**TP 13470E**

# REVIEW OF
# NATURAL GAS FUELLED LOCOMOTIVE TECHNOLOGY

PREPARED FOR

TRANSPORTATION DEVELOPMENT CENTRE

TRANSPORT CANADA

BY

ENGINE SYSTEMS DEVELOPMENT CENTER

AUGUST 1999

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BY

AREF TAGHIZADEH & MALCOLM L. PAYNE

ENGINE SYSTEMS DEVELOPMENT CENTER

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Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

# PUBLICATION DATA FORM

| | | |
|---|---|---|
| 1. Transport Canada Publication No.<br>TP 13470E | 2. Project No.<br>9564 | 3. Recipient's Catalogue No. |
| 4. Title and Subtitle<br>Review of Natural Gas Fuelled Locomotive Technology | | 5. Publication Date<br>August 1999 |
| | | 6. Performing Organization Document No. |
| 7. Author(s)<br>Malcolm L. Payne and Aref Taghizadeh | | 8. Transport Canada File No.<br>ZCD2450-D-708 |
| 9. Performing Organization Name and Address<br>Engine Systems Development Center (ESDC)<br>155 Montreal-Toronto Highway<br>Lachine, Quebec<br>H8S 1B4 | | 10. PWGSC File No.<br>XSD-8-01569 (653) |
| | | 11. PWGSC or Transport Canada Contract No.<br>T8200-8-8598/01-XSD |
| 12. Sponsoring Agency Name and Address<br>Transportation Development Centre (TDC)<br>800 René Lévesque Blvd. West<br>Suite 600<br>Montreal, Quebec<br>H3B 1X9 | | 13. Type of Publication and Period Covered<br>Final |
| | | 14. Project Officer<br>Roy S. Nishizaki |

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Funded by the Program of Energy Research and Development (PERD)

16. Abstract

This report summarizes the current state of technology pertaining to natural gas fuelled locomotives. Over the past ten to twelve years, great advancements have been made to overcome the shortcomings of dual-fuel and single-fuel engine efficiency, infrastructure, and handling. Demonstrations and proof-of-concept programs in the United States indicate that significantly lower levels of oxides of nitrogen ($NO_X$), carbon dioxide ($CO_2$), and particulate matter (PM) can be achieved from natural gas fuelled locomotives. However, carbon monoxide (CO) and total hydrocarbons (THC) will increase sharply. Further development is needed to reduce CO and THC emissions to an acceptable limit. Current technologies appear suitable for urban transit and yard switching systems in populated areas where emissions reduction is desirable.

| | |
|---|---|
| 17. Key Words<br>Natural gas, locomotive, dual fuel, emissions, liquefied natural gas, compressed natural gas | 18. Distribution Statement<br>Limited number of copies available from the Transportation Development Centre |

| | | | | |
|---|---|---|---|---|
| 19. Security Classification (of this publication)<br>Unclassified | 20. Security Classification (of this page)<br>Unclassified | 21. Declassification (date)<br>— | 22. No. of Pages<br>xiv, 26, apps | 23. Price<br>Shipping/ Handling |



Canada

Transports Canada | Transport Canada

# FORMULE DE DONNÉES POUR PUBLICATION

| | | |
|---|---|---|
| 1. N° de la publication de Transports Canada<br>TP 13470E | 2. N° de l'étude<br>9564 | 3. N° de catalogue du destinataire |
| 4. Titre et sous-titre<br>Review of Natural Gas Fuelled Locomotive Technology | | 5. Date de la publication<br>Août 1999<br>6. N° de document de l'organisme exécutant |
| 7. Auteur(s)<br>Malcolm L. Payne et Aref Taghizadeh | | 8. N° de dossier - Transports Canada<br>ZCD2450-D-708 |
| 9. Nom et adresse de l'organisme exécutant<br>Centre de développement de systèmes moteurs inc.<br>155 autoroute Montréal-Toronto<br>Lachine, Québec<br>H8S 1B4 | | 10. N° de dossier - TPSGC<br>XSD-8-01569 (653)<br>11. N° de contrat - TPSGC ou Transports Canada<br>T8200-8-8598/01-XSD |
| 12. Nom et adresse de l'organisme parrain<br>Centre de développement des transports (CDT)<br>800, boul. René-Lévesque Ouest<br>Bureau 600<br>Montréal (Québec)<br>H3B 1X9 | | 13. Genre de publication et période visée<br>Final<br>14. Agent de projet<br>Roy. S. Nishizaki |

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Financé par le Programme de recherche et développement énergétiques (PRDE)

16. Résumé

Ce rapport résume l'état actuel de la technologie des locomotives alimentées au gaz naturel. Durant les dix ou douze dernières années, de grands progrès ont été réalisés pour corriger les faiblesses des moteurs à alimentation simple ou mixte en ce qui a trait au rendement, à l'infrastructure et à la manipulation. Aux États-Unis, des démonstrations et des programmes de validation ont montré que l'on pouvait réduire de façon significative les niveaux des oxydes d'azote ($No_x$), du dioxyde de carbone ($CO_2$) et des particules en suspension dans l'air avec les locomotives alimentées au gaz naturel. Il y a toutefois une forte augmentation des niveaux de monoxyde de carbone (CO) et d'hydrocarbures (HC). Des recherches plus approfondies sont nécessaires pour réduire les émissions de gaz carbonique et d'hydrocarbures à une limite acceptable. Les technologies actuelles semblent appropriées aux systèmes de transport en commun urbains et de manoeuvre de triage dans les régions peuplées où une réduction des émissions est souhaitable.

| | |
|---|---|
| 17. Mots clés<br>Gaz naturel, locomotive, moteur à alimentation mixte, émissions, gaz naturel liquéfié, gaz naturel comprimé | 18. Diffusion<br>Le Centre de développement des transports dispose d'un nombre limité d'exemplaires. |

| 19. Classification de sécurité (de cette publication) | 20. Classification de sécurité (de cette page) | 21. Déclassification (date) | 22. Nombre de pages | 23. Prix |
|---|---|---|---|---|
| Non classifiée | Non classifiée | — | xiv, 26, ann. | Port et manutention |

CDT/TDC 79-005
Rev. 96



Canada

**ACKNOWLEDGMENTS**

The valuable information provided by the following persons is greatly appreciated:

L.E. Olsen - Texas Transportation Institute

P. Jensen - Energy Conversion Inc.

S.G. Fritz - Southwest Research Institute

D.P. Meyers - Southwest Research Institute

W.B. Clary - Miratech Corporation

N. White - Charonic Canada Inc.

R. Selvazzo - Uniongas

P. Ouellette - Westport Innovations Inc.

A. Lawson - GFI Control Systems Inc.

## EXECUTIVE SUMMARY

Greater application of alternative fuels for transportation systems has been encouraged and supported by the Canadian government. A previous program that addressed the use of natural gas (NG) as a fuel for locomotives was aborted prior to the demonstration phase, when Bombardier ceased its activity in locomotive and engine development.

This report is a review of the technological advancements since the earlier work reported in TP 9022E, 1988. The incentive today is not only fuel economy as before, but by Canada's commitment to the Kyoto protocol pertaining to the reduction of greenhouse gases and the Clean Air Act Amendment of the United States.

Apart from the Memorandum of Understanding (MOU) signed by the Railway Association of Canada (RAC) and Environment Canada, no legislation or guideline is in place to limit exhaust emissions from locomotives. The United States, however, has issued final standards for locomotive emissions, which take effect on January 1, 2000. All locomotives manufactured or re-manufactured from 1973 will have to meet one of the three tiers of the rulings. Two points of interest to Canadian railways are cross-border travel and Canadian owned railways located in the United States. They will have to conform to the Environmental Protection Agency's (EPA) regulations according to the percentage of time spent across the border.

Several liquefied natural gas (LNG) fuelled engines and locomotives demonstration programs are under way, primarily in the United States, where exhaust emissions regulations provide the incentive. The most comprehensive endeavour is the GasRail USA project, a multi-year cooperative industry research undertaking. Initiated in 1993 by Southwest Research Institute (SwRI), the development and integration of the LNG engine and its associated fuel storage and handling systems into an EMD-F59PHI passenger locomotive is at the proof-of-concept stage. The fuelling system is of the late-cycle high injection pressure technology (LaCHIP), similar to that of Vancouver's WESTPORT high pressure injection currently being demonstrated in a bus application. Injecting gas at a high pressure and late in the combustion cycle results in a stable process similar to diesel, avoiding the combustion irregularities of early-cycle low-pressure injection. Engine Conversion Inc. (ECI) continued to develop their technology to where it is now commercially available. The combination of computer-based electronic controls have made ECI's system a viable method to convert a two-cycle locomotive engine to run on natural gas, using diesel fuel as an ignition source.

From studies of fuel handling and the necessary infrastructure, crossover components and technology from the marine and cryogenic sectors are being adapted in some rail demonstrations. However, additional research and development is required to ensure railway compatibility.

The major cost in establishing an NG/LNG operation is that of fuel transportation. Of the several solutions, is locating small liquefaction plants at the strategic points on the line.

These facilities can be replenished by truck. In addition, constructing similar plants where the rail line is in proximity to a gas pipeline would reduce the gas supply expense.

NG technology has reached the point where both economical and health benefits can be obtained. From the discussions held with the individuals during data gathering for this report, it can be concluded that, in urban areas where the control and reduction of emissions are warranted, an NG fuelled locomotive would be beneficial. It has been demonstrated that $NO_X$ can be reduced by 50% with no loss of efficiency and up to 75% with a 3% efficiency reduction. It is also evident that in order to reduce greenhouse gases (e.g. CO and methane) effort must be made to adapt exhaust after treatment strategies to an NG locomotive.

**SOMMAIRE**

Le gouvernement canadien a encouragé et appuyé une plus grande utilisation des carburants de remplacement pour les systèmes de transport. Un programme antérieur sur l'utilisation du gaz naturel (GN) pour les locomotives a avorté avant la phase de démonstration quand Bombardier a mis fin à ses activités de développement de locomotives et de moteurs.

Ce rapport passe en revue les progrès technologiques réalisés depuis la publication du rapport *Dual-fuel Locomotive Program*, TP 9022E, en 1988. Présentement, les incitatifs ne se limitent pas à l'économie du carburant, mais proviennent également de la signature par le Canada du Protocole de Kyoto sur la réduction des gaz à effet de serre et de l'adoption du Clean Air Act Amendment aux États-Unis.

Mis à part le protocole d'entente signé par l'Association des chemins de fer du Canada et Environnement Canada, il n'y a aucune loi ou directive pour limiter les gaz d'échappement des locomotives. Toutefois, les États-Unis ont promulgué des normes définitives pour les gaz d'échappement de locomotives, qui entreront en vigueur le 1^er^ janvier 2000. Toutes les locomotives fabriquées ou remises à neuf depuis 1973 devront satisfaire aux exigences de l'un des trois paliers du Règlement. Les déplacements transfrontaliers et les chemins de fer de propriété canadienne se trouvant aux États-Unis sont deux aspects qui concernent les compagnies de chemins de fer canadiennes. Celles-ci devront se conformer à la réglementation de l'Environmental Protection Agency (EPA) d'une façon qui dépend du pourcentage du temps où les locomotives se trouvent outre-frontière.

Il existe présentement plusieurs programmes de démonstration de moteurs et de locomotives alimentés au gaz naturel liquéfié (GNL), principalement aux États-Unis, où la réglementation sur les émissions de gaz d'échappement est un incitatif. Le projet GasRail USA, qui est une entreprise coopérative de recherche industrielle s'étendant sur plusieurs années, est le plus exhaustif d'entre eux. Amorcées en 1993 par le Southwest Research Institute (SwRI), la mise au point du moteur à GNL et de ses systèmes connexes de stockage et de manipulation du carburant, et l'intégration de ceux-ci dans une locomotive pour train de voyageurs EMD-F59PHI, en sont à la phase de la validation de principe. Le système d'alimentation est du type à haute pression d'injection avec retardement et est semblable au système d'injection à haute pression WESTPORT de Vancouver présentement en démonstration sur les bus. L'injection du gaz à haute pression avec un retard dans le cycle de combustion procure un régime stable semblable à celui d'un diesel tout en évitant les irrégularités de combustion des systèmes d'injection à basse pression avec avance dans le cycle de combustion. La technologie de la société Engine Conversion Inc. (ECI) est maintenant disponible commercialement. La combinaison de commandes électroniques informatisées a fait du système ECI un système viable pour convertir les moteurs de locomotive à deux cycles en moteurs au gaz naturel utilisant le carburant diesel pour l'allumage.

En se basant sur des études sur la manipulation du carburant et l'infrastructure connexe, on adapte présentement des éléments et une technologie de conversion provenant du secteur

maritime et du secteur de la cryogénie à des démonstrations dans le secteur ferroviaire. Toutefois, il faudra poursuivre la recherche et le développement afin d'assurer la compatibilité des chemins de fer.

Le transport du carburant est la partie la plus onéreuse d'une exploitation utilisant le GN/GNL. L'une des solutions apportée à ce problème consiste à installer de petites usines de liquéfaction à des points stratégiques sur la ligne; ces installations peuvent être approvisionnées par camion. De plus, on pourrait réduire les dépenses d'alimentation en gaz en installant ce type d'usine aux endroits où la ligne de chemin de fer est proche d'un gazoduc.

La technologie GN a atteint le point où on peut en retirer des avantages économiques et des avantages pour la santé. D'après certaines discussions qui ont eu lieu durant la collecte des données pour ce rapport, on peut conclure que, dans les zones urbaines où le contrôle et la réduction des émissions sont justifiés, les locomotives alimentées au GN seraient avantageuses. On a démontré que les $NO_x$ peuvent être réduits de 50 p. cent sans baisse de rendement, cette réduction pouvant atteindre 75 p. cent avec une baisse de rendement de 3 p. cent. Pour réduire la production de gaz à effet de serre (c'est-à-dire le CO et le méthane), il faut réussir à adapter des dispositifs de post-traitement des gaz d'échappement aux locomotives alimentées au GN.

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## GLOSSARY

| | |
|---|---|
| APCI | Air Products and Chemicals Inc. |
| BN | Burlington Northern |
| $CH_4$ | Methane |
| NG | Natural Gas |
| CNG | Compressed Natural Gas |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| ECI | Energy Conversion Inc. |
| EMD | Electro-Motive Division of General Motors |
| EPA | Environmental Protection Agency |
| ESDC | Engine System Development Center |
| GE | General Motors Corporation |
| HC | Hydrocarbons |
| LaCHIP | Late Cycle High-Injection Pressure |
| LNG | Liquefied Natural Gas |
| MK | Morrison Knudsen Corporation |
| MOU | Memorandum of Understanding |
| $NO_X$ | Oxides of Nitrogen |
| PM | Particulate Matters |
| RAC | Railway Association of Canada |
| RLM | Refrigerated Liquid Methane |
| $SO_X$ | Oxides of Sulfur |
| SwRI | Southwest Research Institute |
| THC | Total Hydrocarbons |

## 1.0 INTRODUCTION

Initial interest in natural gas (NG) as an alternative fuel came about as a result of the desire to reduce fuel costs in railway operations. Early experiments conducted in this area showed discouraging results due to lower fuel efficiency and high exhaust emissions associated with its use.

In the last several years, air quality has become a particularly severe problem in many countries. Growing concern with exhaust emissions from internal combustion engines has resulted in implementation of strict emissions regulations in industrial areas such as the United States and Europe. In addition, global commitment to reduce air pollution and emissions in direct response to the Kyoto protocol has enforced these regulations (1). The Kyoto protocol calls for substantial reduction in greenhouse gas emissions by the period 2008-2012, relative to 1990 levels. Concern with emissions reductions has renewed and reinforced interest in the use of NG as an alternative fuel. Various research projects were undertaken in the United States and Canada to convert light-duty vehicles, passenger cars, and heavy-duty trucks and buses, as well as locomotive engines to use natural gas.

In the mid 1980s, a number of projects were launched in the United States and Canada to assess the viability of NG fuelled locomotives. A research project was attempted by Bombardier to review the use of NG as an alternative fuel for locomotives. This project was short-lived, as Bombardier stopped its activities in locomotive and engine development (2). Southwest Research Institute (SwRI) conducted a similar project on a two-cylinder EMD engine. In the meantime, Burlington Northern Railroad (BN) began its own experiments with dual-fuelled locomotives, using compressed natural gas (CNG) and liquefied natural gas (LNG) in combination with diesel fuel.

Since then, other research projects on NG fuelled locomotives were completed in the United States, Russia, Germany, Japan, Finland, and the Czech Republic. In 1984, Russia started a program to develop NG fuelled locomotives. In 1993, four types of NG fuelled locomotives, which consisted of compressed natural gas (CNG)/diesel switching locomotives and LNG freight trains, were commissioned in the Russian railway industry (3). Germany has successfully developed 165 kW CNG locomotives and tested them in rail yard switching operation. Japan, Finland, and the Czech Republic are also designing locomotives that operate on NG (3).

In the United States, ongoing experiments on LNG/diesel dual-fuelled locomotives were conducted by Burlington Northern Railroad (BN) until the mid 1990s (4,5). Morrison Knudsen Corporation (MK) introduced a MK1200G LNG-burning locomotive in 1994 (6). This type of locomotive is still being used in revenue service in the California area. Meanwhile, General Motors is developing an NG fuelled engine as a part of a cooperative industry research program with SwRI, to furnish new technologies for LNG fuelled freight and passenger locomotives (6).

The use of NG as an alternative fuel can greatly benefit the environment in terms of reduced emissions and health profits at lower operating cost. A comprehensive review was undertaken by ESDC Inc., supported by Transport Canada, to review and evaluate the NG fuelled locomotive technology and operational experiences to date, and to consider the issue and viability of NG as a fuel for railway applications.

To fulfill the objective of this project, the following tasks were undertaken:

- Literature search and review of existing NG fuelled engine technology
- Operational experiences
- Review of operational infrastructure requirements
- Determination of environmental impact of NG in railway applications

The results of these objectives are detailed in the following sections, after which a conclusion is presented along with the recommendations.

# 2.0 REVIEW OF THE NATURAL GAS FUELLED ENGINE TECHNOLOGY AND DEMONSTRATION PROJECTS

A comprehensive literature search was conducted and those actively involved in research in this area were contacted to obtain a thorough understanding of the technology and the evolution that have taken place in this area since 1980. Technical papers relevant to this work are provided in the reference section, while a list of databases and other information sources used in this work are included in Appendix A. Almost all of the technologies used in alternative or dual-fuelled locomotives in the past two decades are based on work performed in the United States. Therefore, this discussion will mainly focus on the technology available in the United States and the relevant literature.

The engine modifications to run on 100 percent NG can be accomplished by gas mixing or by direct injection. Those operating on dual fuel can be modified using low-pressure early-cycle injection or high-pressure late-cycle injection system (7). These technologies are described in the following sub-sections.

## 2.1 Natural Gas Combustion System

### 2.1.1 *Gas Mixing*

Gas mixing is accomplished by feeding NG to the engine through a fuel mixer or an NG injector in the intake manifold that results in a homogeneous mixture. Such a system requires a spark plug as an ignition source. For optimum operation, exact control of ignition timing is crucial. The timing must be optimized over the entire speed-load range. Introducing the NG into the intake manifold reduces the volumetric efficiency and maximum power of the engine. This would make it susceptible to explosion at high load operation or with changes in the gas composition. During part-load operation, the intake air must be throttled, which results in pumping and corresponding brake specific fuel consumption losses. Since NG is mixed with the intake air, some of it is lost during the valve overlap period of the scavenging process, producing high HC emissions (7).

In 1993, MK Rail Corporation presented MK 1200G switcher locomotive. MK 1200G was a LNG mono fuel locomotive powered by a Caterpillar model 3516G. The Caterpillar 3516G is a turbocharged, aftercooled, spark-ignited, lean-burn engine producing 1000kW. An interesting feature of MK1200G locomotive is its fuel tank. The locomotive does not require a fuel tender, since the LNG fuel tank is incorporated into the unit. The intake gas mixing technique is used to feed the LNG to the engine. The MK 1200G specifications are given in Appendix B. MK Rail reported that these engines have NOx levels of 2.7 g/kW-hr, CO levels of 2.5 g/kW-hr, total HC levels of 3.8 g/kW-hr, and PM levels of 0.11 g/kW-hr, measured in accordance with ISO 8178-1 (6). The low exhaust emissions of this LNG engine made it attractive for operation in the Los Angeles area. It should be mentioned that the Union Pacific Railway and Burlington

Northern Santa Fe Railway Company have also operated two of these units in daily switching service in the Los Angeles area (6). Union Pacific has recently renewed its lease for these units.

Although the emission results clearly illustrated the potential for this type of NG fuelled engine to achieve very low exhaust emission levels, the reported performance also showed the limited power density achievable with lean-burn spark-ignited gas engines. These engines are typically rated at nearly 1900 kW on diesel fuel. Since railway companies look for locomotives of high power capacity, spark-ignited lean-burn gas engines do not appear suitable for high power applications. Yet their uses as switching locomotives seem favourable, particularly in urban areas where emission reduction is desired.

#### **2.1.2** *Direct Injection*

NG can be directly injected into the cylinder of an engine using one of two methods. In both cases, an ignition source is required: a spark plug or a glow plug.

NG can be introduced into a pre-chamber situated in the cylinder head and then ignited (3,8). As the mixture burns, it expands into the main chamber where additional NG may be injected but the overall air/fuel ratio remains lean. For optimum operation, ignition timing must be accurately controlled over the entire operating range. The in-head pre-chamber increases heat rejection to the cooling water, which increases fuel consumption. This engine design has been used to convert a number of small size engines for medium-duty on-highway applications. Figure 1 illustrates this type of system. Pre-chamber NG engine conversions are not expected to be applied to locomotives, since reliable, repeatable ignition with extended durability can not be achieved.

NG can be directly introduced into the cylinder. This approach eliminates the need for a pre-chamber (figure 2). This type of combustion system has been the subject of much research in automotive applications using spark plugs, but very little in heavy-duty applications. It suffers from several drawbacks. Depending on the situation, it requires a multi-spark and/or multi-strike ignition system. In heavy-duty applications, spark plug erosion and durability are major problems (7). In addition, controlling the amount of air circulation in the cylinder to provide consistent combustion over the entire speed/load range presents a significant challenge. For these reasons, it has generally been used in large medium-speed engines that operate under constant speed/load conditions.

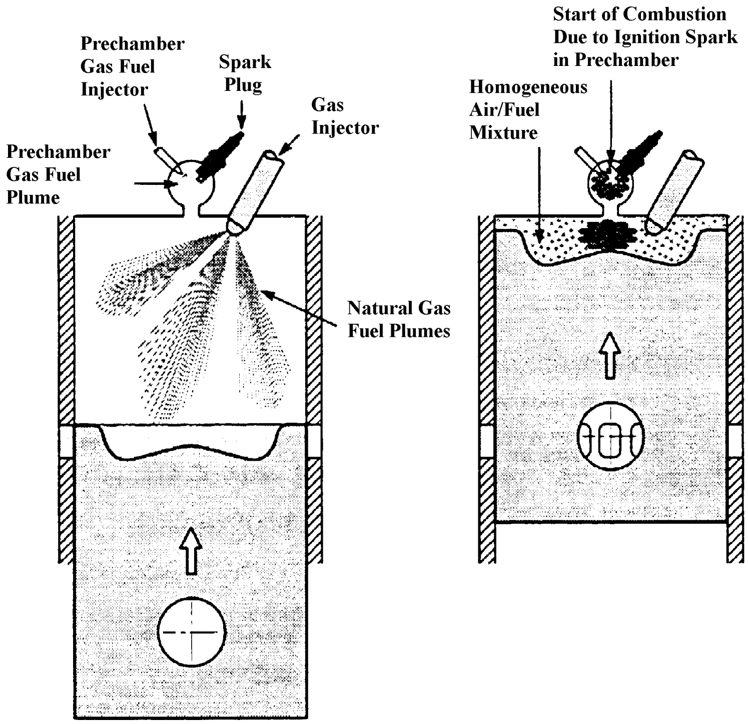


**Figure 1: Pre-Chamber Spark-Ignited Setup (8)**

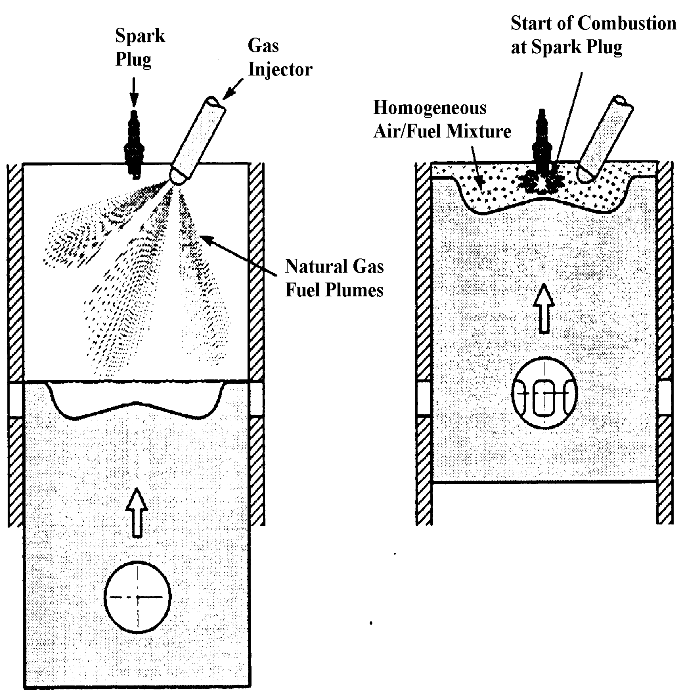


**Figure 2: Spark-Ignited Open-Chamber Combustion System (8)**

## 2.2 Dual Fuel Combustion System

A conventional diesel engine can be operated on a combination of NG and diesel fuel. Using these systems, NG is either added into the intake air stream or directly injected into the combustion chamber (7-9). A minute amount of diesel fuel is then injected into the combustion chamber through a standard diesel injector. The diesel fuel acts as an ignition source. When NG is added to the air stream, some of the fuel-air mixture will go directly into the exhaust, increasing the fuel consumption and hydrocarbon emissions. This is particularly significant in a two-stroke engine during the scavenging process. Therefore, only those systems in which NG is directly injected into the combustion chamber are considered potential candidates for locomotive engines (7).

Pilot diesel injection provides a reliable mode of ignition compared to conventional spark ignition, particularly for very lean mixtures of methane and air. As mentioned previously, precise control of spark timing is crucial in spark ignition engines. With pilot diesel ignition, precise injection timing is not critical and there is less cycle-to-cycle variation, resulting in smoother operation. The engines are unthrottled, which reduces the fuel consumption; however, at light loads the fuel/air ratio becomes very lean, resulting in poor combustion. Hence, at very low loads the engine will be required to operate on 100 percent diesel fuel. Finally, retaining the diesel fuel system allows an engine to continue operation if a failure occurs in the NG supply.

### 2.2.1 *Low-Pressure Early-Cycle Injection*

In this system, NG is injected into the combustion chamber early in the intake cycle (8). In a four-stroke engine, gas injection occurs when the intake valves are closed, while for the two-stroke engine this take place right after the intake ports are closed. Since NG is injected at low pressure (approximately 120 psi), lightweight tubing, fitting, and couplings can be used (5,7). On the other hand, the early injection causes the engine to be sensitive to gas composition and may require high-purity NG for engine operation (10). Sensitivity to fuel composition occurs if the mixture is outside the flammability limits but still ignites irregularly. Care must be exercised during the development process to ensure adequate compression ratio, combustion chamber design, and amount of intake swirl. Such considerations would prevent engine explosion at near full load.

This system has been used successfully for over a decade by BN railroad (3,4,6,10). Figure 3 illustrates the engine hardware.

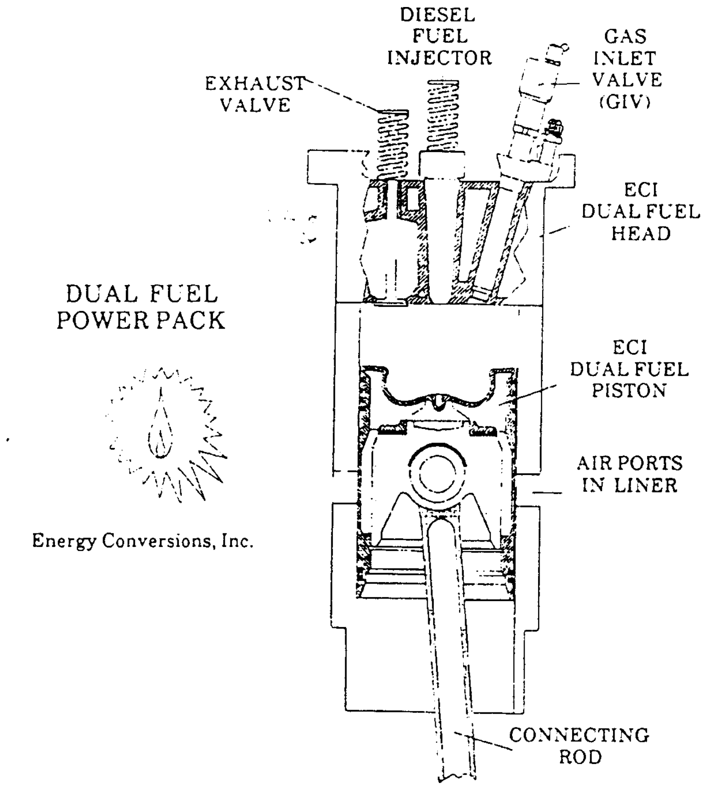


**Figure 3: Configuration of Engine Hardware for Low-Pressure Early-Cycle Injection System (4)**

BN started their experiments with NG fuelled locomotives in 1983. In that year, BN modified an EMD model GP-91 locomotive, powered by a 16-cylinder, 1300 kW, model 567C engine to run on NG (dual fuel). A CNG highway trailer mounted on a flat car was used to fuel the engine. On-the-rail tests conducted between 1985 and 1987 on a route between Minneapolis, Minnesota and Superior, Wisconsin, proved that an NG powered locomotive could be operated safely. This experience also illustrated that the relatively low-energy density of CNG makes it impractical for wide-scale railway use, explaining why BN's focus shifted to LNG.

In 1987, BN reached an agreement with Air Products and Chemicals Inc. (APCI), to develop fuel tender cars, storage, and refuelling facilities for railway application of refrigerated liquid methane (RLM, a purified form of liquid NG). In the meantime, the technology developed by ECI was chosen to convert an EMD model SD40-2 locomotive equipped with a turbocharger 2237 kW model 16-645E3B engine to operate on RLM (4,6,9,10). The converted unit could produce 100 percent of the diesel power rating on a dual fuel mode, while maintaining the capability to operate on diesel fuel when RLM was not available (11). Figure 4 shows a BN locomotive and its RLM tender car.

In 1992, two SD40-2 dual-fuelled locomotives were commissioned by BN, hauling coal trains from Powder River Basin, Montana, to an electric power plant in Superior, Wisconsin. RLM was provided by a 95,000 L tender car placed between two dual fuel locomotives. With this arrangement, the locomotives were able to make the 2,700 km round trip with a single fuelling stop at an RLM fuelling facility near Staples, Minnesota.

These units were in revenue service until late 1995. In 1995, BN merged with the Atchison, Topeka and Santa Fe Railway Company to become Burlington Northern Santa Fe Railway (BNSF). The new management decided to terminate their experiments with SD40-2 dual-fuelled locomotives. At the time this decision was made, new microprocessor-controlled locomotives were introduced by both EMD and GE. These units offered dramatic improvements in power, adhesion, reliability, and fuel consumption, compared to that of SD 40-2 units.

BN's extensive experience with dual-fuelled locomotives clearly demonstrates the reliability, durability, and safety of natural gas fuelled locomotives. The ease of operation and performance compared to their diesel counterparts were witnessed and acknowledged by those who had the opportunity to operate them. The following is an extract from a statement made by the Brotherhood of Locomotive Engineers regarding dual-fuelled locomotives operated at BN (see Appendix C for complete statement).

> *"After operating this locomotive, during this test period and two other occasions, I found very little differences between the gas conversion locomotive and a standard diesel locomotive. Speaking only for myself, I felt comfortable operating this type of locomotive."*
>
> -S.J. Golubic
> Local Chairman
> BLE Division 238

**2.2.2** *Late-Cycle High Injection Pressure*

Late injection of NG into the compression portion of the cycle requires high pressure (normally about 3000 psi). High pressure is required to overcome compression pressure and to provide adequate fuel-air mixing. This system makes the engine less sensitive to explosion and changes in gas composition, but necessitates stronger tubing, fittings, and couplings in the NG part of the fuel system (7). It also requires a high-pressure pump. Since the system uses high-pressure gas injection, the safety issue is the main concern. Any leakage in the fuel system can have catastrophic consequences.

Since 1986, SwRI has been actively involved in development of such a system for railway applications (6). Its performance was evaluated on a laboratory scale using an EMD model 567 two-cylinder engine, but no field demonstration has been performed (12). Figure 5 displays the diagram of the latest combustion system developed by SwRI based on late-cycle high injection pressure (LaCHIP). Figure 6 illustrates the actual cutaway of the LaCHIP system.


**Figure 4: BN’s Dual-Fuelled Locomotive and Its RLM Tender Car**

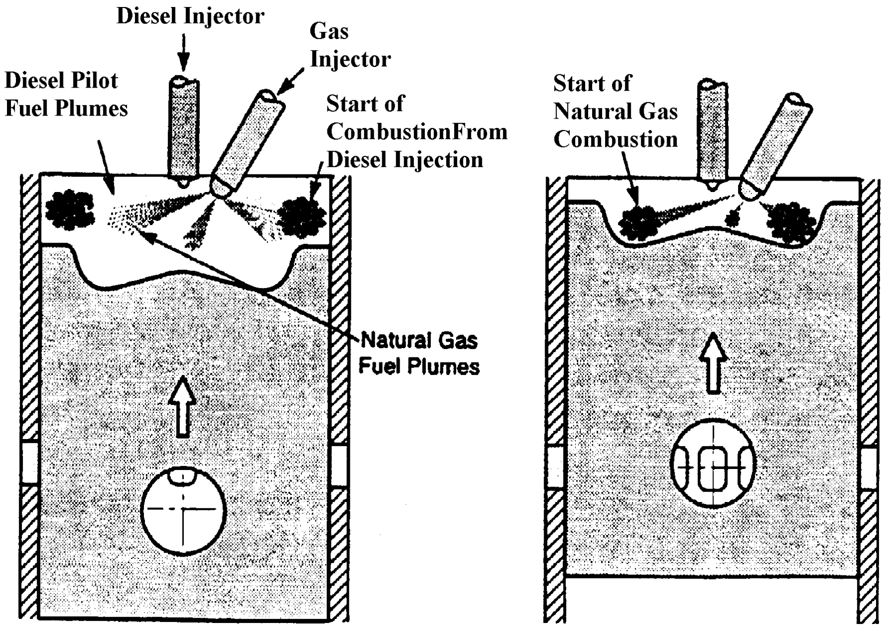


**Figure 5: Combustion System Based on Late-Cycle High Injection Pressure**

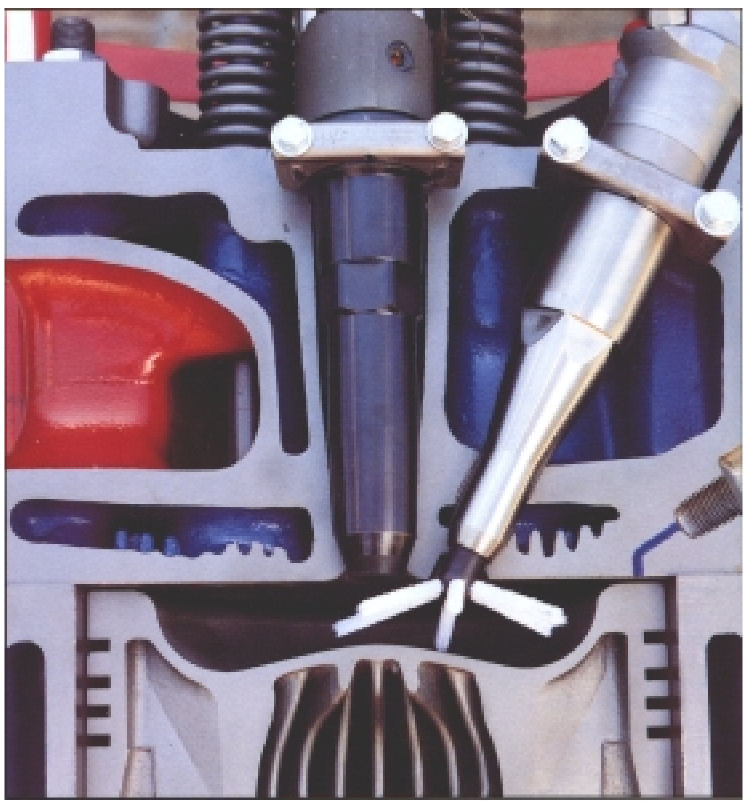

**Figure 6: Cutaway of LaCHIP Combustion System**

In 1986, a model 567B two-cylinder research engine manufactured by the Electro-motive Division (EMD) of the General Motors Corporation, was modified for dual fuel operation using LNG as the primary fuel and diesel fuel as pilot charge to ignite the gas (13). The project illustrated that high-pressure, late-cycle gas injection can produce engine performance that matched that of regular diesel engine with slightly lower thermal efficiency. However, operation on natural gas was limited to notch three and above. Operation below this point was unstable due to the limited turn-down ratio of the gas and pilot injectors. The emission tests also showed excessive smoke, PM, and CO emissions at high-power conditions, indicating over-fuelling and incomplete combustion. Based on these results, it was obvious that the diesel pilot and NG fuel injection systems needed further development.

In 1993, SwRI initiated a collaborative industry research program to develop NG engine technology for U.S. railway passenger and freight locomotives and to illustrate that the use of LNG can produce lower exhaust emissions. Members of the project included the following organizations: the U.S. Department of Energy, South Coast Air Quality Management District, Southern California Regional Rail authority, California Air Resources Board, Union Pacific Railway, Electro-Motive Division of General Motors Corporation, Southern California Gas Company, Gas Research Institute, and Amoco Petroleum Products.

This research program was based on the earlier work performed in 1986. The latest version of the combustion system named LaCHIP was a modified model of the earlier design with an enhanced injector system and a new piston head design. According to SwRI, the new injector and piston head design can achieve 75% $NO_x$ reduction with low CO and THC emissions. $CO_2$ emissions were also reduced by 25%.

It should be noted that the research and development phases of the project included single and multi-cylinder engine development, and integration of a LNG fuelled engine and its associated fuel storage and handling systems into a 2,250 kW EMD model F59HPI passenger locomotive (Figure 7). The on-track demonstration was planned to be conducted in Los Angeles by the Southern California Regional Rail Authority, through its heavy-rail passenger service known as METROLINK. The experimental results and reported claims are only based on the results obtained on an EMD single-cylinder 710 engine. The conversion process and on-track demonstration on a full-size locomotive are still pending the final approval from project members.


**Figure 7: METROLINK F59PHI Passenger Locomotive (6)**

## 2.3 Economics of NG Fuelled Locomotives

The greatest motivation to convert to natural gas is fuel cost saving. Two cost analysis projects were conducted in the United States between 1992 and 1994 to address this issue for NG fuelled locomotives. According to a cost analysis assessment performed by SwRI, conversion of small fleet to operate on LNG would not be economically feasible. The benefits from the cost of fuel and fuelling interval would be too small to offset the large cost of capital equipment purchases (e.g. locomotive, LNG conversion, tender car). Based on this report, the conversion can only be profitable if large numbers of locomotives are converted to LNG.

In 1994, a cost analysis report was prepared for BN by Industrial Engineering to determine the fuel cost saving if diesel fuel is replaced by RLM. Based on this report, if the RLM was purchased at $0.22 per gallon the cost of moving BN's coal trains with NG fuelled locomotives would have been $6756 per round trip. Using straight diesel fuel for the same trip would have been $9774. The difference in fuel cost alone meant an almost 31% reduction in fuel cost per round trip.

These reports only signify the fuel cost saving that can be realized by using NG fuelled locomotives. Use of NG as the primary fuel also yields cleaner lube oil and reduced engine wear. This will mean an extended useful life of the lube oil, fewer oil changes, and extended economic life of the engine, all of which result in a greater overall return per locomotive.

The given cost comparison does not include the impact of any environmental regulations on the cost of locomotive diesel engine since there is no such regulation in effect in Canada. As the air quality due to exhaust emissions deteriorates, it is foreseen that Canada would adapt and implement an environmental regulation identical or similar to that enforced by the EPA in the United States. In order to comply with such a regulation, new, rebuilt, and existing locomotive engines must be modified. Such a modifications would drastically increase the cost of a diesel locomotive engine, making an NG fuelled locomotive even more profitable.

## 3.0 EMISSIONS

In the last few years, emissions reduction has received tremendous attention. This interest is twofold: first, its contribution to global warming and second, concern over PM and $NO_x$ emissions that affect human health because of the particles' toxicity and ground level ozone production.

One approach to emissions reduction in locomotive diesel engines is the use of NG as an alternative fuel or in combination with diesel fuel (dual fuel operation). NG is a mixture of gases typically consisting of at least 90% methane ($CH_4$), along with small amounts of ethane, propane, nitrogen, carbon dioxide, and trace amounts of other gases. In general, its composition and chemical properties should provide a clean-burning fuel with lower emissions than diesel fuel. However, the emission is not solely affected by the fuel properties, but is significantly influenced by the engine design and operating conditions (8,14).

It has been reported that BN's dual-fuelled locomotives could produce full diesel horsepower with emissions reduction of 65% $NO_x$ and $SO_x$ (12,15). The trade-off for such low $NO_x$ emissions is high CO and THC outputs. The high CO and THC emission levels are normally characteristic of dual-fuelled engines that have not been optimized for exhaust emissions. In the early versions of these modified locomotives, CO emissions as high as 300% more than diesel engines were reported (16). High emissions were normally observed because of incomplete combustion of NG. Recent versions of these locomotives should produce lower CO and THC emissions because of better fuel-air ratio, improved electronic controls, and piston head designs that would enhance the combustion process (9,13,16). Unfortunately, limited data are available for NG fuelled locomotives exhaust emissions. The available data includes those reported for BN's EMD E3B 645-16 and MK1200G locomotives. It should be noted that BN's units were converted to improve fuel economy with minimum loss of engine power output and were not optimized for emission reduction. Table 1 displays the data acquired for BN's EMD unit at various speeds and loads. Figure 8 compares the emissions output of this unit in dual fuel mode to that of straight diesel fuel.

**Table 1: Emissions from a Dual-Fuelled EMD Locomotive at Various Speeds**

| **Engine** | | **Power Output** | | **Emissions** | | | | |
|---|---|---|---|---|---|---|---|---|
| Speed (rpm) | Mode | Total HP | Total KW | THC (g/hp-hr) | HC (g/hp-hr) | CO (g/hp-hr) | $NO_x$ (g/hp-hr) | PM (g/hp-hr) |
| 900 | DF | 3062 | 2284 | 7.7 | 0.8 | 10 | 4.2 | 0.226 |
| 900 | D | 3082 | 2299 | 0.6 | 0.6 | 0.191 | 8.355 | 0.364 |
| 835 | DF | 2633 | 1962 | 7.0 | 0.18 | 7.9 | 4.22 | 0.17 |
| 835 | D | 2718 | 2028 | 0.23 | 0.17 | 0.25 | 8.54 | 0.36 |
| 750 | DF | 2072 | 1545 | 5.4 | 0.25 | 6.29 | 4.27 | 0.15 |
| 750 | D | 2057 | 1535 | 0.22 | 0.22 | 0.34 | 8.14 | 0.35 |

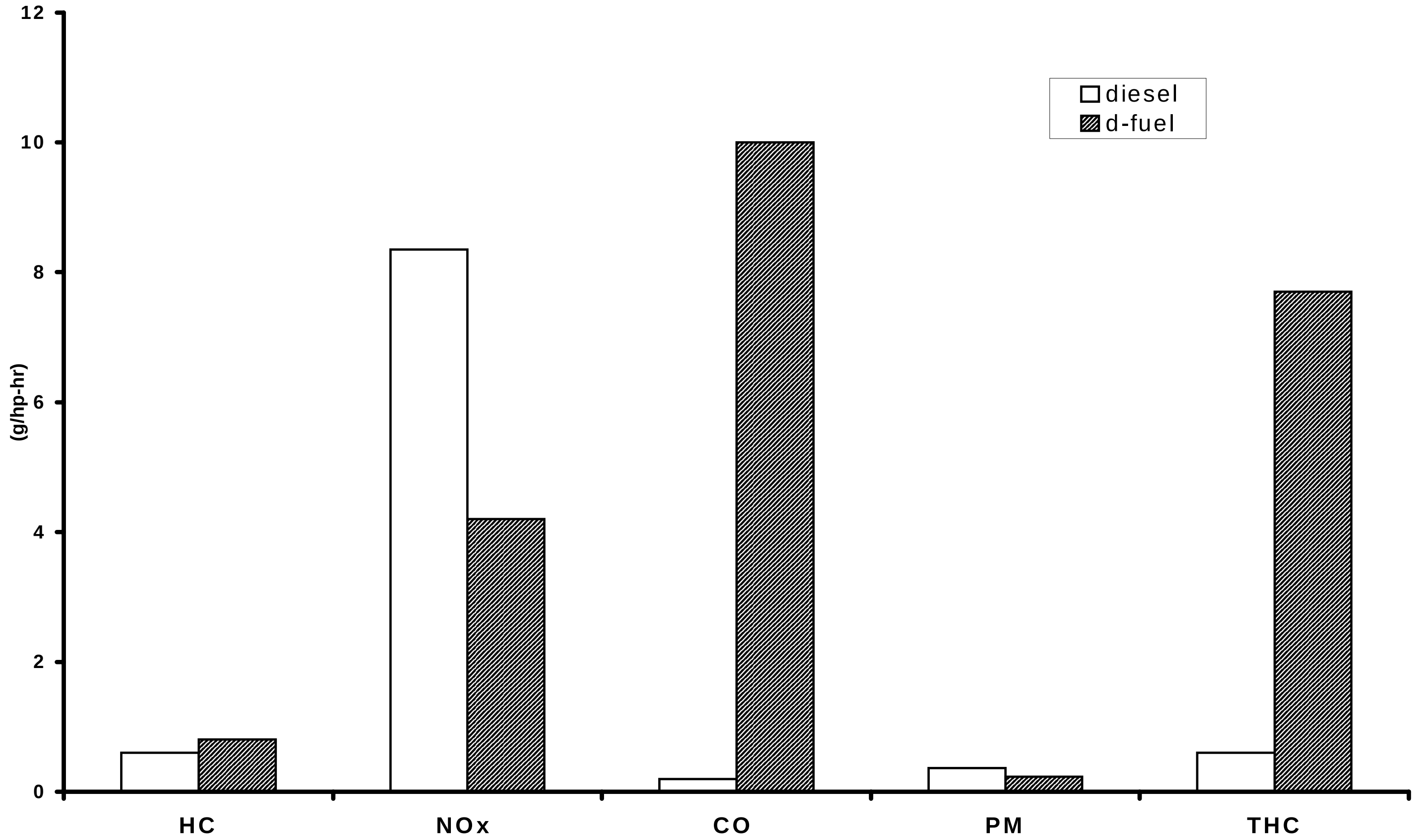


**Figure 8: Emissions from a Dual Fuel Converted EMD Engine Using BN/ECI Technology**
**Speed (rpm) = 900**

Table 2 compares the exhaust emissions of BN's EMD and MK 1200G to the EPA limits set for alternative fuelled locomotives. According to these values, the emission levels for these NG fuelled engines are at the same level or well below the level set by EPA for the engines manufactured from year 2002 to 2004 (Tier 1 EPA standards). Considering the fact that these units were modified between 1990 and 1993 without optimization for reduce emissions in accordance to EPA regulations, their emission properties seem favourable for today's railroad operations. Figure 9 compares the exhaust pollutant levels to Tier 1 limits set by EPA.

**Table 2: Gaseous and Particulate Emissions for BN's EMD, MK1200G, and EPA Emission Levels for Alternative Fuelled Locomotives**

| | THC | NMHC | NOx | CO | PM |
|---|---|---|---|---|---|
| **EMD 645** | 7.70 | 0.80 | 4.2 | 10.0 | 0.23 |
| **MK 1200G** | 2.80 | 0.50 | 2.0 | 1.9 | 0.08 |
| **EPA Tier 0 Emission Levels** | | | | | |
| **Line Haul** | - | 1.00 | 9.5 | 10 | 0.30 |
| **Switch** | - | 2.10 | 14.0 | 12 | 0.36 |
| **EPA Tier 1 Emission Levels** | | | | | |
| **Line Haul** | - | 0.55 | 7.4 | 10 | 0.22 |
| **Switch** | - | 1.20 | 11.0 | 12 | 0.27 |
| **EPA Tier 2 Emission Levels** | | | | | |
| **Line Haul** | - | 0.30 | 5.5 | 10 | 0.10 |
| **Switch** | - | 0.60 | 8.1 | 12 | 0.12 |

The use of NG fuelled locomotives provides an excellent alternative if the objective is to reduce $NO_x$ emissions. However, CO and THC emissions cannot be ignored. THC emissions from NG fuelled locomotives were found to consist of 75%-95% unburned methane. Although methane is a non-toxic gas and its emissions have not been regulated by EPA or any other environmental agency, its contribution to the greenhouse effect is comparable to that of $CO_2$ (14).

If a moderate increase in CO and THC emissions is allowed for locomotives, NG fuelled and/or dual-fuelled locomotives could probably meet the challenge with additional engine development and the use of oxidizing catalytic converters installed in the engine exhaust system. However, these steps would require additional resources to those already needed to introduce this type of engine for railway operation.

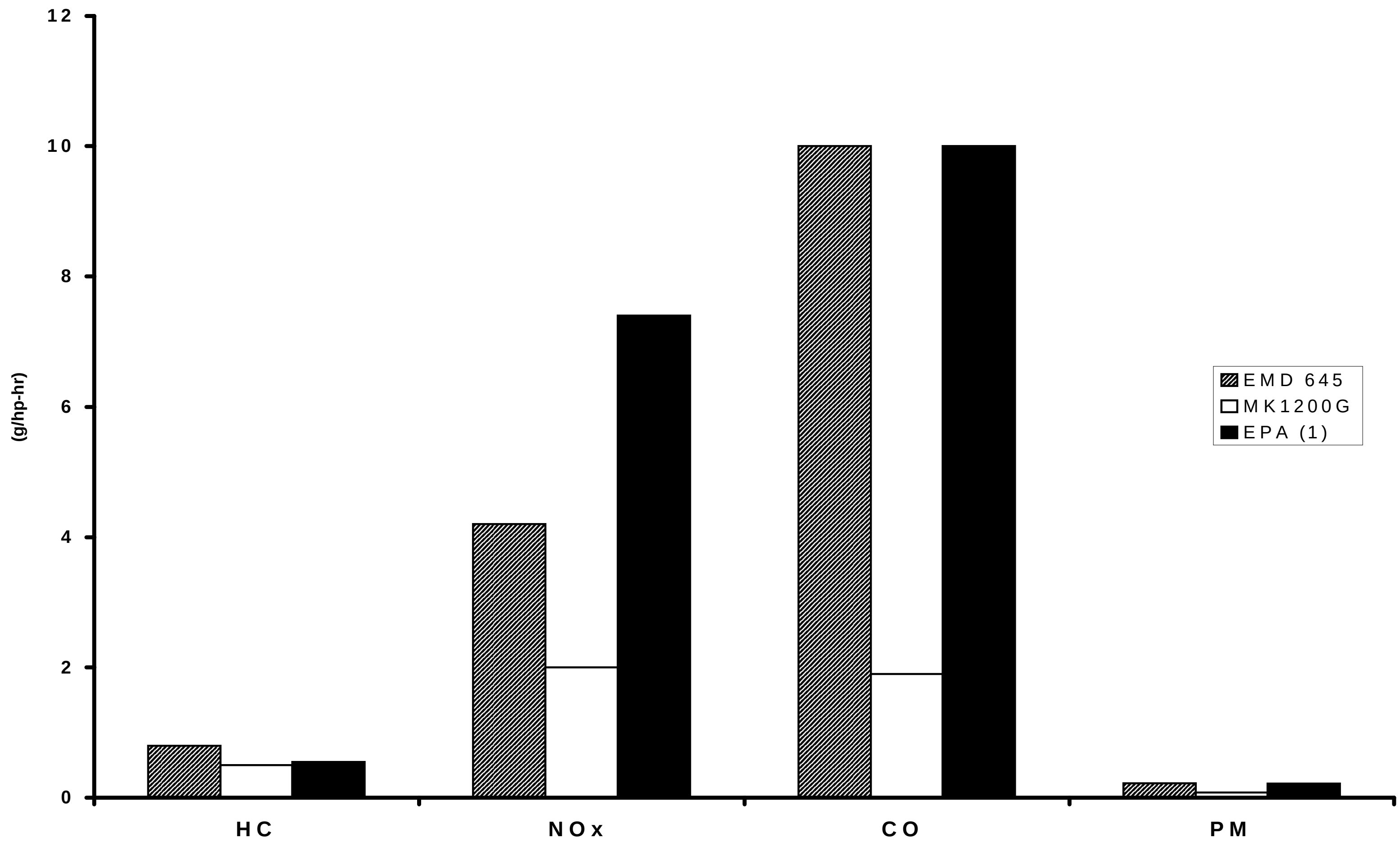


**Figure 9: Comparison of Exhaust Pollutants from BN's EMD and MK 1200G Engines to Tier 1 EPA Emission Levels**

## 4.0 OPERATIONAL INFRASTRUCTURE REQUIREMENTS

### 4.1 Engine Fuelling system and Power Assembly

For a locomotive engine to operate on both diesel and NG, certain modifications are needed. According to the available information from Energy Conversion Inc., the following modifications are required for dual-fuelled engines.

The piston and cylinder head differ from the standard power assembly normally seen in a diesel engine. The piston is of a deep reverse Mexican hat bowl configuration specifically designed to generate in-cylinder turbulence. The turbulence helps mixing of the gas and air charge required for good combustion, providing optimum power and efficiency for the converted unit. The cylinder head is modified to accommodate a gas inlet valve. The gas inlet valve opening is set at an angle to the diesel fuel injector to prevent knocks during full-load operation on NG. The head is cast with water passage blockage around the gas inlet valve boss to avoid any head failure due to overheating.

An electronic control unit (ECU) is used to verify the gas pressure prior to switching to dual fuel operation. In case of any gas leak or inadequate load, ECU prevents the dual fuel operation and reverts to diesel fuel mode. Such a control prevents any accident due to gas leak.

In almost all turbocharged locomotives, a heat exchanger is used to control the temperature of the air exiting the turbocharger. The converted system includes additional radiators with separate cooling water, which provide colder water to the turbocharger aftercooler. Additional cooling is provided by the refrigeration available in LNG. A separate cooling system uses the heat extracted from the charge air to vapourize the LNG as it is used for fuel. This heat exchange is then capable of further reducing the charge air temperature. With this arrangement, at high speed and load, the air from the turbocharger is cooled to a greater extent; therefore, higher power is achieved. At low speed, the water flow is no longer taken from these radiators, but instead from the engine outlet. The water is then directed into the aftercoolers, heating the air for good combustion. Figure 10 displays the cooling system flow schematic used by BN.

The gas fuel is delivered to the engine through solid pipes. The accepted practice for gas line joints is to use a welded joint, double-flared fittings for hard tubing, 36 degree flare fittings for flexible hoses, o-ring seals with double shut-off for quick disconnect fittings. The use of non-welded joint should be minimized and avoided in enclosed area where there is a high risk of ignition or explosion. Areas with gas leak potentials must be equipped with non-overridable gas detectors. These detectors should be placed in key areas such as: near fuel system entry point to the long hood, over the gas fuel control equipment, and in the combustion air supply stream. A similar gas detection system and emergency shutdown were used in MK1200G. Gas sensors and an automatic shutdown system seem to be an integral part of any gas engine.

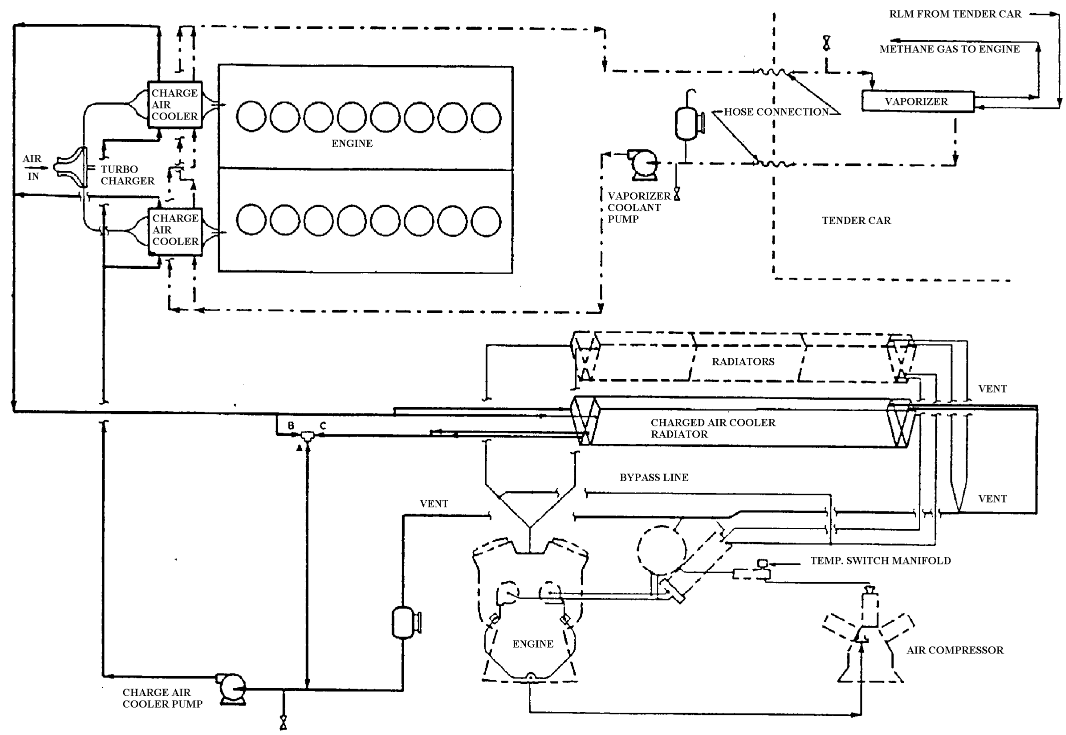


**Figure 10: Cooling System Flow Schematic for BN's Dual-Fuelled Engines (10)**

## 4.2 Infrastructure Requirements for Fuel Transfer and On-Board Storage

Special fuel pumps, delivery pipes, and connectors that are equipped with safety features for LNG delivery must be used for fuel delivery to the tender cars. Current LNG fuelling technology available for use in trucking and marine industry can be adopted for railway applications; however, some design modifications are necessary to fully integrate this existing technology into the railway system (10,17).

Unlike the diesel fuelling system, the LNG fuelling system requires two pipelines: one for LNG delivery to the tender car and the other to remove the vapour (vent line) from the tender. Such a configuration is necessary to eliminate over pressurization of the tender. Furthermore, the vapour can be collected and either liquefied or used in its vapour form. In the GasRail project the vented gas is designed to be used for fuelling a Gen-set, which supplies head-end power.

The fuel transfer system requires dry break emergency disconnection features to avoid LNG spills if the train moves. In addition, an automatic system shutdown is needed to turn off the fuel flow in case a fuel overflow occurs, or when the locomotive is being driven off with the fuel hose attached. LNG couplings used in the transport (buses and trucks) industry or those utilized in the marine industry provide fix connections. Considerable improvement in this area seems to be necessary. Based on available technology, rigid piping with swivel joints seems to be an appropriate choice to transfer fuel from a fixed fuel supply to the tender.

According to BN's experience, LNG can be stored in a double-walled cylindrical storage container mounted on a conventional center sill railway frame and truck assembly. The tender car is vacuum insulated to store the cryogenic LNG for normal runs without any vapour loss by venting. Typical tender cars used by BN had the capacity to store up to 20,000 gallons of LNG, sufficient to fuel two locomotives for the same distance as when using diesel fuel (10). The fuel was stored at approximately 100 psig and –210°F. This tender car incorporated two vapourizers, one for each locomotive being fuelled, plus the valving and controls required for safe fuel storage and refuelling at the base station. The insulation system was successfully tested by Association of American Railroad Transportation Test Center for flame/thermal resistance.

The vapourized liquid gas supply was transferred to the locomotive by a flexible hose connection similar to normal air brake hose connections. The system was designed to automatically activate a control valve to stop the fuel flow in case of hose breakage or car coupling pull-away. The heat exchange fluid from the locomotive to the tender car was also by flexible hoses similar to the gas supply hose using 50:50 mixture of ethylene glycol and water as heat transfer fluid. Figure 11 shows the cooling system for the engine and tender car.

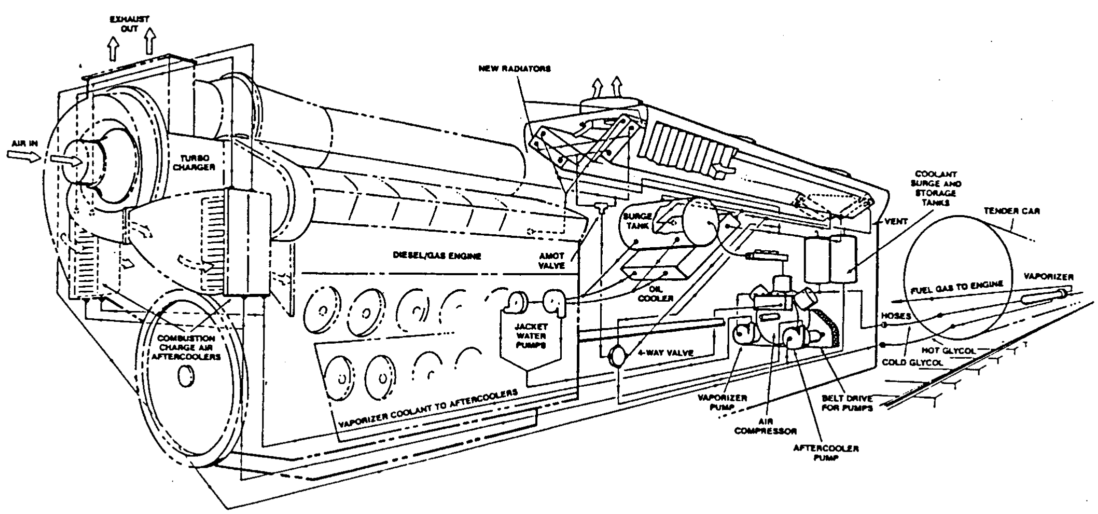


**Figure 11: Cooling System for LNG Engine and Tender Car (10)**

## 4.3 Requirements for Off-Board Transportation and Storage of LNG

One of the major factors that have limited the use of NG as a transportation fuel is the infrastructure requirement for its transport and storage. NG can be stored as compressed gas or as a cryogenic liquid. Both forms have physical characteristics that make transport more difficult and expensive than diesel fuel. LNG is favoured over CNG as a transportation fuel, since it offers the best storage density of the two (14). In addition, the liquefaction process removes impurities that solidify at temperatures at or above the boiling point of methane (e.g. water, $CO_2$, and heavy hydrocarbons), thereby eliminating the problem of fuel weathering in storage (17).

LNG can not be efficiently transported by pipeline for long distances because of pipeline costs and heat transfer. Thus, it must be produced at the site, near the point of consumption, or transported by truck or tank car. The logical approach is that the NG will be transported from the refinery to liquefaction plants, which are situated near the fuelling sites. The fuel consumption rate will determine the plant and the main fuel storage tank size. In addition, mobile liquefaction units are also available that can be used to produce LNG at the fuelling site if a low quantity of LNG is desired.

LNG production and storage are well understood and the technology is readily transferable to conditions likely to be encountered in railway applications. Operational, storage, and safety guidelines are established and available through the LNG and general cryogenic industry. They appear to present no actual problems in setting up the equipment and facilities required to supply LNG in the quantities and delivery rates needed by the railway.

## 5.0 CONCLUSIONS

The evolution of NG fuelled locomotive technology has been reviewed. The available technologies for railway applications were identified and their viability was assessed based on the operational experiences and their environmental impact. The infrastructure requirements for NG implication were also determined.

Available technologies with proven records are those used in BN's dual-fuelled locomotives and MK 1200G locomotives. The reported operational experiences for these units clearly demonstrate their viability for railway operations. The major evolution in engine technology was the use of microprocessor-controlled injection systems, which significantly improved the performance, efficiency, and durability of the engine.

The environmental benefits offered by NG fuelled engines make them an ideal candidate for operation in urban areas, which have air quality and health concerns. Although these engines exhibit low emissions, additional work is required to lower CO and THC.

Fuelling technology has not undergone any revolutionary changes, but fuelling hardware and practices have continued to evolve. It was determined that LNG is the most practical choice for fuelling purposes, as it offers better fuel quality, density, and fuel properties than CNG.

The use of NG as a primary fuel would provide environmental and fuel cost saving. However, the fuel cost saving is affected by the size of fleet being converted. The major barrier in the implementation of NG fuelled locomotive technology seems to be the initial capital investment required for construction of storage and fuelling stations. It is expected that methodologies and infrastructures being implemented by airport shuttle and parcel post organizations will help remove this obstacle.

## 6.0 RECOMMENDATIONS

Air quality has become a significant issue in recent years. Strict emission regulations are in place in industrial countries such as the United States that would limit exhaust emission from mobile sources. One example is the EPA exhaust emissions regulation for locomotives. This law will take effect on January 1st, 2000. The required emission reductions would necessitate significant engine modifications, which would considerably increase the cost of locomotives, making NG fuelled engines an attractive option.

Furthermore, deteriorated air quality in large Canadian cities such as Toronto and Vancouver would provide the incentive for the Canadian government to adapt similar or identical emission regulations to those enforced by EPA. Exhaust emissions regulations in Canada and the United States will probably be an incentive for the introduction of NG into wide-scale locomotive use. In addition, the future price of crude oil and the possible supply disruptions could initiate even greater interest. The impending regulations will require the use of clean fuel (reformulated diesel or engineered diesel), which will also affect the consideration of LNG as an option. At the 1999 Windsor Workshop it was stated that California has decided that NG is the option to meet the regulations in the near term.

Advantages over the diesel engine are well known and are significant, especially in urban locations where passenger or switcher locomotives operate. Interest has been shown by Canadian passenger railway service organizations and LNG and gas fuel injection equipment suppliers are interested in taking part in future development. Technology transfer with the United States is an additional possibility.

The following steps are recommended:

- Conduct a feasibility study with a view to creating a consortium and selecting technology for demonstration in Canada.

- Set up an in-service demonstration, using an NG fuelled locomotive.

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# APPENDIX A: DATABASES & INFORMATION SOURCES

**DATABASES**

A1-SAE WEBDEX

A2-SAE GLOBAL MOBILITY

A3-SAE AUTOMOTIVE ENGINEERING ON CD-ROM

A4-SAE FUELS & LUBRICANTS ON CD-ROM

**WEBSITES**

A5-LNGEXPRESS.COM

**INSTITUTION AND COMPANIES**

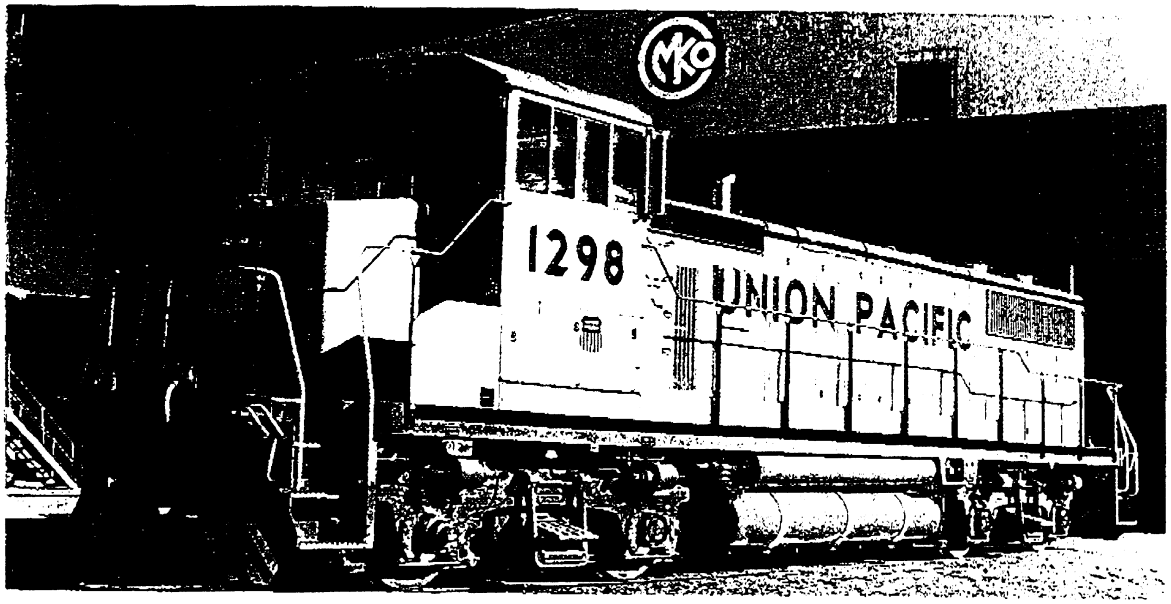
A6-SOUTWEST RESEARCH INSTITUTE

A7-ENERGY CONVERSION INC.

A8-TEXAS TRANSPORTATION INSTITUTE

A9-CHRONIC CANADA INC.

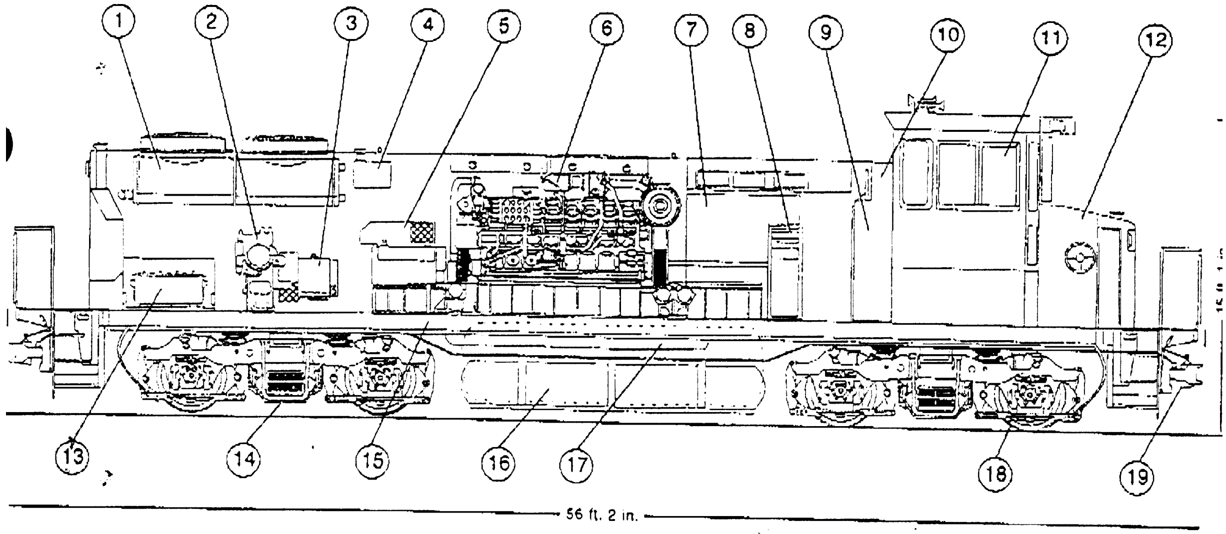
# APPENDIX B: MK 1200G SPECIFICATIONS




# MK1200G Switcher Locomotive

Model Designation ..........................MK1200G
Locomotive Type...........................(B-B) 0440
Traction Horsepower.............................1200
Liquefied Natural Gas (LNG) Engine
  Model...............................Caterpillar G3516
  Type.....................................Spark-ignited, Turbocharged-aftercooled (SITA)
  Number of Cylinders...............................16
  Cylinder Arrangement.....................60° Vee
  Cylinder Bore x Stroke...........6.7" x 7.5" (170 x 190mm)
  Operating Principle....................Four-stroke
  Full Speed...................................1500 RPM
  Idle Speed (Normal)...................... 800 RPM
Main Traction
  Alternator (AC).................KATO 8P6.5-3000
  Rectified Output..........................4400 amp
  Number of Poles.......................................8
  Nominal Voltage (DC)...........................1050
Companion Alternator..KATO series 6P2-1450
  Number of Poles.......................................6
  Nominal Voltage (AC).............................183
  Frequency......................................100 Hz
  Power Rating.....................................130kW
Auxiliary Alternator.......KATO series 6P2-0500
  Voltage Rating (DC).................................74
  Power Rating (AC)..............................18kW

Traction Motors
  Model..................................................D78B
  Number.....................................................4
  Type..........................Motor Coils DC, Series Wound, Axle Hung
Minimum Continuous Speed...............6.2 mph
Maximum Continuous Tractive Effort.............................60,000 lbs.
Maximum Continuous Traction Motor Ampere Rating...................................1,050
Electrical Control System...................MK-LOC Microprocessor
Wheel Slip System Control...................MK-LOC Microprocessor
Driving Wheels
  Number.....................................................8
  Diameter.................................................40"
  Tread......................Smooth and Concentric
Dimensions
  Width Over Cab Sheeting..................10'-1/8"
  Width Over Basic Arm Rests...........10'-6 1/8"
  Height, Cab Roof to Top of Rail......................................15'-1"
  Distance Between Coupler Faces........56'-2"




1. Radiators
2. Air Compressor
3. Air Compressor Motor
4. Expansion Tank
5. Companion & Auxiliary Alternator
6. Prime Mover
7. Traction Alternator
8. Traction Motor Blower
9. Electrical Control Cabinet
10. Microprocessor Control System
11. Comfort Cab
12. Short Hood
13. Battery
14. Truck Assembly
15. Underframe
16. 1,400 Gallon Fuel Capacity
17. Main Air Reservoir
18. Wheel - 40" Diameter
19. Coupler and Draft Gear

Dimensions
- Distance, Coupler Face to Truck Centerline ........................ 12'-7"
- Distance Between Bolster Centers...... 31'-0"
- Truck Wheel Base................................ 9'-0"

Minimum Curve Negotiation Capability
- 150 ft. Radius – 39° Curve – Single Unit
- 274 ft. Radius – 21° Curve – Two Units with Type "E" Coupling

Air Compressor
- Type............................................... 2 Stage
- Number of Cylinders.................................. 3
- Capacity (At 900 RPM).......... 254 cu. ft./min.
- Air Compressor Cooling...................... Water
- Lube Oil Capacity........................... 10.5 gal.

Storage Batteries (2)
- Number of Cells...................................... 32
- Voltage.................................................. 64
- Rating (8 Hour)....................... 500 amp. hr.

Supplies
- Lubricating Oil Capacity.................. 219 gal.
- Cooling Water Capacity.................. 190 gal.
- Fuel Capacity (LNG)...................... 1400 gal.
- Sand............................................ 50 cu. ft.

Air Brake Type...................................... 26L UL

Approximate Weight on Rails....... 250,000 lbs.

Weight on Drivers.................................. 100%

LNG Fuel Properties
- Methane............................................. 97%
- Other Hydrocarbons.............................. 1%
- Inert Gases........................................... 2%
- Boiling Point.................................... -259°F
- Lower Heating Valve.............. 21,500 btu/lb.
  76,000 btu/gal.
  905 btu/ft$^3$

Energy Comparison to No. 2 Diesel:
1 gal. diesel = 1.6 gal. LNG

Flammability range as a percent of air volume............................ 5% – 15%

Methane number (min.) at rated engine hp.................................. 70


MK RAIL CORPORATION
P.O. BOX 73/BOISE, IDAHO U.S.A. 83729
PHONE: (208) 386-5950/FAX: (208) 386-5967

# APPENDIX C: STATEMENT MADE BY BROTHERHOOD OF LOCOMOTIVE ENGINEERING REGARDING DUAL-FUELLED LOCOMOTIVE OPERATED AT BN

**Brotherhood of Locomotive Engineers**

"Serving Since 1863"

DIVISION 238 — TACOMA, WASHINGTON 98446
S. J. Golubic, Local Chairman
7623 60th Street East
Puyallup, WA 98371
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11 February 1992

Mr. D. L. McPherson
General Chairman, G. C. of A., BNRR/MRL
333-on-Sibley Street, Suite 410
St. Paul, Minnesota 55101

Dear Sir and Brother:

Early in December 1991, I was contacted by a local BN officer to participate in a test of locomotive BN 7890 (Natural Gas Fueled-refrigerated liquid methane RLM). This is a joint venture between the BN and the Air Products and Chemicals, Inc., who designed and built the fuel tender. The conversion of the locomotive fuel system was done by Energy Conversions, Inc., of Fife, Washington.

The initial test was conducted for nine days between Elma and Bremerton, Washington. Before testing began, Mr. Leslie Olson, Manager, Energy, BN Research and Development, instructed the train and engine crew on the natural gas operation, addressing safety concerns and procedures. He showed videos on the flammability of LRM, safety programs, and locomotive and tender inspection.

On December 10, with representatives of the BN and Energy Conversion along to observe, testing of BN 7890 began. The main objective of the test was the performance and reliability of both locomotive and fuel tender. The locomotive, tender, back-up locomotive, and business car were operated between Tacoma and Centralia on the BN's 4th sub-division main line. Several stops, including emergency stops, crossover movements, and other normal operating procedures were made to observe the action of the fuel tender and locomotive consist.

At Centralia, six or eight ballast cars were picked up and the train proceeded to the Elma-Bremerton branch line to test the locomotive with tonnage on grades and different track conditions. Representatives of ECI wished to see how the locomotive would react to wheel slip and transition. They had to program the computer to get satisfactory results when the locomotive was operating on gas as well as diesel.

After operating this locomotive, during this test period and two other occassions, I found very little difference between the gas conversion locomotive and a standard diesel locomotive. Speaking only for myself, I felt comfortable operating this type of locomotive. The question most asked by other employees is about having the fuel tender next to the locomotive. I am sure others may have questions and concerns about the conversion locomotives.

Please contact me if I can answer any questions about this test. I will try to assist in any way I can.

Fraternally yours,

S. J. Golubic
LC 238

cc: Mr. L. E. Olson, BNRR
Mr. Paul Jensen, Energy Conversions