pouvant être financée. Le problème, dans l'immédiat, est de disposer d'une technologie pour convertir les locomotives existantes au gaz naturel sans en diminuer la puissance ni augmenter la consommation de carburant.

17. Mots clés Chemin de fer, moteur diesel, locomotive, carburants de substitution, gaz naturel, gaz naturel liquéfié, GNL, gaz naturel comprimé, GNC, émissions de gaz d'échappement, CO_2, particules, gaz à effet de serre		18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.		
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EXECUTIVE SUMMARY

This project developed schema for implementing a project in Canada to demonstrate a railway operation fueled by natural gas. The motivation to consider natural gas as a fuel for railway locomotion is that it is 25 percent less carbon intense than conventional railway diesel fuel. This results in lower exhaust emissions content of carbon dioxide (CO_2) and particulate matter (PM) as compared to using conventional diesel oil. CO_2 is a greenhouse gas and PM affects human health. Hence, the wider use of natural gas as a transportation fuel could help Canada attain its goal of stemming the harmful effects on the environment. The railways can contribute to this goal. The study concluded that more benefits accrued from a demonstration based on liquefied natural gas (LNG) than compressed natural gas (CNG), and on direct injection combustion than spark ignited.

Three candidate sites for a demonstration were examined, namely the regions around Vancouver, Toronto and Montreal. The Vancouver-centred region provided more potential for the realization of a demonstration because of the variety of commuter, switcher yard and regional freight operations, and the existence of an LNG production facility and distribution network. Toronto and Montreal are also sites for potential commuter operation demonstrations but lacked an LNG network. What is problematic is the immediate availability of appropriate technology to convert existing locomotive prime movers to operate on natural gas without a power or fuel penalty.

Options for demonstration projects are (in order of ease of implementation):

1) Arrange for conversion from diesel fuel to LNG (or CNG) of a Railpower Technologies Corporation “Green Goat” or “Green Kid” switcher locomotive powered by a hybrid micro gas turbine / storage-battery power pack.

2) Arrange to bring to Canada for a one-year commuter rail demonstration the California-based *CleanGas USA Project* locomotive fitted with LaCHIP injectors and LNG tender.

3) Arrange to retrofit Budd Rail Diesel Cars as used either by BC Rail or in VIA Rail Canada’s Vancouver Island services with new Cummins diesel engines fitted with Westport Innovations Inc.’s LNG fuel system with proprietary integral natural gas / diesel pilot fuel injector.

Interest was found at the technical staff level in the organizations consulted for a demonstration, but more economic substantiation would be required to obtain corporate-level buy-in and commitment. The measurable objective would be whether a 25 percent reduction in CO_2 emissions occurred as a result of the use of natural gas, with concomitant reductions in oxides of nitrogen (NOx) and PM. In this regard, the recommended next step is for a sponsoring governmental agency to issue a “Call for Expressions of Interest” to the railway and natural gas sectors for the undertaking of a bankable feasibility study.

SOMMAIRE

Ce projet a élaboré un schéma pour la réalisation, au Canada, d'un projet de démonstration d'un service ferroviaire fonctionnant au gaz naturel. La raison pour laquelle on s'intéresse au gaz naturel pour l'alimentation des chemins de fer est que l'intensité des émissions de carbone de celui-ci est inférieure de 25 p. cent à celle du diesel classique utilisé par les locomotives. Cela se traduit par une diminution du contenu de dioxyde de carbone (CO_2) et de particules générées par les gaz d'échappement que ceux produits par les locomotives mues au diesel classique. Le CO_2 est un gaz à effet de serre et les particules présentent un risque pour la santé. Ainsi, l'utilisation de véhicules de transport mus au gaz naturel peut aider le Canada à atteindre son objectif de réduire les effets nocifs de l'activité humaine sur l'environnement. En ce sens, les chemins de fer peuvent contribuer à cet objectif. Les chercheurs ont conclu qu'il est préférable de recourir, aux fins de la démonstration, à du gaz naturel liquéfié (GNL) plutôt qu'à du gaz naturel comprimé (GNC), et à des moteurs à injection directe plutôt qu'à allumage commandé.

Trois sites candidats ont été envisagés pour la tenue de la démonstration, soit les régions de Vancouver, de Toronto et de Montréal. La région de Vancouver offre un meilleur potentiel en raison de la diversité des services ferroviaires (trains banlieue, gares de triage, transport de marchandises) et de l'existence d'un réseau de production et de distribution de GNL. Toronto et Montréal sont aussi des sites intéressants pour des démonstrations de services de trains de banlieue, mais l'approvisionnement en GNL y est difficile. Le problème, dans l'immédiat, est de disposer d'une technologie pour convertir les locomotives existantes au gaz naturel sans en diminuer la puissance ni augmenter la consommation de carburant.

Voici quelques scénarios de projets de démonstration possibles (par ordre de facilité de mise en oeuvre) :

1) convertir du diesel au GNL (ou au GNC) une locomotive de manœuvre *Green Goat* ou *Green Kid* à propulsion hybride microturbine à gaz/bloc d'accumulateurs construite par la Railpower Technologies Corporation;

2) emprunter, pour une démonstration d'un an au Canada, la locomotive qui a servi au *CleanGas USA Project* mené en Californie, équipée d'un système d'alimentation du type à haute pression d'injection avec retardement (*LaCHIP*) et d'un ravitailleur de GNL;

3) modifier les Budd Rail Diesel Cars exploités par BC Rail ou par VIA Rail pour la desserte des îles de Vancouver : les équiper des nouveaux moteurs diesel Cummins munis du système d'alimentation GNL de Westport Innovations Inc., dont le nouvel injecteur breveté injecte à la fois le gaz naturel et le carburant diesel servant à l'allumage du gaz naturel.

Le projet a suscité, sur le plan technique, l'intérêt des organisations approchées pour réaliser la démonstration, mais une justification économique sera nécessaire pour qu'elles

consentent à s'y engager. L'objectif mesurable serait de déterminer si une diminution de 25 p. cent des émissions de CO_2 est le résultat de l'utilisation du gaz naturel, accompagnée de diminutions concomitantes en ce qui a trait aux taux d'oxydes d'azote (NO_x) et de particules. Il est donc recommandé, pour la prochaine étape, qu'un organisme gouvernemental parrain émette un «Avis de manifestation d'intérêt» à l'endroit des secteurs ferroviaire et du gaz naturel, en vue de la réalisation d'une étude de faisabilité pouvant être financée.

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GLOSSARY

Terminology Related to Natural Gas as a Railway Fuel

Natural Gas: a combustible gas composed principally of methane (CH_4), with smaller quantities of other hydrocarbons, nitrogen, carbon dioxide and water. Natural gas is less carbon intense than conventional railway diesel fuel. This results in lower emissions of carbon dioxide and particulate matter (solidified carbon particles, or soot). The quality of the natural gas, that is, the content of the component gases, directly affects the efficiency, power, emissions and longevity of an engine. The higher the methane content, the higher the fuel quality. The minimum preferable methane content is 92 percent, while Canadian gas, as transmitted by pipeline, averages 95 percent.

Compressed Natural Gas (CNG): natural gas that is stored in tanks in the gaseous state, typically at 3,000 to 3,600 psi pressure.

Liquefied Natural Gas (LNG): natural gas that has been cooled to the liquefied state and stored in temperature-controlled tanks at cryogenic temperatures (below -161.5°C), the point at which LNG boils). LNG does not require high-pressure tanks and is much more compact than CNG: the ratio of gas to liquid is 625:1. On a fuel energy ratio basis, that is, BTU per gallon, LNG is 0.57 that of diesel fuel and 2.56 that of CNG.

CO_2 (Carbon Dioxide): this gas is by far the largest by-product of combustion emitted from engines and is the "greenhouse gas" that, due to its accumulation in the atmosphere, is considered to be the principal contributor to global warming. CO_2 and water vapour are normal by-products of the combustion of fossil fuels. The only way to reduce CO_2 emissions is to either reduce the consumption of fossil fuels or use a fuel that is less carbon intense. CO_2 is colourless, odourless and non-toxic.

NOx (Oxides of Nitrogen): these are the products of nitrogen and oxygen that result from high combustion temperature. NOx has implications for the health of humans, animals and the ecology. NOx reacts with hydrocarbons to form ozone in the presence of sunlight. The NOx emissions level from diesel and gas turbine engines tends to be lower when natural gas versus standard diesel fuel is burned.

PM (Particulate Matter): this is residue of combustion consisting of solidified carbon particles (or soot) suspended in air that is formed by incomplete combustion of fuel and engine lubricating oil. Compression ignition (diesel) engines generate significantly higher PM emissions than spark ignited engines.

g/bhp-hr (grams per brake horsepower-hour): a standard unit of measurement for the amount of a particular pollutant (in grams) emitted by an engine for a given amount of mechanical work (brake horsepower) in one hour. This measurement allows an easy comparison of the relative cleanliness of two engines, regardless of their rated power.

1.0 INTRODUCTION

The motivation to consider natural gas as a fuel for railway diesel locomotives is that it is less carbon intense than conventional railway diesel fuel. This results in lower exhaust emissions of carbon dioxide (CO_2) content and particulate matter (PM), which is solidified carbon particles, or soot. CO_2 is a principal greenhouse gas (GHG) that contributes to the potential for global warming. Natural gas is a recognized alternate fuel for transportation prime movers. The widespread use of natural gas as a transportation fuel can help Canada meet its commitment to the Kyoto Protocol on Climate Change, which Canada signed in December 1997 and which the federal government expects to ratify in 2002 [1]. The goal of the commitment is to reduce greenhouse gas emissions (CO_2, etc.) to 94 percent of 1990 levels by year 2012. Figure 1 projects the emissions reductions necessary from Canadian sources to meet the Kyoto Protocol. The railways can help attain this goal. During 2000, the Canadian railways consumed 1.92 billion litres of diesel fuel [2]. Previous considerations by the railways to use natural gas were predicated on a lower cost per unit of energy. The cost differential with conventional diesel fuel has since narrowed but due to its lower carbon density (approximately 25 percent), natural gas is considered a more environmentally acceptable fuel, albeit more complex to store and handle.

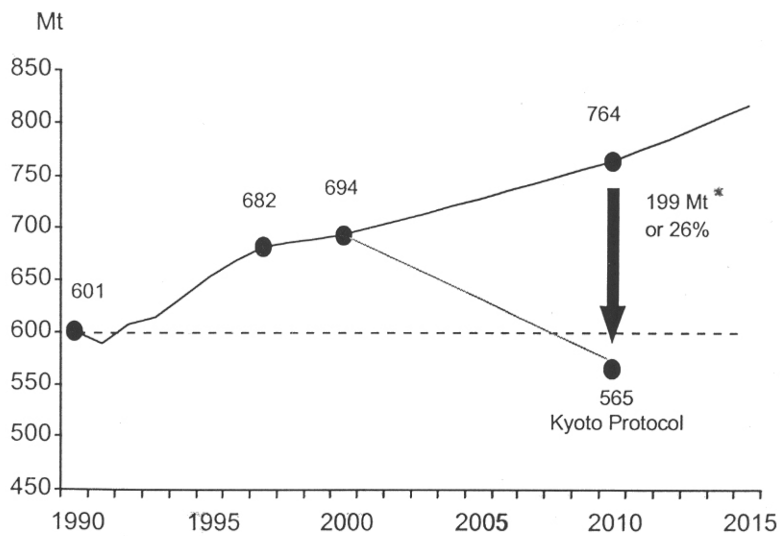

Figure 1: Canada's Greenhouse Gas Emissions Projection and the Kyoto Protocol

Source: The Path Forward to Sustainable Development Strategy 2000 - A Decision Paper. Natural Resources Canada, July 2000
*** Note:** Updated projection in 2002 now estimates an annual reduction of 240 Mt will be required by 2012 to comply with Protocol

To permit the Canadian railway sector to gain the necessary experience and verify the incremental environmental benefits of natural gas over conventional diesel fuel, a preliminary plan for a natural gas-fueled railway operation demonstration project is defined herein. The measurable objective of the demonstration is whether a 25 percent reduction in CO_2 emissions occurred as a result of the use of natural gas versus railway diesel fuel. Also targeted are concomitant reductions in oxides of nitrogen (NOx) and PM.

2.0 NATURE OF STUDY

To examine whether promoting natural gas as a fuel for railway locomotives in Canada is still a viable consideration in today's context, the Transportation Development Centre of Transport Canada awarded a contract to Peter Eggleton Enregistré (Consultant in International Transportation Technology) to define schema for setting up a project to demonstrate a natural gas-fueled railway operation in Canada. For the envisaged demonstration, the consultant focused on identifying the circumstances favourable to implementing a demonstration in Canada, considering such variables as the type of railway operation, location, appropriate participants, technology options, site impact, regulatory context, financing, timeframes and emissions standards [3]. This is a prelude to an envisaged follow-on phase to undertake an in-depth bankable feasibility study addressing the site-specific configuration, the engineering definition, detailed operational and performance specifications, and estimated costs for a railway operation fueled by natural gas.

3.0 DEFINITION OF A DEMONSTRATION PROJECT

As a prelude to addressing the task to identify schema to demonstrate a railway operation fueled by natural gas, it is useful to agree on when a project can, or cannot be considered a "demonstration project" [4]. Generally, it is considered that:

- in a research project, the risks and uncertainties are mainly technical;
- in a demonstration project, the risks are primarily non-technical (financial, market-related, public acceptability and employee considerations such as skills training, safety concerns, real and perceived risks, etc.); while
- in a pilot project, a new operation using new technology is implemented with the expectation that, subsequently, it will be expanded upon according to demand and favourable economics.

For demonstration projects, the key issues are "sufficient knowledge to implement the demonstration, adequate scale and acceptable risks". A demonstration phase has to come "not too early, not too late" to make the technology attractive. All the necessary tools must be ready for implementation of the demonstration (e.g., for construction and validation of a prototype, all specifications for building the prototype have to be known). If the level of knowledge is not sufficient and laboratory research or development is needed before the demonstration can be implemented, the project cannot be accepted as demonstration – but may be acceptable as a research project. Again, to qualify for support as a demonstration, the validation of the new technology must be planned on a scale representing reality or under realistic operating conditions. Demonstration projects have a limited timeframe. For transportation demonstration projects in the Canadian context, the timeframe is preferably two years, as this permits operations over two winters (to cover extremes in severity). Also, in Canada, it is a given that a demonstration not be started during wintry conditions when transportation operations are more challenging.

4.0 INPUT ASSUMPTIONS

For the envisaged demonstration, the site circumstances, participants and context judged favourable to its implementation are listed below as a reference base, considering such variables as the type of railway operation, location, appropriate participants, technology options, site impact, regulatory context, financing and timeframes. It was judged that the proposed demonstration should be regionally focused, thus excluding lines operated by Canada's two Class I mainline railways. The functional specifications for the operational aspects of a demonstration are expected to contain elements from the following variables.

4.1 Type of Operation

- Yard Switching
- Short-Line Freight
- Commuter Rail
- Regional Passenger

4.2 Location

- North Vancouver
- Lower Fraser Valley of British Columbia
- Metropolitan Vancouver, Toronto or Montreal
- Vancouver Island

4.3 Candidate Participants

A Consortium approach is envisaged having:

- Railway Companies with:
  - Yard Switching Operations
  - Regional Freight Operations
  - Commuter Rail Operations
  - Regional Passenger Operations
- Natural Gas Distributors
- Natural Gas Equipment Suppliers
- Combustion Component Suppliers
- Safety / Environmental Agencies

4.4 Technology Options

- <u>Engine</u>: existing railway Original Equipment Manufacturer (OEM) diesel or a non-conventional prime mover, i.e., new to Canadian railway operations;
- <u>Combustion System</u>: retrofitted to an existing OEM diesel engine, or an advanced design that is an integral element of a new prime mover;

- Combustion Technology: spark ignition or either low or high pressure direct injection - both using pilot diesel fuel to initiate combustion;
- Fuel Distribution / Handling: natural gas in compressed or liquefied state;
- Fuel On-board Storage: use of on-board tanks or separate tender railcar;
- Risk Factor in Assembling Technological Configuration: opt for existing technology or technology under development

4.5 Site Impact

In a metropolitan area that can yield, for the railway:

- kudos from the local population as a good corporate citizen;
- a measurable reduction in emissions;
- operational and costing experience that can be scaleable and realistically transferable to other railway operations in Canada;
- experience in Canadian climatic conditions.

4.6 Regulatory Context

- Emissions: in absence of Canadian federal and provincial emissions standards for railway diesel engines, should limits referenced (for design purposes) be those set by the U.S. Environmental Protection Agency, the California Air Resources Board or the Euro Standards?
- Safety: which authorities have jurisdiction regarding handling natural gas?

4.7 Financing

- Presumption 1: that a decision by a railway operator to participate in a demonstration will be on the basis that operating costs over the duration of the demonstration are equivalent to, or lower than using railway diesel fuel;
- Presumption 2: that tax credits will be available from federal and provincial governments wishing to promote a more environmentally friendly fuel;
- Presumption 3: that expenses incurred to make one-time equipment modifications and to meet incremental operating, monitoring and data-gathering requirements will be covered by support contracts from federal and provincial assistance programs such as, for example, those administered by:
    - Natural Resources Canada (NRCan) Program for Energy R&D
    - NRCan TEAM - Technology Early Action Measures
    - Environment Canada Transportation Systems Directorate
    - National Research Council - Industrial Research Assistance Program
    - Transport Canada - Transportation Development Centre
    - Revenue SR&ED tax rebate program
    - Provincial Environmental Programs

- in-kind contribution of operating railways via the Railway Association of Canada (RAC) or Association of Regional Railways of Canada (ARRC);
- in-kind contributions from natural gas distribution companies;
- Greenhouse Gas Emission Reduction Trading (GERT) actions.

4.8 Timeframe Scenarios

- implementation of demonstration preferably to be by 2005;
- duration of demonstration to be 2 to 5 years, with possibility of considering it as a pilot project for an indeterminate operation should service demand, financial and environmental credits warrant it.

4.9 Experience Dissemination

It is envisaged that the demonstration would be overseen by an advisory committee in which membership from the rail transport sector would be coordinated by the RAC (having representation of Canada's Class I railways and 50 short lines, industrial and passenger railways) and the ARRC. This strategy would facilitate the dissemination of information and data throughout the Canadian railway sector.

5.0 RELEVANT DEMONSTRATIONS AND TECHNOLOGY INITIATIVES IN THE U.S.A. AND CANADA

During the last decade, there have been demonstrations of natural gas-fueled railway operations on American railroads, the experience from which can be referenced for any similar application in Canada. The demonstrations also spurred engine and locomotive conversion technology developments and accompanying safety procedures, the availability of which could facilitate implementation of any demonstration in Canada. Current technology to convert engines to operate on natural gas include dual-fuel (injection of pilot diesel fuel to ignite gas) and two gas-only arrangements (throttled intake and spark ignited or high-pressure gas injection). Demonstration operations included the following:

- Between 1985 and 1987, the Burlington Northern Railroad operated a General Motors EMD model GP-9 locomotive with a dual fuel 1,750 horsepower (HP) two-stroke 16-cylinder EMD 567C engine between Minneapolis and Superior, Wisconsin, a distance of 240 km. The natural gas was stored as CNG in cylinders mounted on a highway trailer which, in turn, was mounted on a railway flat car behind the locomotive [5].

- A demonstration from 1992 to 1995 on the Burlington Northern Railroad used two General Motors EMD SD-40-2 locomotives equipped with 3,000 HP turbo-charged 16 cylinder two-stroke EMD 645E3B engines that were converted to natural gas operation using a dual-fuel system made by Energy Conversions Inc.

(Tacoma, Washington). The locomotives shared a directly coupled LNG supply tender having a capacity of 95,000 litres which allowed the locomotives to make the 2,700 km round trip with one fueling stop when hauling 13,500 tonne coal unit trains from the Powder River Basin of Montana to Superior, Wisconsin. Air Products and Chemicals Ltd, (Allentown, Pennsylvania) supplied the natural gas handling and tender technology [6].

- A demonstration in the Los Angeles area was made on both Union Pacific and Burlington Northern Santa Fe railroads using two Boise Locomotive / Motive-Power Industries MK 1200G switcher locomotives equipped with an LNG mono-fuel locomotive powered by a Caterpiller model 3516G turbocharged, aftercooled, spark-ignited, lean-burn engine producing 1,350 HP. The LNG was supplied by AMOCO Petroleum from its natural gas processing plant in Painter, Wyoming, of which Union Pacific Resources Corporation owns 35 percent. The demonstration operation on Union Pacific is continuing [6].

In addition to the above service demonstrations, there have been other initiatives in the U.S.A. and Canada that are relevant to this study, namely:

- Between 1992 and 1995, both the principal U.S. locomotive OEMs worked on dual-fuel prototype locomotives destined for demonstration operation on Union Pacific. These were the 4,000 HP GM EMD SD 60M and 4,000 HP GE Dash 8 freight locomotives. However, the work was suspended due to other priorities [6].

- Development at the Southwest Research Institute (SwRI), San Antonio, Texas, of *Late-Cycle High-Injection Pressure (LaCHIP)* dual-fuel combustion technology for locomotive-sized medium speed diesel engines [7]. This activity was stimulated by the 1993 GasRail USA project (see next item), the goal of which was a 75 per-cent reduction in NOx emissions below a baseline diesel locomotive. Six natural gas combustion technologies were evaluated on a single-cylinder EMD 710 test engine, resulting in further development of LaCHIP technology using a 16-cylinder EMD 710 engine with encouraging results [8]. Full diesel efficiency was achieved with a 50 percent NOx reduction goal and a 75 percent NOx reduction with an approximate loss in efficiency of 10 percent. However, GM EMD (which owns the technology) took a corporate decision in 1998 to suspend the work until market economics improve.

- *GasRail USA* was an industry cooperative initiative orchestrated by SwRI between 1993 and 1998 to perfect natural gas technology for U.S. freight and passenger locomotives. Participants were the California Air Resources Board, California Regional Rail Authority, Southern California Gas Company, Gas Research Institute, South Coast Air Quality Management District (SCAQMD), Southern California Regional Rail Authority (SCRRA), U.S. Dept. of Energy, Amoco Petroleum Products, GM EMD and Union Pacific Railroad [9]. Using the

LaCHIP combustion technology and gas systems integration developed by SwRI, the GasRail USA goal was to demonstrate a 3,000 HP GM EMD model F59PH1 passenger locomotive in the Los Angeles area on the SCRRA's Metrolink service.

- *CleanRail - Development and Demonstration of an LNG Passenger Locomotive* has been proposed by the SCAQMD to pick up where the original GasRail USA project work left off [10]. It is understood that implementation arrangements are in place. The elements, estimated to cost US $5.6 million over three years, are:
    - convert an SCRRA Metrolink F59PH1 locomotive to low emissions LaCHIP natural gas combustion technology (developed by SwRI but GM EMD owned);
    - convert a baggage car to an LNG tender;
    - convert the head-end power (HEP) auxiliary diesel engine housed in the baggage car to natural gas operation;
    - perform emissions testing on the converted locomotive to validate emissions benefits;
    - conduct testing at the Transportation Technology Center Inc. test track, Pueblo, Colorado, to validate the performance and operation of the converted locomotive and tender consist;
    - conduct a one-year demonstration on SCRRA to determine the feasibility of the technology in actual heavy-rail commuter revenue service.

- Canadian *ENERDEMO* project initiated in 1985 to convert a Bombardier M420 locomotive to operate on natural gas [11]. The intent was to convert an ALCO 251 engine to spark ignition, (to have been undertaken by Bombardier Rail and Diesel Products Division, Montreal). The natural gas was supplied from a closely-coupled tender containing multiple high-pressure CNG cylinders. The plan was for the initial demonstration to be on the private railway of Kidd Creek Mines, Timmins, Ontario. This site was selected as it had proximity to a natural gas pipeline and, being a dedicated railway, the accepted railway practice that hazardous commodities be positioned at least six cars from the front of the train (locomotive) was obviated. The project was terminated in 1987 due to a Bombardier Inc. decision to withdraw from the diesel locomotive sector.

- An Alternate Fuels Study commissioned in 1995 by GO Transit examined converting to LNG operation the EMD F59PH locomotives used in the Toronto-centred heavy rail commuter service [12]. The study found that unless there would be tax rebate incentives available for the use of an alternate fuel such as natural gas, a fleet conversion could not be justified from an economic point of view. For operational reasons It was also judged that on-board LNG tankage was preferable to the use of an LNG tender railcar.

Three recent Canadian technology developments appear to have relevance when consider-ing which locomotive / prime mover technology could be available for natural gas-fueled railway demonstrations in Canada, as follows:

- The "Green Goat" prototype switcher locomotive having, as prime mover, a battery pack of 30 custom-designed 20 volt batteries that are kept charged by a 60 KW diesel-electric generator set [13]. The prototype is an initiative of Rail-power Technologies Corp. (Vancouver) and was constructed by Southern Railway of British Columbia, New Westminister, B.C. The developers claim a 35 percent reduction in fuel consumption and a 80 to 90 percent reduction in NOx. The original design considered an integral Capstone micro gas turbine generator set, the design of which lends itself to burning natural gas instead of diesel fuel. At present, the prototype is being tested in railyard switching operations in California by the Union Pacific Railroad. The batteries produce the equivalent tractive effort of a 2,000 HP diesel locomotive. A smaller "Green Kid" variant is being designed that would be equivalent to a 1,000 HP diesel locomotive.

- The development by Westport Innovations Inc., Vancouver, B.C., of a combined high-pressure natural gas and diesel pilot fuel injector for the direct replacement of the standard diesel fuel injector [14]. For mobile applications, it has also developed a compact cryogenic pump capable of delivering LNG at 4,500 psi to the fuel injector. Of particular relevance vis-a-vis this study is that the focus of Westport's applications is on diesel engines manufactured by Cummins Diesel that are used in heavy duty trucks and diesel-electric generating sets. The interest vis-a-vis a possible natural gas railway demonstration in Canada is that similar-sized Cummins diesel engines are used in railway diesel cars (such as the Budd Rail Diesel Car in use on Canadian railways) and in locomotives elsewhere in the world up to 2,250 HP.

- The conversion by Bombardier Transportation of a 240 km/hr *Acela* locomotive from electric to gas turbine propulsion. A prototype has been produced with a 5,000 HP gas turbine prime mover supplied by Pratt & Whitney of Canada [15]. As gas turbines can readily operate on gaseous as well as liquid fuels, any conver-sion to natural gas operation would be far less onerous than for a diesel engine.

6.0 DEMONSTRATION DESIGN ISSUES

The chart attached as Appendix A contains a decision matrix to select parameters to define a demonstration of a natural gas-fueled railway operation. Each of the parameters will be discussed in this section as a basis for the recommendation (in Section 7) as to which of the alternatives to opt for in the final consortium design. Each parameter, of course, would have to be examined and updated for the final design of the demonstration. Of note as an excellent reference for the in-depth design of a demonstration service is the comprehensive study undertaken by SwRI in 1994 for the GasRail U.S.A. initiative [16].

6.1 Raison d'être for the Demonstration

6.1.1 Impact on the Environment: The principal motivation, currently, to consider natural gas as a fuel for railway operations in Canada is the potential for a positive impact on the environment. Combustion of natural gas in prime movers (diesel or gas turbine engines) of railway locomotives can reduce CO_2 emissions by up to 25 percent as compared to conventional diesel fuel, at equivalent power output [17]. In addition, the combustion of natural gas yields reductions in NOx and PM, as compared to conventional diesel fuel. Hence, as well as effecting a reduction in GHG build-up, there is a reduction in harmful health effects for humans, animals and the ecology. A secondary impact is that the refining of natural gas emits nowhere near the CO_2 as for diesel fuel. For example, every barrel of diesel fuel from the Athabaska Tar Sands (that is widely used in railway operations in western Canada) requires the combustion of an equivalent barrel of oil to heat release the tar from sand [18].

6.1.2 Enhanced Public Image: The public image of natural gas is that it is a "green" fuel [19]. Hence, use of natural gas by the railway sector would give visibility that the railway sector is making a measurable contribution to the Canadian government's goal of meeting the Kyoto Protocol targets. In the same way that many Canadian transit bus operations and automotive fleets now advertise their "environmental friendliness" by using less carbon-intensive alternate fuels, a railway demonstration would project a similar image as a responsible corporate citizen to the Canadian public.

6.1.3 Fuel Supply Security: The demonstration would assemble the technology and operational know-how for the Canadian railway sector to have a secure, less environmentally stressing alternate fuel supplied totally from within Canada.

6.1.4 Reduced Operating Costs: Historically, natural gas has been provided to the consumer at a price lower than conventional diesel fuel on a comparable energy basis. Although there may be price peaks, this relative price advantage is presumed to continue over the long term. It is realized that a significant variable in railway fuel pricing is federal and provincial taxes. However, pressures to find ways to lower GHG emissions may result in governments relaxing taxation of alternate or "green" fuels. Also, use of natural gas as a fuel has knock-on attributes, one of which is less contamination of the lubricating oil resulting in extended periods between oil changes.

6.1.5 Gain Experience for New Business: A demonstration of a natural gas-fueled railway operation would bring together a new range of suppliers and skills that will add to Canada's technological capabilities. For each participant, it is an opportunity to gain experience that leads to new business with the railway sector and will yield spin-offs to other sectors that use medium speed diesel engines, such as the marine propulsion and electrical generating sets . The demonstration will have particular significance for Canadian railway equipment re-builders and combustion component suppliers as well as the suppliers and handlers of natural gas.

6.1.6 Technology Advancement: The demonstration will require equipment not readily available on the market. The specifications of this equipment are expected to be an extrapolation of what is now available. The required engineering development by suppliers to provide this equipment will advance the state of the art of technology.

6.2 Techno-Economic Performance Parameters to Be Measured

6.2.1 Energy Input versus Power Output: These are the locomotive parameters that will be most closely measured during the demonstration. They provide the measure of relative efficiency and utility of natural gas as a fuel versus conventional diesel fuel. An important measure of freight railway efficiency is "revenue tonne-kilometres per litre of fuel consumed". For passenger railway efficiency, it is "passenger-kilometres per litre of fuel consumed". In the case of natural gas, the measure would be the energy equivalent of a litre of conventional diesel fuel.

6.2.2 Availability / Reliability: These parameters are critical to railway operators and, of course, would be among the principal operational parameters judged in the demonstration. These parameters are influenced significantly by the care with which the demonstration is managed and supported by the operating railway. It would be hoped that a Reliability-Centred Maintenance philosophy could be applied to the demonstration so that, inherently, a product improvement feed-back would occur.

6.2.3 Economic Balance: It is important that the demonstration be orchestrated in such a way that all costs related to the natural gas operation can be isolated so as to be able to measure and monitor that the cost of using natural gas is in balance with its benefits.

6.2.4 Energy Costs ($ / HP-hr): This locomotive parameter is a derivative of the data collected in 6.2.1 and 6.2.3 and provides the numeric comparison for the final assessment of the results of the demonstration. The parameter will also be an input into the Emissions Performance Parameters described in Section 6.4.

6.2.5 Investment Payback Period: This parameter is of significance for applying the experience of the demonstration to further segments of the Canadian railway sector. The railways prefer projects that have at least a 25 percent investment rate of return, that is, there can be payback within at least four years. In addition, a factor could be included to show the dollar equivalent value of the reduced CO_2 emitted (of value should emissions credits trading be an option).

6.3 Regulatory Compliance Parameters

6.3.1 Safety: The handling of natural gas is currently an unknown for the Canadian railway sector and, hence, the first concern is in regard to safety in the workplace [16.1] [16.2]. A significant element of the design phase of the demonstration project would be a transfer into the Canadian railway context of the safety codes and regulations that have been developed for the use of natural gas in the road transport and industrial sectors. A first reference would be the safety procedures that were put in place by U.S. regulatory authorities during the 1990s when the Burlington Northern Railroad tested of two LNG locomotives with two LNG tender cars hauling unit coal trains [16.3]. Several videos and training material exist based on the U.S. experience.

6.3.2 Emissions Standards: In the absence of Canadian standards limiting emissions from railway locomotives, the standards for reference are those promulgated in 1998 by the U.S. Environmental Protection Agency (EPA) [20] [21]. The standards are applicable to when a locomotive was built. It is recommended that Tier 2 emissions limits be the target for any natural gas railway demonstration in Canada. The units for the emissions limits are grams per brake horsepower-hour (g/bhp-hr), as follows:

Table 1: U.S. EPA Emissions Standards for Locomotives (g/bhp-hr)

Duty Cycle	HC*	CO	NOx	PM
Tier 0 (1973 - 2001)				
Line-haul	1.0	5.0	9.5	0.60
Switcher	2.1	8.0	14.0	0.72
Tier 1 (2002 - 2004)				
Line-haul	0.55	2.2	7.4	0.45
Switcher	1.2	2.5	11.0	0.54
Tier 2 (2005 and later)				
Line-haul	0.3	1.5	5.5	0.20
Switcher	0.6	2.4	8.1	0.24
Current Estimated Locomotive Emission Rates (1997)				
Line-haul	0.5	1.5	13.5	0.34
Switcher	1.1	2.4	19.8	0.41
* *HC standard is in the form of THC (total hydrocarbon) for diesel engines. For locomotives and locomotive engines fueled by alcohol or natural gas, equivalent THC standards apply.*				

Of note vis-a-vis the fact that combustion of natural gas in some engine designs results in high CO emissions (but low PM values) is that the U.S. EPA allows alternative standards for CO and PM to be used by manufacturers or re-manufacturers when seeking certification (for which both emissions must be complied with) as shown in Table 2:

Table 2: Alternative CO and PM Standards Allowed by U.S. EPA (g/bhp-hr)

	Line-haul Cycle		Switcher Cycle	
	CO	**PM**	**CO**	**PM**
Tier 0	10.0	0.30	12.0	0.36
Tier 1	10.0	0.22	12.0	0.27
Tier 2	10.0	0.10	12.0	0.12

6.3.3 Labour Codes: This is a subject that will require careful interaction between the operating railway on which the demonstration would be conducted and the provincial and federal codes applicable to railway workers. It would also be advisable to involve, early on, labour syndicates such as the Brotherhood of Locomotive Engineers.

6.3.4 Training: Special training will be required for the railway staff and supply company workers for the operation of the natural gas-fueled locomotive and the respective handling and fueling procedures [16.4]. Although the aim would be for the operation of a locomotive fueled by natural gas to be transparent vis-a-vis a conventionally fueled locomotive, the operating crew must be cognizant of the additional equipment, gauges and recording equipment for the demonstration. Regarding the fueling procedure, it is envisaged that this would be provided by outside specialty suppliers. Their workers would require training or be supervised vis-a-vis railway safety practices for the fueling operation. At present, railway fuelers (for conventional diesel fuel) are the lowest on the skills ladder.

6.4 Emissions Performance Parameters

6.4.1 Emissions Levels: The recommended method to assess the impact of natural gas as a railway fuel on air pollution is to compare locomotive exhaust emissions over an actual revenue train route by using emissions factors from existing diesel engines, and comparing those results with locomotives of the same power that are operating on natural gas [16.5]. To perform this analysis, the two key inputs are the duty cycles (time-in-notch) and the actual exhaust emissions of each locomotive in each throttle notch [22]. Emissions factors exist for the great majority of locomotives currently operating in Canada on diesel fuel. However, measurement of emissions would have to be done for the locomotives converted to natural gas, the capability for which exists in Canada [23].

6.4.2 Emissions Reduction Cost / Benefit Ratio ($ / tonne reduced): If one considers that, currently, interest in natural gas as a fuel stems primarily from its potential to stem the degradation of the environment, then a principal factor to measure in a demonstration is the incremental cost per tonne of emissions reduced. This factor is important for both investment considerations by the rail sector and the possibility for banking, or trading the resulting reductions as "emissions credits". Various studies in the U.S. have estimated the cost to reduce one ton of NOx emissions from a locomotive using LNG could be in the order of US $1,000 [24]. This could improve the payback for the conversion costs depending on the market value of a tonne of CO_2, NOx, etc.

6.4.3 Public Accolades: Currently, the bus transit sector is receiving accolades from the public through highly visible advertising segments of the fleet operating on alternate fuels such as natural gas, biofuels or hydrogen. A railway operation using natural gas could derive similar accolades. However, this also raises the responsibility of ensuring that a public relations program be established together with implementation of the demonstrations service.

6.5 Type of Operation

6.5.1 Yard Switching: Locomotives in this type of service are dedicated to switch rail-cars in a rail yard to make up trains for mainline operation. These locomotives idle about 80 percent of the time. Purpose-built switchers are of the order of 1,400 HP while it is common for older mainline locomotives (2,000 to 3,000 HP) to be cascaded to this service. This category also includes locomotives operations in industrial terminals, ports, etc.

6.5.2 Short-Line Freight: Short-line railways are feeder operations totally within a province and came into existence as a result of de-regulation that permitted the Class I railways to withdraw from branch line operations. The locomotives used are generally a mix of older locomotives in the 1,500 to 3,000 HP range.

6.5.3 Commuter: Heavy-rail commuter operations feed passengers into and out of metropolitan business centres primarily during the morning and evening. As there are frequent stops following by high acceleration rates, the locomotives are generally in the 3,000 to 4,000 HP power range and fitted with an auxiliary diesel generating set known as head-end power (HEP) to supply electrical power to the coaches.

6.5.4 Mainline Freight: This refers to mainline train operations over long distances hauling unit trains of bulk commodities, intermodal containers or mixed goods. The locomotives in these operations are sized from 3,000 to 6,000 HP. The duty cycle averages 14 percent of the time at full power (Notch 8) and 54 percent idle.

6.5.1 Mainline Passenger: This refers to intercity passenger-carrying operations using 3,000 to 4,000 HP locomotives which were purpose-designed for passenger rail operations. The duty cycle averages 20 percent of the time at full power (Notch 8) and 70 percent idle. The locomotives can either have HEP installed or have an auxiliary electrical generator coupled with the main traction generator. On some branch lines, diesel multiple units (DMUs) are used instead of separate locomotive / coach consists.

6.6 Location

6.6.1 Vancouver: Located on the seaward side of the Lower Fraser Valley in British Columbia, the Vancouver-centred metropolitan region contains 2 million inhabitants and examples of each type of railway operation listed in Section 6.5. It is designated by Environment Canada as a Tropospheric Ozone Management Area (TOMA), that is, an area of particular interest for gaseous emissions [25]. About 20 percent of railway fuel consumed is in the TOMAs. A locomotive re-building facility exists in the Vancouver-centred region as well as an LNG production plant with distribution network.

6.6.2 Toronto: With a catchment area of almost 5 million inhabitants, Toronto, Ontario, is Canada's largest metropolitan area and a principal emissions node in the Windsor-Quebec City Corridor TOMA. Examples of each type of railway operation type exist in the Toronto area. It has the most extensive diesel locomotive-hauled commuter rail network in Canada. A pipeline from Western Canada brings natural gas to Toronto.

6.6.3 Montreal: With a catchment area of 3.5 million inhabitants, Montreal, Quebec, is a principal emissions node in the Windsor-Quebec City Corridor TOMA. Rail yard switching, commuter and mainline freight and passenger operations exist in Montreal, plus locomotive re-building and full emissions testing facilities. A pipeline from Western Canada brings natural gas to Montreal. An LNG production plant exists in the Montreal area but is only used on an intermittent basis.

6.6.4 Other: A location having a high public sensitivity about emissions is the Victoria to Courtenay corridor of Vancouver Island, British Columbia. The current VIA Rail Canada passenger operation there uses DMUs, actually 1950s' era Budd Rail Diesel Cars with updated Cummins diesel engines (which are mounted underfloor).

6.7 Candidate Participants in Consortium

6.7.1 Railway Operators

- **BC Rail:** Headquartered in North Vancouver, BC Rail is owned by the province of British Columbia and operates mainline freight services from Vancouver to northern British Columbia. Passenger services using Budd Rail Diesel Cars were suspended in October 2002. BC Rail has a rail yard in North Vancouver that is visible to the public and in close proximity with housing. It could be a candidate site to demonstrate a switcher locomotive fueled by natural gas.

- **Southern Railway of BC:** Headquartered in New Westminister, B.C., but part of a family of U.S. owned short lines, this is a short-line railway providing feeder operations to the Class I railways in the Vancouver area as well as freight service to industrial sidings in the Fraser Valley through fairly densely populated areas. The railway has its own locomotive re-building capability and provides maintenance and re-work for other short lines and industrial locomotive operators. It could be a candidate site for a natural gas-fueled freight locomotive demonstration as well as undertaking the work to convert the locomotive and its engine.

- **GO Transit:** Owned by the province of Ontario, GO Transit operates a fleet of GM EMD F59H locomotives and bi-level passenger rail cars along nine commuter corridors within a 50 km radius of Toronto. The locomotives are fitted with head-end power (HEP), that is, separate auxiliary diesel generator sets to provide

500 KW of electrical power for heating and air conditioning of the passenger cars. GO Transit operates on rail lines owned by Canadian National (CNR) and Canadian Pacific (CPR) railways and must schedule its operations to inter-mingle with the operations of these railways. Its operations and fueling facilities are centralized at its Willowbrook site on the outskirts of Toronto. As mentioned in Section 5.9, GO Transit has examined the feasibility of a conversion to LNG fuel for its bus and railway operations and could be considered a site for a possible demonstration on its rail commuter service. Any conversion of GO Transit locomotives to LNG would also require conversion of the HEP auxiliary engine.

- **Montreal AMT:** Reporting directly to the Quebec government, the Agence métropolitaine de transport (AMT) is charged with developing and improving all modes of transport in the Greater Montreal region. It operates a commuter rail service on both its own electrified line and lines owned by CNR and CPR. The AMT subsidiary, GESPROEX, specifies service levels and purchases railway operations from these two Class I railways. It currently uses a variety of old and new diesel locomotives.

- **Others:** Without wishing to preclude possible other candidate railway participants, it is judged that the only other non-Class I railways having services candidate for conversion to natural gas fuel would be the diesel locomotive hauled commuter rail operations of West Coast Express linking Vancouver and Mission, B.C. and the VIA Rail Canada DMU passenger operations on Vancouver Island.

6.7.2 Natural Gas Distributors

- **BC Gas:** Of significance for siting any demonstration is the fact that BC Gas has had in operation since 1971 an LNG production plant with a capacity to liquefy 120,000 cubic metres of natural gas per day and a capacity to store 28,000 cubic metres of LNG (equivalent to 17 million cubic metres of natural gas at atmospheric pressure) [26]. It is located in the Vancouver area on Tilbury Island. It is used to supplement the Lower Mainland gas supply during peak demand. BC Gas has a fleet of tank trucks to deliver LNG to customers. An associate company of BC Gas, e-Fuels, can provide technical assistance and equipment to assist users to apply LNG to their operations. For a railway demonstration in the Vancouver area, BC Gas would be an obvious participant. Appendix B describes the plant in further detail.

- **Enbridge Consumers Gas:** This organization distributes natural gas in the Toronto region that has been delivered by pipeline from Western Canada. An infrastructure now exists for the production and distribution to refueling stations of CNG used to fuel automotive fleets. The distributor is NGV Business Development, Toronto. LNG is currently not available in the Toronto area unless brought by truck from American suppliers. The Ontario Energy Board regulates natural gas rates in Ontario. An issue common to all sites is whether the rates charged for a railway demonstration would be fully allocated or incremental.

- **Gaz Métropolitain:** About 97 percent of the natural gas consumed in Quebec is delivered by Gaz Métropolitain Inc. (Gaz Metro) via a 8,500 km grid serving 160,000 customers [27]. An LNG production plant exists but is only operated on an as-required basis for peak demand shaving. Gaz Metro is a supporter of the Montreal-based Natural Gas Technologies Centre, an entity supported 65 percent by local gas distributors. This is of significance vis-a-vis the recent closure of the Canadian Gas Research Institute (an entity of the Canadian Gas Association).

6.7.3 Natural Gas Injection Technology for Diesel Engines

- **Westport Innovations Inc:** Located in Vancouver, this company has developed and is commercializing the patented high-pressure direct injection (HPDI) technology invented by Dr. Philip Hill at the University of British Columbia [28]. The core of the technology is a combined natural gas and diesel pilot fuel injector that is designed as a direct replacement for an existing diesel fuel injector (as shown in Appendix C). The integral injector design is a design breakthrough as it permits diesel engines to operate on natural gas while maintaining full diesel performance and fuel economy but with lower CO_2 , NOx and PM emissions. For mobile applications, the natural gas is stored as LNG. Westport has entered into a commercial arrangement with Cummins Engine Company to provide LNG-based combustion technology for its heavy-duty truck engines and large-sized diesel electrical generating sets (gen-sets). These applications are receiving priority as they have large market bases as contrasted to the medium-speed diesel engines used by the railway sector. However, of significance vis-a-vis a potential natural gas-fueled railway demonstration is that the truck-sized Cummins diesel engines are similar to those installed in DMUs (such as Budd Rail Diesel Cars) and the gen-set sized engines are installed in locomotives operating in Europe, the Middle East and Asia [29]. The locomotive engines are sized to 2,500 HP. If higher traction power is required, such engines could be installed in tandem in a locomotive to provide up to 5,000 HP.

- **Energy Conversions Inc:** This company, sited in Tacoma, Washington, and operating under the acronym ECI, specializes in dual-fuel conversion systems for GM EMD 645 and 710 engines used in the offshore oil and power generation industries. Recently its system has been applied to Caterpillar D399, D398 and D379 engines [30]. The ECI dual-fuel system allows a converted engine to run on either dedicated diesel fuel or a natural gas/diesel fuel mixture. In the dual-fuel mode, low-pressure natural gas is delivered to the combustion chamber through the open intake valve of the engine cylinder. Once in the cylinder, a small amount of diesel pilot fuel ignites to initiate combustion of the natural gas. A standard ECI conversion system incorporates modified pistons, a special gas supply, diesel control components for simultaneous pilot fuel control, an automated electronic monitoring and control system and supplemental engine cooling. ECI provided its system for the EMD 16-643 E3B locomotives used by Burlington Northern Railroad in its natural gas demonstration (described in Section 5.2).

- **GM EMD LaCHIP System:** Under contract to GM EMD, SwRI developed a LaCHIP (Late Cycle High Injection Pressure) natural gas combustion system tailored for a 16-cylinder EMD 16-710 medium speed diesel locomotive engine. This system uses a standard diesel fuel injector to supply pilot fuel with a separate natural gas injector operating at about 3,000 psi. SwRI developed the LaCHIP system and tested it on the converted EMD engine with encouraging results. For example, a reduction in NOx of 75 percent of baseline diesel was achieved with a 10 percent efficiency penalty and CO and THC levels the same as baseline. With a 50 percent reduction in NOx, full diesel efficiency was obtained. The LaCHIP engine was targetted to be installed in a GasRail USA passenger locomotive to be demonstrated in the Los Angeles area (see Appendix D). A corporate decision by GM suspended the work. There is consideration to re-start the project under the title of "CleanRail USA" and ECI has offered to produce the LaCHIP system under licence from GM EMD.

- **Caterpillar Lean-burn Combustion:** Based on extensive experience producing natural gas engines for stationary applications such as compressors and gen-sets, Caterpillar developed a 1,200 HP spark ignited natural gas version of its 16-cylinder 3500 engine which is installed in switcher locomotives manufactured by MotivePower Industries (MK Rail) [31]. Its specifications are detailed in Appendix E. This engine uses a lean-burn combustion strategy featuring a prechamber in the cylinder head where gas is admitted to form a locally rich mixture and then spark ignited. Gas is also admitted into the main combustion chamber at the intake port by a camshaft-actuated gas valve. The jet of hot, expanding products of combustion from the prechamber flows through a nozzle into the main chamber, where it ignites the extremely lean mixture present there. This configuration allows stable ignition at leaner overall mixtures than is possible with spark-ignited homogeneous mixtures, resulting in very low NOx emissions.

6.7.4 Alternate Prime Movers: Prototype locomotives of two Canadian technology development initiatives were unveiled during 2002. Both designs are amenable to being considered for motive power in a natural gas-fueled demonstration. They either are, or can be, equipped with gas turbine engines.

- **Railpower Technologies Corporation's "Green Goat"** switcher locomotive powered by a battery pack that is trickle-charged by a 60 KW gen-set (as shown in Appendix G). The engine for the gen-set can be a small diesel engine (as currently installed in the first prototype) operating on diesel fuel or a small gas turbine that can operate either on diesel fuel or natural gas. Capstone (California) manufactures such small integral natural gas-fueled gas turbine gen-sets. The locomotive has space for on-board LNG fuel tanks.

- **Bombardier Transportation's *JetTrain*** high-speed passenger locomotive, a non-electric version of the *Acela* units operating on AMTRAK. The *JetTrain* is fitted with a Pratt & Whitney of Canada 5,000 HP gas turbine (see Appendix F), which replaces the on-board electrical equipment and permits *JetTrain* consists to run on non-electrified rail lines. The lightweight gas turbine engine also permits the *JetTrain* to run at higher speeds with less track forces than if a heavy diesel engine were used. Although configured to run on standard railway diesel fuel, technology to convert a gas turbine to natural gas operation is readily available. LNG could be stored either in on-board tanks or in a tender car. Although less fuel efficient than a diesel engine, this gas turbine produces lower emissions (for example, 0.5 g/bhp-hr of NOx versus 5.5 g/bhp-hr for a Tier 2 diesel engine).

6.8 Technology Options

6.8.1 Locomotive: When considering which type of locomotive to opt for in a demonstration, the decision will be influenced not only by the type of service in which the locomotive would be operated (as described in Section 6.5) but also from where it would be sourced. Locomotives are classified as either "freshly manufactured", that is, brand new, or "rebuilt", that is, re-manufactured to original specifications following expiration of their "useful life". For rebuilt locomotives, the only variance from conforming to original specifications is the installation of retrofit kits to meet the U.S. EPA emissions standards plus any safety-related features subsequently mandated. Locomotives are re-built about every 10 years or 1.2 million kilometres. If the locomotive is equipped with a megawatt hour (MW-hr) recorder throughout its operating life, it will be rebuilt when a MW-hr reading of 7.5 times the rated horsepower occurs. For data repeatability purposes, it would be preferable that locomotives designated for conversion to natural gas for use in a demonstration operation be either rebuilt or freshly manufactured.

- **Rebuilt Units:** There exists capability in Canada to rebuild to original specifications locomotives of all types, be they yard switchers, road switchers**,** mainline freight and passenger locomotives and diesel rail cars. It would appear that, from a cost viewpoint, use of rebuilt units would be the preferable option for any demonstration. A drawback for some service applications of rebuilt "older design" locomotives is that they lack the modern electronics systems that provide improved control, adhesion and monitoring capabilities.

- **Freshly Manufactured:** If affordable, it is preferable to initiate railway demonstrations with brand new equipment. However at present, the OEMs are only focusing on the production of high-horsepower mainline freight and passenger locomotives. Switchers are being produced by MK Rail Corp. (Boise Locomotive). Regarding self-propelled passenger equipment, an interesting development is that Colorado Railcar, Fort Lupton, Colorado, has designed and manufactured a DMU unit that during tests in February, 2002, met the U.S. DOT Federal Railroad Administration's structural compliancy standards for operation on mainline tracks [32]. A cross section of the DMU is shown in Appendix H. The DMU is powered by two Detroit Diesel 600 HP engines with an auxiliary generator unit powered by a 240 HP Deutz diesel, all of which could conceivably be converted to operate on natural gas.

6.8.2 Engine / Prime Mover: A critical decision in the design of a natural gas-fueled railway operation is the choice of engine, or prime mover, installed in the locomotive. There are a variety of technical designs and arrangements plus considerations regarding whether the engine is in common use by Canadian railways.

- **Design:** Engines used in Canadian railway service are classified as either "conventional" or "unconventional". Conventional engines are the medium-speed diesel engines produced by the two dominant American OEMs, GM EMD and GE Transportation. Unconventional engines / prime movers include all other designs such as medium-speed diesel engines produced by non-OEMs, higher-speed diesel engines, gas turbine engines, hybrid battery power packs and fuel cells.

- **Type:** For a demonstration, the engines could be either purposely designed and freshly manufactured for natural gas operation, or be rebuilt units that have been converted for natural gas operation.

- **Maker:** The dominant companies that have supplied, and continue to supply medium-speed diesel engines for the Canadian railways are the two U.S. based OEMs, GM EMD and GE Transportation. Other North American suppliers are Fairbanks-Morse (which supports the ALCO medium-speed diesel engine) and Caterpillar Engine Company, Cummins Engine Company and Detroit Diesel, which supply higher-speed diesel engines for auxiliary head-end power and niche applications. Pratt & Whitney of Canada provides industrialized versions of its aircraft gas turbines and Capstone (California) offers an integral gas turbine - electrical generator unit for auxiliary power.

6.8.3 Combustion System: Natural gas does not auto-ignite. When natural gas is used in engines originally designed for a diesel combustion system, ignition requires either a spark, glow plug or a pilot injection of conventional diesel fuel. Experience has shown that with spark ignition, the power output is down about 25 percent whereas with the pilot injection combination, up to full rated power can be achieved.

- **Retrofitted:** Diesel engines of North American design used in railway applications that have been converted to date to operate on natural gas are primarily retrofits of liquid-fueled engines. This has been done by:
    - introducing the natural gas into the intake manifold and replacing the injectors with spark plugs; or

- injecting the natural gas at low pressure into the combustion chamber during the intake stroke of the piston and igniting it either by a spark or pilot diesel fuel; or
- injecting the natural gas at high pressure directly into the combustion chamber concomitant with pilot diesel fuel.

Retrofitting a gas turbine engine to natural gas is relatively straightforward.

- **Integral Design:** Diesel engines for automotive and gen-set applications having integral purpose-design natural gas supply and combustion systems exist for both low pressure direct injection and high pressure injection. An integral design having potential for a DMU rail demonstration is the patented High Pressure Direct Injection system technology being commercialized by Cummins Engine / Westport Innovations for injection of gaseous fuels into engines using the diesel cycle. "High pressure" means roughly 3,000 psi at injection, "directly" into the combustion chamber, generally through a single integral fuel injector.

6.8.4 Technology Risk Factors: A demonstration of a technology new to an application, such as the use of natural gas in Canadian railway operations, inherently has technological risks associated with it. These risks stem from the degree of maturity of the technology, the relative background experience of the operators, the ready availability of expertise and the business strategies concerning proprietary technology. Judgement is required to balance the risks when selecting the final configuration of the natural gas fuel arrangement for any demonstration. A significant risk variable is whether technology available uses existing "off-the-shelf" componentry or whether the technology is still under development and, although has promising performance parameters, does not have the reliability needed for an operational context.

6.8.5 Natural Gas Fuel Delivery / Storage: For an envisaged demonstration, it is judged more feasible for the natural gas to be purchased from a vendor and delivered either directly to the train consist or into a rail yard storage tank for subsequent dispensing by railway crews. The gas can be delivered either at pipeline pressure or as CNG or LNG. However, LNG is preferred because of the 625 times volume ratio between CNG and LNG. In some regions, such as Vancouver, LNG can be delivered by a vendor. For regions where LNG does not exist, small LNG production facilities such as produced by CFS Alternate Fuels Inc., Victoria, B.C., and others could be an option [33]. Where a just-in-time LNG delivery infrastructure does not exist, the recommended rail yard storage tank capacity should be equivalent to at least seven days of fuel use. Dispensing and storage options include:

- **Dispensing to the Train Consist:** Depending on the operational schedule, natural gas in the LNG state can be dispensed either directly to the train consist by a local vendor, or from specially insulated rail yard storage tanks. Awareness of the specific cryogenic characteristics of LNG would need to be emphasized with employees and detailed training programs instituted.

- **Storage on the Train Consist:** On-train storage of natural gas in would be via either CNG bottles (not recommended) or specially insulated LNG tanks. The LNG tanks can either be on-board the locomotive (or power car) in place of the existing diesel fuel tank or as a separate tender railcar closely coupled to the locomotive. The tender would have the appearance of a tank car but, in fact, would be quite sophisticated with multiple safety and protective devices, extensive piping and control systems for filling, venting and vapourizing the gas. Based on the tender designed for the Burlington Northern Railroad demonstration, it would be constructed of a stainless steel inner tank shell surrounded by 15 cm of vacuum drawn insulation which, in turn, is encased in a carbon steel tank shell. Unlike conventional tank cars that use stub-endsills, the entire structure would be supported by an underframe.

6.9 Site Impact

6.9.1 Urban: Mounting a demonstration in an urban context would appear to have the largest impact from a public perception viewpoint. It would be seen by more people and could be linked to the overall efforts of the adjoining city or municipality to reduce harmful emissions into the atmosphere, particularly those affecting the health of humans, animals and the ecology. The demonstration would most likely be a rail-yard switching operation adjacent an urban area or a commuter rail service. An urban site is recommended for initiating any series of demonstrations in Canada to evaluate the emissions reduction merit of natural gas as a railway fuel. However, because the amount of natural gas consumed would be less than mainline operations, the relative reduction in various emissions (CO_2, NOx, PM, etc.) from an urban site would be less.

6.9.2 Suburban: A demonstration in a suburban operation using a road switcher locomotive or regional commuter operation would likely have a similar public perception impact as for an urban site and, as well, consume more fuel; hence there would be an increase in contribution to reducing CO_2 emitted. A suburban freight service would likely include a duty cycle that ranges from switching operations (with extensive idling) through to local freight services.

6.9.3 Countryside: A demonstration that includes drag freight operations through a populated regional countryside, likely on a short-line railway, would have a duty cycle reflecting considerable variability in power notch setting. Another option would be a regional passenger rail operation, likely using DMUs, that has an impact on the local communities served. Such rail operations tend to experience several speed restrictions as they traverse smaller communities and level crossings. The regional drag freight operations would likely have a flexible schedule, hence complicating the comparison between natural gas and diesel fueled operations. A strategy to overcome this would be to always run two locomotives in tandem separated by an LNG tender. One locomo-tive would draw natural gas from the tender while the other locomotive would use conventional diesel fuel. Such an operation bodes well to produce representative data for scale-up to Class I railway conditions.

6.9.4 Unpopulated Regions: A demonstration traversing unpopulated regions suggests a mainline heavy-haul freight operation. Although such an operation would have lower public visibility, it would consume more natural gas fuel and, hence, emit less CO_2. Such a demonstration operation could yield considerable emissions reduction credits that could be banked and traded on a reimbursable basis, thus offsetting the incremental cost of converting the locomotives and mounting the demonstration. However, it is judged that implementation of a demonstration using natural gas as a fuel for operations over unpopulated regions should only follow on from experience first gained in urban-centred operations where maintenance and servicing are easier.

6.9.5 Ecology Sensitive: It is expected that as more and more ecology-sensitive zones are designated in Canada, opportunities may arise to justify a natural gas-fueled railway demonstration that traverses such a zone, particularly if it is linked to a high-profile site or event. One possible opportunity would be the proposed passenger rail link to Whistler if the Vancouver bid to host the 2010 Winter Olympic Games is successful [34]. The envisaged rail link would be an upgrade of the present BC Rail line between Squamish and Whistler. Travellers would be transported to Squamish by high-speed ferry boats from Vancouver terminals and would then transfer to the train. The line passes through sensitive seashore and mountain valley ecology. A demonstration associated with the Olympics would catch the attention of the rest of Canada and the world. The special funding allocated for the infrastructure to put on the Olympic Games could be the source to cover the demonstration preparation costs.

6.9.6 Stations and Tunnels: A challenge for the design of any commuter rail demonstration is, for safety considerations, whether LNG fuel operations would be allowed adjacent passenger platforms, in enclosed stations and through tunnels. This is a key element in any safety plan to be worked out with safety regulators. Considerable experience could be referenced vis-a-vis CNG in automotive and bus operations in enclosed spaces.

6.10 Targeted Emissions Standards

6.10.1 RAC, as Measured: No legislated standards exist in Canada for locomotive emissions. However, emissions targets exist in the form of a voluntary monitoring action that the Railway Association of Canada (RAC) entered into with Environment Canada to strive to cap locomotive emissions at 1989 annual levels for 1990 through 2005. This cap is 115,000 tonnes per year for NOx and is derived from the reported annual diesel fuel consumed by the railways and locomotive emissions factors established during testing by the AAR and SwRI. The monitoring action results are published annually in Environment Canada's Locomotive Emissions Monitoring report series. Hence, data captured in any natural gas demonstration could be reported similarly to show the emissions reduction contributed by using natural gas as the fuel.

6.10.2 Transport Canada: Amendments in 1990 to the Railway Safety Act empower Transport Canada with the authority to regulate emissions from railway locomotives. The statement in the Act pertaining to *Regulations - protection of the environment* is:

> *47.1 (2) The Governor in Council may make regulations restricting or otherwise governing the release of pollutants into the environment from the operation of railway equipment.*

To date, Transport Canada has not promulgated any emissions standards or limits.

6.10.3 Environment Canada: Fuel quality specifications are set by Environment Canada, particularly regarding sulphur content so as to lower emissions of oxides of sulphur (SOx). At present, diesel fuel sulphur content is approaching 0.05 weight percent (500 ppm) with the outlook that by 2007, on-highway vehicles will require an ultra-low sulfur content of 0.0015 weight percent (15ppm). It is expected that the natural gas used in any demonstration would meet these Environment Canada fuel standards.

6.10.4 U.S. EPA: In April 1998, the U.S. Environmental Protection Agency (EPA) promulgated a rulemaking concerning standards for locomotives and locomotive engines operating in the U.S.A. These incremental standards (Tier 0, Tier 1, Tier 2) are described in Section 6.3.2. In the absence of Canadian standards limiting emissions from railway locomotives, the EPA standards are the technical reference for Canadian railways purchasing new locomotives from the OEMs or rebuilding older units. The EPA is drafting ever more stringent standards (Tier 3 and Tier 4) which will be promulgated later this decade.

6.10.5 CARB: The California Air Resources Board (CARB) is the most active state-based air quality regulatory agency in the U.S.A. In many cases, its emissions standards are the precursor of those promulgated nationwide by the EPA. Its enforcement strength stems from the emissions-intensive demographics of California and particular atmospheric conditions that further intensify the harmful effects of the emissions. CARB has a priority interest in the use of natural gas as a transportation fuel as a way to reduce, specifically, PM formation.

6.10.6 Kyoto Protocol: This is an international agreement negotiated in Kyoto, Japan, in 1997 by 150 countries. The goal for Canada is, by 2012, to reduce annual green-house gas emissions (CO_2, etc.) by six percent below the 1990 level of 565 million tonnes (Mt). Figure 1 projects that the Canadian level would rise to 805 Mt annually by 2012 unless reductions occur to lower this amount by 240 Mt by 2012. The Canadian railway sector has excellent data in this regard since 1990 and appears to be on target. In fact, it could exceed the targeted reduction and accrue emissions reduction credits that could be traded.

6.11 Safety Code Compliance

6.11.1 Canadian Standards Association: No regulation or standard currently exists at either the provincial or federal level with respect to the handling, storage or utilization of LNG as a fuel for railway locomotives, or with respect to small LNG storage and dispensing facilities. There is a standard, Can/CSA-Z276-M89, which applies to large liquefaction facilities. It is understood that guidelines have been drafted for small LNG facilities but, as yet, have not been formalized.

6.11.2 Transport Canada: Any demonstration affecting federal jurisdiction would have to have its technical and operating features reviewed by Transport Canada's Railway Safety Bureau before being cleared for operation. Any design activity for a natural gas-fueled railway operation should involve, from the start, consultation with this Bureau to establish the compliance procedure and requirements. This is because the envisaged demonstration would be the test case in Canada for LNG in railway applications. The development of legislative standards and regulations should go hand in hand with the demonstration design.

6.11.3 U.S. DOT/FRA: The U.S. Department of Transportation's Federal Railroad Administration (US DOT/FRA) possesses a wealth of experience regarding the application of safety codes and procedures for railway operations. In addition, the FRA oversees the Transportation Test Center at Pueblo, Colorado, where new rail technology can be operated under controlled conditions on its test track.

6.11.4 AAR: The Association of American Railroads (AAR) has, inter alia, the mandate to ensure interoperability of railway equipment throughout the North American railway network. In this regard, standardized fittings, appurtances and limits on weights and dimensions have been established, and should be referenced for a demonstration.

6.11.5 Provincial Codes: Applicable regulations and codes regarding the handling and storage of LNG exist in varying degrees in provincial jurisdictions, many of which were drafted for automotive applications. Fire safety standards are of foremost concern. Many provinces reference the fire safety standards of the U.S. National Fire Protection Association for the design and installation of LNG systems in vehicles including railway applications.

6.11.6 Canadian Gas Association: Although this organization is primarily an advocacy group promoting the natural gas sector and championing market-related issues, it can provide advice and direction concerning the safety aspects for handling, storage and utilization of LNG.

6.11.7 Labour Codes: The labour codes and training requirements for the skills needed in any demonstration would be under provincial jurisdiction. Involvement of the Brotherhood of Locomotive Engineers during the design phase of the demonstration would contribute to an understanding of the training requirements.

6.12 Financing

6.12.1 Consortium Absorbed: Financing arrangements for the envisaged demonstration would be a function of such variables as the participants constituting the implementation consortium, the site, nature and duration of the operation, and the technology options for the locomotive conversion. Because of the large number of permutations and combinations, this study does not address estimated costs of equipment and infrastructure installations. Whether the financing would be "consortium absorbed" or require assistance from government or other funding sources would depend on whether the economic analyses (to be the subject of a follow-on detailed feasibility study) could show an encouraging corporate rate of return.

6.12.2 Assistance Required: It is highly likely that the consortium assembled to implement the demonstration would need, and seek, funding assistance from granting agencies. A general rule in transportation demonstrations, the operator seeks funding assistance to cover the incremental cost of acquiring, operating and managing the introduction of new technology. The unveiling of the federal government's plan to meet the Kyoto Protocol indicates that financial incentives will be available for initiatives to reduce emissions of greenhouse gases [36]. The source of the funding, in this regard, is primarily federal and provincial science-based departments and agencies (SBDAs) having mandates to support such initiatives. In addition to in-kind contributions expected from the consortium members, from the railway sector via the RAC and ARRC associations, and from the natural gas sector via the Canadian Gas Association, the candidate federal and provincial SBDAs include:

- Natural Resources Canada with its Alternate Fuels Technology and Emissions Research (AFTER) sub-program of the Program for Energy R&D (PERD) and its Technology Early Action Mechanism (TEAM);
- Environment Canada's data gathering and monitoring support actions;
- National Research Council Canada's Industrial Research Assistance Program (IRAP)
- Transport Canada's support for increase in use of urban transit and initiatives of its Transportation Development Centre;
- Revenue Canada's Scientific Research and Experimental Development tax rebate arrangement; and
- applicable support possibilities from provincial SBDAs, such as waiver of sales tax and similar duties.

6.12.3 Emissions Reduction Credits Trading: These are "credits" earned for good emissions reduction performance. For the envisaged natural gas-fueled railway demon-stration, they may be either not considered, or banked and actively traded on a financial exchange to be purchased by polluters who cannot meet regulated emissions targets. One such exchange is the Greenhouse Gas Emission Reduction Trading (GERT) pilot that was launched by a multi-stakeholder partnership in June 1998 to provide registration and practical experience for a market-approach for trading emissions credits [37]. This would appear relevant for the envisaged demonstration.

6.13 Management: It is assumed that the demonstration project would be implemented by a consortium made up of like-minded organizations from the railway and natural gas sectors. How the project is managed and orchestrated is key to the demonstration being implemented and operated successfully. It would appear preferable that the managerial leadership be provided by the consortium expecting to implement the demonstration project, with preferably a railway, or railway association, having the dominant role. This is to ensure that the performance specifications and resulting design have been inherently developed to be compatible with a railway operating context. An alternate managerial arrangement would be commissioning a consulting company experienced in railway infrastructure projects to manage the implementation on behalf of the consortium. Other possibilities could see the management provided by a research institute or a para-public agency that would be guided by a committee composed of consortium members and regulatory agencies. It is envisaged that the project team being managed would primarily have a techno-economic systems integration function and could be facilitated by concurrent engineering techniques.

6.14 Timeframe

6.14.1 Planning the Implementation: As can be appreciated from the plethora of design issues listed in this section, there is an array of permutations and combinations of arrangements to be sifted through, analyzed and decided upon before action could be taken to assemble the technology to implement a demonstration. It goes without saying that the critical first step is to assemble a consortium of interested sponsors and participants and then develop designs and estimated costs for a site-specific implemen-table demonstration. One tactic to expedite this is for a sponsoring governmental agency to issue a "Call for Expressions of Interest" to the Canadian railway and natural gas sectors. After first receiving expressions of interest from prospective con-sortia, token funding of amounts of $15,000 to $25,000 could be offered for the preparation of detailed proposals. The resulting information, data, assumptions and requirements would be the basis for submissions to the executive levels of all the prospective participants and sponsoring governmental agencies seeking consensus for the commitment for the necessary resources to mount the demonstration. Two scenarios are envisaged:

- **Optimistic Scenario (one to two years):** This scenario presumes that a sponsor, likely a governmental agency having access to incentives that will become available to expedite Canada's compliance with the goals of the Kyoto Protocol, will identify it as a candidate project to be actioned. The "one to two years" timeframe to plan the implementation is premised on the fact that the "first ones on the list are the first ones to be actioned".

- **Most Likely Scenario (two to four years):** This scenario stems from experience by the author to assemble the appropriate discussion forums, obtain consensus on the results of the feasibility study and whether it is bankable, prepare the necessary substantiation, and arrange for contractual relationships and other steps needed to action the detailed planning of a transportation demonstration project.

6.14.2 Demonstration Duration: Selecting the duration, including the starting time, is a critical factor in the design of the envisaged demonstration. The duration is highly influenced by such variables as the type of technology to be used in the demonstration, characteristics of the site and the intended railway operation, public visibility, the regulatory compliance to be met and resources committed. Three scenario options are envisaged:

- **Minimum Duration (two years):** The golden rule for the demonstration of new technology in a transportation operation in Canada is that the operation should cover at least two winters (because the first winter is either the most, or least, severe in recent history) and that it is never first implemented during wintertime. A minimum of two years permits supporting crews to become familiar with and dedicated to the operation, resulting in relevant data of a comparable nature to be obtained.
- **Preferred Duration (three to five years):** The preferred duration for a railway demonstration is three to five years, as this timeframe permits longer term contracts to be placed with, for example, fuel vendors and specialty maintenance support suppliers, enables more crews to become familiar with the technology involved and allows operators to implement reliability-centred maintenance tactics to provide equipment suppliers with feedback about the reliability of their technology so as to effect engineering improvements.
- **Pilot for Expanded Operations:** A "demonstration project" can evolve into a "pilot project", that is, if the results of a demonstration are sufficiently encouraging, it can be the trigger, or pilot operation, for subsequent expansion.

6.15 Experience Dissemination

6.15.1 RAC Advisory Committee: A premise for the demonstration, particularly if government-provided funding is involved, is that the results of the demonstration be made available to the Canadian railway community and all parties implicated. The mechanism for this is a combination of the issuance of interim and final reports containing data and experience (both of a quantitative and qualitative nature) and regular reviews by a committee of representatives from the railway sector and regulatory authorities. It is envisaged that such a committee would be under the auspices of the Railway Association of Canada.

6.15.2 Transport Canada: The demonstration would appear to generate data and information of direct interest to Transport Canada's railway safety mandate and authorization to regulated emissions from railway operations, as well as the technology development mandate of its Transportation Development Centre.

6.15.3 Environment Canada: The experience of the demonstration to reduce greenhouse gas emissions vis-a-vis use of conventional diesel fuel would appear to be of interest to Environment Canada's mandate regarding fuel quality limits and to lead the Canadian government's effort to comply with the Kyoto Protocol.

6.15.4 Provincial Agencies: It is envisaged that the province in which the demonstration would be sited would have a particular interest in the operation, not only because of its jurisdiction over safety in the workplace, labour codes and public perception, but also because the demonstration could complement the initiatives of that province for the Kyoto Protocol.

6.15.5 Private Sector: There will be considerable equipment, components, monitoring and testing required from private sector suppliers, all of which would be interested in the experience. They would use the experience to advance their product lines and skill.

6.15.6 Others: Other constituents such as the natural gas production / distribution sector and environmental advocate groups would obviously have an interest in the results as they are promoting the merits of natural gas as an interim fuel to stem the rise in greenhouse gas emissions until hydrogen as a fuel becomes widely available, as fore-seen in Figure 2 for the 200 year global energy systems transition [37].

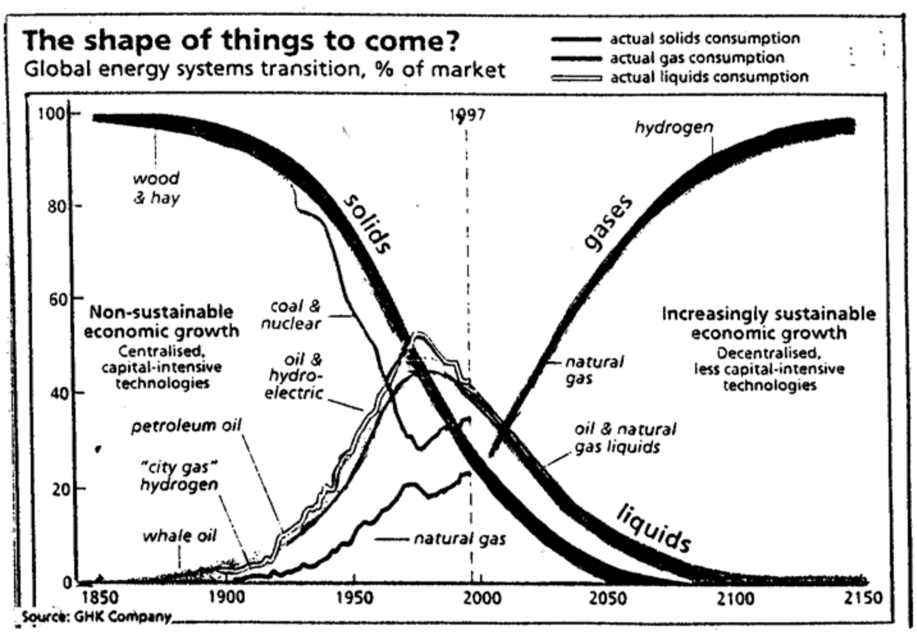

Figure 2: 200 Year Global Energy Systems Transition

7.0 RECOMMENDED CONFIGURATIONS TO DEMONSTRATE

An analysis of the design issues and parameters as listed in Section 6 and portrayed schematically in Appendix A, combined with the author's judgment as to availability of appropriate technology and site circumstances, resulted in the following configuration options being identified for consideration (in order of ease of implementation):

a) Arrange for conversion to CNG or LNG from diesel fuel of a Railpower Technologies Corporation "Green Goat" or "Green Kid" locomotive powered by a hybrid micro gas turbine / storage-battery power pack to be demonstrated in railyard switcher operation in the Vancouver area.

b) Arrange to bring to Canada for a one to two-year demonstration the locomotive converted for the California-based *CleanGas USA Project* and fitted with LaCHIP injectors and an LNG tender. Candidate sites would be commuter rail operations on GO Transit in the Toronto area, Westcoast Express in the Vancouver area, and Agence métropolitaine de transport (AMT) in the Montreal area.

c) Arrange to retrofit self-propelled Rail Diesel Cars (either existing Budd Rail Diesel Cars or newly developed Colorado Railcar units) with new Cummins diesel engines outfitted with Westport Innovations Inc.'s proprietary integral natural gas / pilot diesel-fuel injector and LNG fuel system. Candidate sites could be the Vancouver Island services of VIA Rail Canada or services on the BC Rail line to Whistler should the 2010 Winter Olympic Games be awarded to Vancouver.

Other options can be configured using the "Decision Matrix to Select Parameters to Define a Demonstration of a Natural Gas-Fueled Railway Operation" found in Appendix A. The decision matrix permits the linking of combinations of parameters that characterize the circumstances of possible demonstration sites and technology arrangements, thus facilitating the examination of a range of configuration options.

8.0 CONCLUSIONS

The examination of schema to arrange a demonstration of a railway operation in Canada fueled by natural gas has concluded the following:

a) The use of natural gas can contribute to the railway sector's overall contribution to help Canada comply with the goals of the Kyoto Protocol but only if the prime mover (diesel or gas turbine engine) of the motive power unit (locomotive or DMU) utilizes direct injection (versus spark ignition) and an LNG fuel system (versus a CNG fuel system) so as to maintain the engine's rated power and efficiency.

b) The use of natural gas by operating railways has the potential to generate emissions reductions credits that could be banked and traded as a revenue-generating activity.

c) There does not exist readily available motive power units that have been converted to an LNG fuel system and use engines fitted with high-pressure direct injection (for maximum thermal efficiency with lower emissions). Hence, any demonstration would require the assembling of the technology appropriate for the operation and site.

d) The detailed design of an LNG-based demonstration would expose certain gaps in the Canadian safety codes and related regulations pertaining to LNG as a fuel for railway operations. However, relevant codes either existing or in drafted form in the U.S.A or the European Union could be referenced to fill these gaps and, in the process, contribute to the Canadian technology knowledge base.

e) In terms of ease of implementation, a Vancouver site for a demonstration appears the most feasible due to the variety of railway operations within a densely populated environmentally-stressed region, the existence of LNG-based technology developers, and the existence of an LNG production plant operating year round with an associated LNG distribution network.

f) Initiating action to establish expressions of interest from consortia interested in undertaking a bankable feasibility study to substantiate a demonstration project of a railway fueled by natural gas would appear to require the intervention and stimulation of governmental agencies in the context of Canada's Kyoto Protocol initiatives.

9.0 RECOMMENDATIONS

The following recommendations stem from the findings and conclusions of the study:

a) A follow-on, in-depth, bankable feasibility study should be conducted to establish a detailed definition, produce an operational design, and perform a cost-benefit analysis of a railway operation fueled by natural gas. This recommendation stems from the fact that the author found interest at the technical staff level in the various organizations consulted but that more economic substantiation would be required to obtain corporate-level buy-in and commitment.

b) The tactic for initiating the feasibility study is (as described in Section 6.14.1) for a sponsoring governmental agency to issue to the Canadian railway and natural gas sectors a "Call for Expressions of Interest" to examine the case for a site-specific implementable demonstration. This recommended initiating action on the part of a sponsoring governmental agency would provide the credible attention and *raison d'être* for railway, natural gas and interested private sector organizations to examine the prospect. The nature of their responses would identify the degree of interest to which to consider natural gas as a fuel for railway operations.

REFERENCES

1. Government of Canada, *Energy and Sustainable Development: A Canadian Perspective,* (for United Nations Commission on Sustainable Development), Ottawa, Ontario, 2001

2. Eggleton, P.L., Dunn, *R., Review of Memorandum of Understanding Between Environment Canada and the Railway Association of Canada Regarding Railway Locomotive Emissions,* prepared for Environment Canada (Air Pollution Prevention Directorate, Transportation Systems Branch), Gatineau, Quebec, June 2001

3. Eggleton, P.L., *Impact of EPA Locomotive Emissions Standards on Canadian Railway Sector,* TP 13475E, prepared for Transportation Development Centre, Transport Canada, Montreal, Quebec, July 1999

4. Eggleton, P.L., *The Innovation Cycle in Transportation Technology Development,* presented at Panamerican Transport Congress, Buenos Aires, Argentina, 4 June 1983

5. Driscoll, M.L., Young, J.D., *Status Report - Conversion of Burlington Northern Locomotive for Diesel Fuel / Natural Gas Operation,* Canadian Institute of Guided Ground Transport, Kingston, (for Energy, Mines & Resources), Ottawa, Ontario, August 1985

6. Fritz, S.G., *The Potential for LNG as a Railroad Fuel in the U.S.,* Southwest Research Institute, San Antonio, Texas, ASME paper 97-ICE-12, April 1997

7. Bourn, G., Hedrick, J., Kubesh, J., Meyers, D., *Multi-Cylinder Development of the LaCHIP Combustion Technology,* paper presented at ASME Conference, Fall 1998

8. Meyers, D., *Development of a Low Emissions, Dual Fuel Locomotive Engine,* Southwest Research Inst., presented at ASME ICE meeting, San Antonio, Texas, May 2000

9. Hedrick, J., *Development of a Low Emissions Dual Fuel Locomotive GasRail USA*, presented to Conference on Exploring New Technologies for Clean Air: Zero and Near-Zero Emissions Technologies, San Antonio, Texas, 6 October 1999

10. Bogdanoff, M., *CleanRail - Development and Demonstration of an LNG Passenger Locomotive,* South Coast Air Quality Management District 'white paper', April 2001

11. Payne, M.L., *Dual-Fuel Locomotive Program - Program Definition and Preliminary Investigation,* Rail and Diesel Products Division, Bombardier Inc. Montreal, Quebec, September 1988

12. Delcan / Booz-Allen & Hamilton Inc. *Alternate Fuels Study - A Study of the Operational and Economic Impacts of LNG and CNG as Alternate Fuels in the Bus and Rail Fleets,* Project No. 6213 Final Report undertaken for GO-Transit, May 1995

13. Lustig, F., *The Power of Green (the Green Goat hybrid diesel / battery switcher locomotive),* Trains magazine, Waukesha, Wisconsin, October 2001

14. Westport Innovations Inc., *Westport Innovations Set to Demonstrate Natural Gas Technology,* reprinted from 'Diesel Progress North American Edition', March 2000

15. Shalom, F., *Bombardier set to launch JetTrain*, The Gazette, Montreal, Quebec, 12 October 2002

16. Southwest Research Institute, *Analysis of an LNG Locomotive System,* Final Report on Project No. 03-5285, San Antonio, Texas, April 1994, undertaken for the Gas-Fueled Railway Cooperative Research Group and consisting of the following volumes:
    - 16.1 Bergmann, E.P., *Risk Assessment*
    - 16.2 Bergmann, E.P., *Accident Scenarios*
    - 16.3 Beaty, K.D., *Implementation / Regulatory Study*
    - 16.4 Owens, E.C., *Natural Gas Fueling*
    - 16.5 Fritz, S.G., *Locomotive Exhaust Emissions*
    - 16.6 Markworth, V.O., *Natural Gas Locomotive Engine Technologies*
    - 16.7 Mulik, J., *Natural Gas Market Impact Analysis*
    - 16.8 Latusek, J.P., *Cost Analysis*

17. The Centre for Sustainable Transportation, *Sustainable Transportation Monitor,* Toronto, Ontario, Issue No. 2, February 1999

18. Gas Research Institute 'information release' *LNG as a Railroad Fuel: Technology Status and Economics,* Chicago, Illinois, June 1993

19. Weaver, P.E., *The Cleaner Choice - Natural Gas as a Substitute for Diesel,* Engine, Fuel and Emissions Engineering Inc., Sacremento, California, prepared for Gas Research Institute, December 1999

20. U.S. Code of Federal Regulations (CFR) Parts 85, 89 and 92, *Emission Standards for Locomotives and Locomotive Engines; Final Rule,* Federal Register, 16 April 1998

21. Moulis, C., *U.S. Emission Standards for Locomotives and Locomotive Engines,* U.S. EPA, presentation to Railways and Environment Workshop, Winnipeg, Manitoba, 21 June 1999

22. Dunn, R., Eggleton, P.L., *Influence of Duty Cycles and Fleet Profile on Emissions from Locomotives in Canada,* TP 13945E, prepared for Transportation Development Centre, Transport Canada, Montreal, Quebec, June 2002

23. Payne, M., Su, F., *Testing and Control of Emissions for Locomotives and Locomotive Engines,* Engine Systems Development Centre Inc., presented at the Windsor Workshop, Toronto, Ontario, 5-7 June 2000

24. Engine, Fuel and Emissions Engineering Inc., *Cost Estimates for Meeting the Proposed Locomotive Emissions Standards,* Sacremento, California, note prepared for the U.S. Environmental Protection *Agency*, September 1997

25. Environment Canada Transportation Systems Br, Air Pollution Prevention Directorate *Locomotive Emissions Monitoring Programme 1999 - 2000,* EPS 2/TS/15, April 2002

26. BC Gas, *Liquefied Natural Gas Plant,* brochure on Tilbury Island plant, Delta, B.C.

27. Reed, J., *Robert Tessier Discusses the Importance of Natural Gas R&D in Canada,* Canadian Natural Gas magazine, Toronto, Ontario, Summer 1992

28. Westport Innovations Inc., *Message to Our Shareholders,* Vancouver, B.C., 1999

29. Cummins Engine Company Ltd., *Powering Forward Rail Diesel Technology- 50 to 1,900 KW,* Rail Group, Daventry, U.K., Issue 2000

30. Wadman, B., *Dual Fuel Conversion of Cat D399 Engine,* article in Diesel & Gas Turbine Worldwide magazine on Energy Conversions Inc, Tacoma, Washington, April 1999

31. MotivePower Industries, *Boise Locomotive Operations,* with specifications of company's 1,200 horsepower, liquefied natural gas-fueled switcher locomotives

32. Colorado Commuter Rail News, *Colorado Railcar's New DMU First to Pass FRA Structural Test!,* Denver, Colorado, Edition 2002

33. Tucker, E.B., *A Plant that Grows Anywhere,* Natural Gas Fuels, U.S.A., January 1999

34. The Gazette, *Timing Favours Vancouver Olympics Bid,* Montreal, Quebec, 10 May 2002

35. The Gazette, *Ottawa Proposes to Cut Greenhouse-Gas Emissions,* Montreal, Quebec, 25 October 2002

36. Greenhouse Gas Emission Reduction Trading Pilot (GERT), *Trading - News about GHG reduction trading,* Newsletter Number Two, Victoria, B.C., March 2000

37. The Ecomomist, *Energy, A Brighter Future?,* London, U.K., 10 February 2001

BIBLIOGRAPHY

Information from the Internet

There is considerable information now available electronically from a number of sites on the Internet and World Wide Web pertaining directly or indirectly to diesel engine emissions and their application in railway locomotives. One principal source is "dieselNet", which can be accessed electronically at *www.deiselnet.com.*

Several hundreds of pages of information were scanned electronically. The pages are filed under the following generic and specific titles and can be referenced by contacting the library of the Transportation Development Centre.

Bibliographic Survey of Internet Literature on Natural Gas Technologies to Reduce Emissions from Locomotives

(prepared by Dr. Eric Archambault, bibliometrist, for Peter Eggleton)

Volume I: General

Volume II: Locomotives and Railroads

Volume III: Technology

Volume IV: Experience from Large Size Engine Manufacturers

Volume V: Evidence from Cars, Buses and Trucks

APPENDIX A

DECISION MATRIX TO SELECT PARAMETERS

TO DEFINE A DEMONSTRATION OF A

NATURAL GAS-FUELED RAILWAY OPERATION

(not available in electronic format/
pas disponible en format électronique)

APPENDIX B

BC GAS LIQUEFIED NATURAL GAS PLANT

(not available in electronic format/
pas disponible en format électronique)

APPENDIX C

WESTPORT INNOVATIONS INC.

COMBINED HIGH PRESSURE NATURAL GAS

AND PILOT DIESEL FUEL INJECTOR

(not available in electronic format/
pas disponible en format électronique)

APPENDIX D

CROSS SECTION OF LaCHIP INJECTION ARRANGEMENT

AND

PROPOSED “*CLEANRAIL*” DEMONSTRATION LOCOMOTIVE

FITTED WITH LNG LaCHIP TECHNOLOGY

(not available in electronic format/
pas disponible en format électronique)

APPENDIX E

MK1200 SWITCHER LOCOMOTIVE

CONVERTED TO SPARK - IGNITED LNG OPERATION

(not available in electronic format/
pas disponible en format électronique)

APPENDIX F

BOMBARDIER TRANSPORTATION

GAS TURBINE-POWERED "*JetTrain*"

HIGH SPEED PASSENGER LOCOMOTIVE

(not available in electronic format/
pas disponible en format électronique)

APPENDIX G

RAILPOWER TECHNOLOGIES CORPORATION

***"GREEN GOAT"* SWITCHER LOCOMOTIVE WITH**

HYBRID BATTERY PRIME MOVER

(not available in electronic format/
pas disponible en format électronique)

APPENDIX H

COLORADO RAILCAR SELF-PROPELLED

DIESEL MULTIPLE UNIT (DMU) COMMUTER CAR

(not available in electronic format/
pas disponible en format électronique)