TP 13783E

DIESEL FUEL QUALITY AND LOCOMOTIVE EMISSIONS IN CANADA

Prepared for

Transportation Development Centre
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by
Robert Dunn

April 2001

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This report reflects the views of the author and not necessarily those of the Transportation development Centre.

Since the accepted measurers in the industry are both imperial and metric, both appear in this report.

Un sommaire français se trouve avant la table des matières.

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16. Abstract

This report details the quality of locomotive diesel fuel in Canada and reviews the fuel consumption trend of the Canadian locomotive fleet. It also details the locomotive emissions regulations in Canada and the United States, and shows how locomotive emissions in Canada have been affected by a change to modern, higher horsepower, fuel-efficient locomotives.

A survey was taken of the quality of diesel fuel being supplied to Canadian railways. It shows that locomotive fuel properties differ from those of on-road fuel in sulphur content and cetane number. It also shows that Eastern Canada and Western Canada fuel properties differ mainly in sulphur content.

After a review of the literature on locomotive emissions, a calculation of the emissions from the Canadian locomotive fleet was performed. The results show that the replacement of older locomotives with new fuel-efficient locomotives has significantly reduced annual fuel consumption and that emissions have been maintained at 1989 levels.

This study concludes that Canadian railways are currently meeting the terms of their Memorandum of Understanding with Environment Canada on locomotive emissions.

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16. Résumé

Ce rapport examine la qualité des carburants diesel utilisés dans les locomotives au Canada et l'évolution de la consommation de carburant par le parc canadien de locomotives. Il se penche également sur les règlements relatifs aux émissions de locomotives en vigueur au Canada et aux États-Unis, et met en lumière le lien entre les émissions des locomotives au Canada et la mise en service de locomotives modernes, plus puissantes et moins énergivores.

Au terme d'une étude de la qualité des carburants diesel fournis aux chemins de fer canadiens, les chercheurs ont constaté un écart entre la teneur en soufre et l'indice de cétane des carburants ferroviaires et des carburants routiers. Ils ont également observé des différences entre les carburants utilisés dans l'Ouest du Canada et ceux utilisés dans l'Est, différences qui tiennent essentiellement à la teneur en soufre de ceux-ci.

Une recherche documentaire sur les émissions des locomotives a permis de calculer les émissions produites par le parc canadien de locomotives. Les valeurs ainsi établies indiquent que le remplacement des vieilles locomotives par de nouvelles locomotives consommant moins de carburant a entraîné une réduction importante de la consommation annuelle de carburant et a maintenu le rejet d'émissions aux niveaux de 1989.

L'étude conclut que les chemins de fer canadiens respectent les conditions du Protocole d'entente qu'ils ont signé avec Environnement Canada sur les émissions des locomotives.

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EXECUTIVE SUMMARY

This project was initiated to assess the impact of the quality of diesel fuel used by the Canadian railway industry on locomotive emissions. It reports on the differences in physical properties between Eastern and Western Canadian locomotive diesel fuel and on the potential impact of future diesel sulphur levels on the Canadian railway industry. An assessment was also made of how the changes to the locomotive fleet have affected locomotive emissions in Canada.

Canadian railway locomotive engines consume approximately two billion litres of diesel fuel annually. In Western Canada, most diesel fuel is derived from the Canadian tar sands while in Eastern Canada it is derived mostly from conventional crude oil. Railway diesel fuel properties differ from those of on-road diesel fuel in two main areas – sulphur content and cetane number. Sulphur levels are set by railway specifications at 0.50 percent maximum, compared to 0.05 percent maximum for on-road fuel; however, the railways receive fuel well below this maximum value. In Western Canada the sulphur content is delivered at 300 to 500 ppm while in Eastern Canada it is delivered at 1500 to 2500 ppm (0.15 to 0.25 percent). The cetane number of railway diesel fuel is in the 37 to 42 range, compared to 40 to 45 for on-road diesel fuel.

Canadian railways have agreed to control locomotive emissions. The Railway Association of Canada (RAC) and Environment Canada (EC) have in place a Memorandum of Understanding (MOU) wherein the RAC members have agreed to cap the annual tonnage of oxides of nitrogen from Canadian locomotive engines at 1989 levels from 1990 through 2005 and report on other pollutants. In 1998 the United States Environmental Protection Agency published rules that force U.S. locomotive builders to manufacture locomotive engines with reduced exhaust emissions. A three-phase (Tiers) approach was used. The first phase (Tier 0) took effect January 1, 2000; Tier 1 comes into effect on January 1, 2002; and Tier 2 begins in 2005. Rules have also been issued for exhaust emission limits on rebuilt locomotive engines. Canadian railways have received locomotives meeting Tier 0 standards and have indicated that they will purchase locomotives meeting Tier 1 and Tier 2 standards.

A recent survey of railways showed that the Canadian locomotive fleet has changed considerably from the mid-1990s. Modern, higher horsepower, fuel-efficient locomotives are replacing (2 for 3) older model locomotives (SD-40 types, the workhorse of the 1980s and early 1990s). Locomotive emission calculations show that the older locomotives still represent approximately 50 percent of the exhaust emissions from the Canadian locomotive fleet.

The study showed that RAC is currently meeting the terms of its MOU with EC.

SOMMAIRE

L’objectif de ce projet était de déterminer le lien entre la qualité des carburants diesel utilisés par les chemins de fer canadiens et les émissions des locomotives. Les chercheurs ont étudié les différences, sur le plan des propriétés physiques, entre les carburants diesel pour locomotives utilisés dans l’Est et dans l’Ouest du Canada, et les effets possibles de la teneur en soufre des futurs carburants diesel sur l’industrie ferroviaire canadienne. Ils ont également étudié les conséquences de la transformation du parc de locomotives sur les émissions des locomotives au Canada.

Les locomotives des chemins de fer canadiens consomment environ deux milliards de litres de carburant diesel par année. Dans l’Ouest du Canada, la plupart du carburant provient des sables bitumineux de l’Ouest, tandis que dans l’Est, il est surtout produit à partir de pétrole brut classique. Les propriétés des carburants diesel ferroviaires diffèrent de celles des carburants diesel routiers à deux égards : la teneur en soufre et l’indice de cétane. Les spécifications des chemins de fer limitent à 0,50 p. cent la teneur en soufre admissible des carburants, comparativement à la limite de 0,05 p. cent établie pour les carburants routiers; mais le carburant livré aux chemins de fer affiche des teneurs de beaucoup inférieures à cette valeur maximale. Ainsi, dans l’Ouest du Canada, la teneur en soufre du carburant varie de 300 à 500 mg/L, par rapport à une teneur de 1 500 à 2 500 mg/L (0,15 à 0,25 p. cent) dans l’Est du Canada. L’indice de cétane du carburant diesel ferroviaire se situe dans la fourchette de 37 à 42, comparativement à une fourchette de 40 à 45 pour les carburants diesel routiers.

Les chemins de fer canadiens ont convenu de réduire les émissions des locomotives. C’est ainsi que l’Association des chemins de fer du Canada (ACFC) et Environnement Canada ont signé un Protocole d’entente en vertu duquel les membres de l’ACFC ont accepté, pour la période de 1990 à 2005, de maintenir aux niveaux de 1989 le nombre de tonnes d’oxydes d’azote rejetées annuellement par les locomotives, et de produire des rapports sur les autres émissions polluantes. En 1998, l’Agence de protection de l’environnement (EPA) des États-Unis a publié des règles qui obligent les constructeurs américains de locomotives à construire des locomotives plus propres. Une démarche en trois phases (niveaux) a été adoptée. La première phase (niveau 0) est entrée en vigueur le 1er janvier 2000; la deuxième (niveau 1) entrera en vigueur le 1er janvier 2002, et la troisième (niveau 2), en 2005. Des règles ont également été édictées concernant les limites des émissions admises dans le cas des locomotives remises à neuf. Les chemins de fer canadiens se sont équipés de locomotives qui respectent les normes du niveau 0 et ils ont fait part de leur intention d’acheter des locomotives conformes aux normes des niveaux 1 et 2.

Un sondage récent mené auprès des chemins de fer a révélé que le parc canadien de locomotives a beaucoup changé depuis le milieu des années 1990. Des locomotives modernes, plus puissantes et consommant moins de carburant, remplacent (2 pour 3) les vieux modèles (de type SD-40, la locomotive à tout faire des années 1980 et du début des années 1990). Les calculs des émissions de locomotives révèlent que

les vieilles locomotives sont encore responsables d’environ 50 p. cent du total des émissions polluantes produites par le parc canadien de locomotives.

L’étude a révélé que l’ACFC respecte les conditions de son Protocole d’entente avec Environnement Canada.

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GLOSSARY

ABBREVIATIONS, ACRONYMS AND SYMBOLS

Organizations, Societies and Agreements

AAR	Association of American Railroads
ASTM	American Society for Testing and Materials
CGSB	Canadian General Standards Board
CN	Canadian National Railways
CP	Canadian Pacific Railway
EC	Environment Canada
EMD	Electromotive Division of General Motors
GE	General Electric Transportation Division
MOU	Memorandum of Understanding
RAC	Railway Association of Canada
US EPA	United States Environmental Protection Agency

Chemical Symbols and Emissions Related Abbreviations

bsfc	brake specific fuel consumption
CO	Carbon monoxide
cSt	centiStoke
g/bhp-hr	grams per brake horsepower hour
g/IG	Grams per Imperial Gallon
GTM	Gross Ton Miles
HC	Hydrocarbons
NOx	Oxides of Nitrogen
NTM	Net Ton Miles
PM	Particulate Matter
ppm	parts per million
THC	Total Hydrocarbons

1.0 INTRODUCTION

The Canadian railway industry uses approximately two billion litres of diesel fuel in the engines of its locomotive fleet. Sixty percent of the fuel is consumed in Western Canada and the balance in Eastern Canada. Diesel fuel in the west is derived mostly from crude from the Canadian tar sands while in the east the diesel fuel is derived mostly from conventional crude oil. The chemical and physical properties of fuel derived from these two crude sources are quite different (1).

Some Canadian railways, after extensive testing, have found that diesel fuel derived from the Canadian tar sands – with higher aromatics content and lower cetane number – perform in an acceptable manner in locomotive engines. Consequently, they have worked with their diesel fuel suppliers to develop a similar lower cetane number fuel for Eastern Canada. As a result, Canadian railways in Eastern Canada use diesel fuel that is essentially home heating oil (furnace oil).

Diesel fuel specifications are used by the Canadian railways to procure diesel fuel for their locomotive engines and to control the physical properties of the fuel that is delivered. Railway-specific diesel fuel specifications have developed because of the acceptance of lower cetane number and because sulphur levels are not currently regulated in locomotive diesel fuel in Canada.

Locomotive emissions are of interest because of Canada's commitment to reduce the amount of carbon dioxide emissions into the atmosphere (Kyoto agreement) and by the desire to reduce the amount the oxides of nitrogen (NOx) that affect low level ozone development and the associated health problems.

In 1995 the Canadian railway industry, through the Railway Association of Canada (RAC), entered into a voluntary agreement with Environment Canada (EC) (2,3). It agreed to cap the amount of NOx produced by the railways at 1989 levels from 1990 through 2005. This cap is 115,000 tonnes per year. The make-up of the Canadian locomotive fleet has changed significantly in the last ten years. Modern, higher horsepower locomotives have significantly better fuel consumption but higher per-locomotive emissions of NOx and other pollutants than the older locomotives. The result is a net overall constant level of locomotive exhaust emissions, in terms of annual tonnages produced. Fifty percent of exhaust emissions from the Canadian locomotive fleet originate from older locomotives.

2.0 RAILWAY DIESEL FUEL SPECIFICATIONS

The chemical and physical properties of diesel fuel procured by the Canadian railway industry are controlled by the requirements of a referenced specification. This can be a formal diesel fuel specification, such as one issued by the Canadian General Standards Board (CGSB), an "in-house" specification, or simply a statement that the fuel should be a #2 diesel fuel. Formally, the term "number 2 diesel fuel" refers only to the American Society for Testing and Materials (ASTM) specification Grade No. 2-D; however, in a generic sense it means diesel fuel suitable for on-road/off-road diesel engines. Canadian railway diesel fuel suppliers likely interpret the phrase to mean a diesel fuel that meets CAN/CGSB 3.6 standard for regular sulphur diesel fuel.

Similarly, in Canada, the term "low sulphur number 2 diesel fuel" means diesel fuel meeting CAN/CGSB 3.517 standard for automotive low sulphur diesel fuel.

Table 1 is a list of formal specifications available to the railway industry in North America. Table 2 lists the tests specified to control fuel properties. Table 3 compares the properties specified in the various diesel fuel specifications.

Table 1: Diesel Fuel Specifications

Specifications Specifically for Railway Locomotives:	
CAN/CGSB 3.18	Diesel Fuel for Locomotive-Type Medium-Speed Diesel Engines
EMD MI 1750	Electro-Motive Division of General Motors – Diesel Fuel Specification
GE MI 00128F	General Electric Transportation Division – Diesel Fuel Specification
Specifications for On-Road or Off-Road Vehicles:	
CAN/CGSB 3.6	Regular Sulphur Diesel Fuel
CAN/CGSB 3.517	Automotive Low Sulphur Diesel Fuel
ASTM D 975	1. Grade: No. 2-D 2. Low Sulphur No. 2-D

Table 2: Specification Tests

	Test Description	Test Procedure
1. Low Temperature Operability	**Cloud Point**	**ASTM D 2500 or D 5773**
	Wax Appearance Point	ASTM D 3117
	Low Temperature Flow Test	CAN/CGSB-3.0 No. 140.1
2. Contaminants	**Water & Sediment**	**ASTM D 1796**
	Ash	**ASTM D 482**
	Filterability Test	EMD MI 1750
3. Corrosivity	**Copper Strip Corrosion**	**ASTM D 130**
4. Storage Stability	**Acid Number**	**ASTM D 974**
	Storage Stability	ASTM D 4625 or D 2274 or 5304
5. Safety	**Flash Point**	**ASTM D 93 or D 3828**
	Electrical Conductivity	**ASTM D 2624**
6. Pump Wear	**BOCLE Test**	**ASTM D 6078**
	Reciprocating Rig Test	**ASTM D 6079**
	Other Rig Tests	**SAE Papers: 952370, 981363, or 961944**
7. Fuel Performance	**Ignition Quality (Cetane number)**	**ASTM D 613 or 4737 or CAN/CGSB 3.0 No. 20.9**
	Kinematic Viscosity (40ºC)	**ASTM D 445**
	Distillation	**ASTM D 86**
	Sulphur	**ASTM D 1226 or D 1552 or D 2622 or D 4294 or D 5453**
	Carbon Residue	**ASTM D 4530 or D 524**
	Density	ASTM D 1298
Bold Type – Usual specification requirements Regular Type – Possible additional requirements		

Table 3: Comparison of Specifications

Specification	Application	ASTM D 976 Cetane Index Minimum	ASTM D 445 Viscosity cSt @40ºC	ASTM D 86 Distillation 90% over ºC Maximum	ASTM D 4294 Sulphur % Mass Maximum	ASTM D 1298 Specific Gravity @ 15ºC Maximum	ASTM D 524 Carbon Residue Ramsbottom % Mass Maximum
CAN/CGSB 3.18	Railway	37.0	1.70 - 5.00	360.0	0.50	900	0.35
EMD MI 1750	Railway	40.0	1.7 - 5.5	343.0	0.50	NR	0.35
GE MI 00128F	Railway	40.0	1.9 - 4.1	338.0	0.50	NR	0.35
CAN/CGSB 3.6 (B)	Automotive	40.0	1.70 - 4.10	360.0	0.50	NR	0.20
CAN/CGSB 3.517 (B-LS)	Automotive	40.0	1.70 - 4.10	360.0	0.05	NR	0.20
ASTM D 975	On Road or Off Road	40.0	1.9 - 4.1	338.0	0.50	NR	0.35
NR – No Requirement							

Railway in-house specifications generally have one or more individual properties that are either slightly broader or slightly narrower than any of the above formal specifications. A broader allowance of a property might permit the railway to take advantage of a pricing arrangement through negotiation with its suppliers. A narrower requirement of a property might be demanded as a result of some operating experience.

Viscosity

It is difficult to produce Arctic grade diesel fuel for the Canadian Prairie Provinces with a cloud point requirement of – 40ºC and having a viscosity above 1.7 cSt at 40ºC. Therefore, a lower viscosity could be specified after negotiation with the suppliers. The railway would then accept some risk of potentially higher injector or pump wear with lower viscosity fuel in the winter.

Cetane Number

Some Canadian railways permit the use of diesel fuel with cetane number as low as 33. These railways have used fuel with low cetane number fuel for many years without mechanical operating problems and have demonstrated that engine performance is not compromised with such fuel.

Density

Density is not usually specified in diesel fuel specifications. It has become important for at least one Canadian railway as a means to reduce the volume of fuel purchased. The higher density fuel may have cetane number below 37 and higher aromatics content.

Railway diesel fuel with some broadened specification properties (cetane number or density) as described above is often referred to as Railway #3 Diesel Fuel. In many cases the fuel is furnace oil (CAN/CGSB 3.2 Heating Fuel Oil, Type 2).

3.0 REFINERY PRODUCT SPECIFICATIONS

The quality of any middle distillate product produced by a refinery must always meet the minimum requirements of the specification for which it is designed. The refiners, therefore, ensure that the refinery product specifications are better than the minimum requirements of the national standards or customer purchasing standards.

A railway could request diesel fuel with physical properties outside the normal refinery production specification, such as higher density, that is without a black oil component. This might require special blending of components and a separate storage tank would be needed. This is costly and will take place only if both the railway and the supplier believe it is of mutual benefit.

The petroleum refining industry produces diesel fuel continuously and stores the product in tanks on its property. From the storage tanks diesel fuel is delivered to customers by truck, railway tank car or pipeline. Space for on-site storage tanks is always scarce; therefore, there is a desire to keep the number of products in storage to a minimum.

4.0 DIESEL FUEL QUALITY

Eastern and Western Canada are two distinct supply zones for Canadian railways. In Eastern Canada, diesel fuel is refined from crude oil from conventional sources and is mostly home heating oil (furnace oil). In Western Canada, diesel fuel is derived from Canada’s tar sands and has different physical and chemical properties. For example, it typically has very low sulphur levels (less than 500 ppm), higher aromatics content (typically 30 to 40 percent), and lower cetane number (37 to 40) (1).

Canadian railways have been large volume users of diesel fuel derived from the Canadian tar sands since the early 1970s. Consequently they have many years of experience using diesel fuel with cetane number in the range of 35. There have been no operating or mechanical problems reported directly attributable to fuel with these properties.

4.1 Eastern Canada

The diesel fuel specifications discussed in Section 3 control the physical properties of railway diesel fuel. A recent survey of suppliers shows that the quality of the diesel fuel being supplied to the Canadian railway industry in Eastern Canada is significantly better than that described in the specifications listed in Table 3. Table 4 lists typical performance properties of diesel fuel for both Eastern and Western Canada. The average values shown have been determined by taking into consideration the current market share of the suppliers to the Canadian railway industry and the properties from each of the refineries from which the fuel is supplied.

The railways receive about 10 to 20 percent of their fuel by truck delivery directly to their locomotive fuel tanks. This is a convenience to the railway and reduces the amount of storage tanks required on the railways' property. Truckers making diesel fuel delivery direct-to-locomotives pick up the fuel at the truck fuel rack at the refinery and it could be heating oil, regular sulphur diesel fuel or low sulphur automotive diesel fuel. In most cases it has been found that diesel fuel delivered direct-to-locomotive is low sulphur diesel fuel. Obviously, the more low sulphur fuel the railways use in this manner, the lower the overall average sulphur content will be of railway diesel fuel. Table 4 shows the Eastern Canadian sulphur values to be, on average, 0.20 percent.

Table 4: Canadian Railway Diesel Fuel Properties

	ASTM D 976 Cetane number	ASTM D 445 Viscosity cSt @40ºC	ASTM D 86 Distillation 90% over ºC	ASTM D4294 Sulphur % Mass	ASTM D 1298 Density @ 15ºC	ASTM D524 Carbon Residue Ramsbottom % Mass
Eastern Canada	39.5	2.40	324.0	0.20	827.0	0.00
Western Canada	37.4	3.10	335.0	0.04	866.0	0.01
Canadian Average	38.2	2.80	330.6	0.10	850.4	0.00

4.2 Western Canada

Canadian railways operating in Western Canada use diesel fuel derived from the tar sands. These fuels typically have exceptionally low cloud points, low sulphur content, higher density and low cetane number numbers (Table 4). Chemically they have higher aromatics, lower polyaromatic compounds and higher cycloparaffins than diesel fuel derived from conventional crude sources. These differences do not affect the performance of railway diesel engines.

In British Columbia most of the fuel delivered to locomotives is low sulphur, on-road quality diesel fuel that meets the CAN/CGSB 3.517 specification.

4.3 Overall Diesel Fuel Supply

Sixty percent of the fuel the railways purchase is sourced in Western Canada. A Canadian railway diesel fuel quality average has been calculated taking into consideration the fuel properties from the two regions and the share of the supply. As shown in Table 4, the average sulphur level is 0.10 percent. This is lower than the value used by RAC for its 1998 annual report to EC under the terms of their MOU. The current sulphur level shows a definite lowering trend for fuel being delivered to the Canadian railway industry in Eastern Canada.

5.0 FUTURE RAILWAY DIESEL FUEL

Diesel fuel will be the fuel of choice for the railways for the foreseeable future.

Future railway diesel fuel will continue to follow the trends of highway diesel fuel: that is, toward lower sulphur content. As new oil sands projects come on stream, the percentage of crude from the oil sands will increase from about 25 percent up to 50 percent or higher. Crude from the oil sands is today being pipelined to Eastern Canada and blended with conventional crude oil. Blending oil sands with conventional crude oil will increase in Eastern Canada. From a railway operating point of view, this change will have no impact.

Railway purchasing officers will always be interested in working with their suppliers to have a special railway fuel such as heating oil or higher-density fuel. This could become more difficult in the future. EC has issued a notice of intent (4) regarding the sulphur content of off-road diesel fuel, including railway, but has not yet published the sulfur value. It could, however, be set at 0.05 percent (500 ppm). Future furnace oil could have a maximum sulphur content regulated to about 0.10 percent (1000 ppm). If EC does regulate sulfur levels in railway diesel fuel to a level such as 500 ppm, then the railways will be unable to use furnace oil because of its higher sulfur content.

By 2007, on-road vehicles will require a diesel fuel with ultra-low sulphur (15 ppm maximum). The railways would most likely have on-road diesel fuel supplied for direct-to-locomotive deliveries. The overall average sulphur content of railway diesel fuel will be reduced, therefore, from the current 0.10 percent level toward 0.05 percent (500 ppm) or lower.

In the future, US EPA regulations could require on-road emissions levels for locomotives (beyond Tier 2). The technology to meet these regulations would require ultra-low sulphur fuel because of exhaust after-treatment equipment sensitivity to sulfur. In this case, sulphur levels of 15 ppm or lower in diesel fuel could become standard for locomotives.

Other fuel chemistry changes that could develop are the mixtures of methanol or ethanol (renewable resource). The railways have no experience with this type of fuel so extensive testing would be required. Alcohols have less energy per litre so operating range could be a factor. Early work indicates a 40 percent reduction in particulates and no change in NOx. Ten percent ethanol blends (emulsions) add considerably to the cost of diesel fuel. A lower flash point of 10 to15ºC is a concern.

Bioester blends are also being studied. A demonstration bioester pilot plant has been constructed in Oakville and a public transit fleet in Montreal is testing a 5-percent blend with diesel fuel. Current costs are high.

Diesel fuel emulsions with water are also reported to reduce NOx by lowering the combustion temperature. Ensuring that the water/fuel emulsion is stable over the operating temperatures in Canada is the current challenge. This could be overcome with the appropriate selection of emulsifying surfactants.

6.0 CANADIAN LOCOMOTIVE FLEET

Table 5 shows the Canadian locomotive fleet from a recent survey taken at the end of 2001. This can be compared to the fleet make-up for 1998 shown in Appendix A, (road units) and Appendix B (switcher units). It clearly indicates the reduction of the older style SD-40 type locomotives (1980s manufacture) and an increase in newer high-horsepower types. This trend will continue. Both CN and CP will continue to modernize their fleets at the rate of 40 to 100 per year. They have indicated that they will purchase locomotives that will meet US EPA Tier 1 requirements, with lower NOx and improved fuel economy. Table 6 shows the downward trend of fuel consumption using figures listed in Environment Canada's Report on Locomotive Emissions for 1997 and 1998, and the latest survey taken by the author for the year 2000.

Table 5: Canadian Locomotive Fleet – Survey for the Year 2000

Engine	HP	Total
<u>FREIGHT AND ROAD LOCOMOTIVES ONLY</u>		
EMD		
SD-75 16V-710	4300	223
SD-70 16V-710	4000	26
SD-60 16V-710	3800	63
SD-40 16V-645	3000	1006
Subtotal EMD		1318
GE		
16V-7FDL-16	4400	325
16V-7FDL-16 (Tier 0)	4400	40
16V-7FDL-16	3800	61
Subtotal GE		426
Total		1744

Source: Private survey by author.

Table 6: Canadian Railway Annual Fuel Consumption Comparison

	Million IG / year	Billion litres / year
1997 (5)	473	2.20
1998 (6)	458	2.06
1999 (7)	429	1.97
2000*	407	1.92

*Source: Private survey by author.

7.0 LOCOMOTIVE EMISSIONS

7.1 Effect of Diesel Fuel Quality on Emissions

As shown in Table 4, diesel fuel being supplied to Canadian railways is of high quality. The properties are comparable to on-road diesel fuel except for cetane number and sulfur.

Cetane number is a property that affects start-up of cold engines and cold idling. Railways, however, do not routinely shut down locomotives below 10ºC because the radiator cooling water does not contain antifreeze. Automatic locomotive restart devices have been installed on switcher type locomotives. These devices sense oil and water temperatures and do not allow the engine to cool too much before restarting the engine. Cold idle is also affected by cetane number. Tests done by the Association of American Railroads (AAR) in the early 1980s showed that locomotives idle in an acceptable manner with cetane number values above 32.

EC has issued a notice of intent to regulate the sulfur content of off-road, including railway, diesel fuel (4). Until the regulated level of sulfur in off-road vehicles has been published, the impact on future sulfur emissions remains speculative. Sources within the supply industry, however, suggest that off-road sulfur levels could be regulated at 500 ppm maximum. In this scenario, the sulfur content in railway diesel fuel would drop to below 500 ppm.

7.2 Emissions Regulations

7.2.1 United States

The U.S. Government's Clean Air Act (Section 213) directs the US EPA to adopt emissions standards for locomotives (8 to 11). As a result, in 1998 the US EPA published its *Rulemaking on Emission Standards for Locomotives and Locomotive Engines* operating in the United States (8). The rules set minimum "tailpipe" emissions standards for locomotives. The EPA Office of Mobile Sources administers the rules. The provisions include EPA certification test procedures, production compliance testing and in-use compliance testing procedures. Three levels, or Tiers, exist and apply to the date of a locomotive's original manufacture or re-manufacture.

Based on 1997 levels:
Tier 0 (1973 to 2001 locomotives), 34% NOx reduction with a cap on other pollutants.
Tier 1 (2002 to 2004 locomotives), 49% NOx reduction with a cap on other pollutants.
Tier 2 (2005 and later locomotives), 62% NOx reduction with a 50% particulate matter (PM) and hydrocarbon (HC) reduction.

The EPA emissions standards and current locomotive emission levels are listed in Table 7.

Table 7: 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 Emissions 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 total hydrocarbons (THC) for diesel engines. For locomotives and locomotive engines fuelled by alcohol or natural gas, equivalent THC standards apply.*				

7.2.2 Canada

No legislation exists in Canada for locomotive emissions; rather, RAC and EC have opted for voluntary monitoring of emissions levels.

In December 1995 RAC signed an MOU with EC (2) that required RAC to prepare an annual report on the emissions of exhaust gases from locomotives used in rail service and to provide data on the tonnage of traffic moved and fuel consumed, emissions estimates of certain exhaust gases, and information on improvements to equipment or practices that would lead to a reduction in exhaust emissions. RAC agreed to voluntarily cap NOx emissions at 1989 levels between 1990 and 2005.

Locomotive emissions fall under the terms of the Canadian Railway Safety Act. Responsibility for monitoring locomotive emissions has recently been transferred from EC to Transport Canada.

The annual RAC reporting quantifies the NOx emissions relative to gross ton miles (GTM) and net ton miles (NTM) for freight services and per passenger mile for passenger services. In addition to reporting on emissions across Canada, the MOU requires RAC to report on emissions in the three densely populated Troposphere Ozone Management Areas where NOx emissions, and hence ground-level ozone, are more critical and of more concern. These are the Quebec-Windsor corridor, the Lower Fraser Valley and the Southern Atlantic Region. The reporting takes into consideration seasonal variations in railway traffic in these designated areas.

The latest EC report on locomotive emissions (6) published in 2000 is for 1998 and shows that while the tonnage of freight traffic is increasing, fuel consumption is decreasing and the annual tonnage of NOx is little changed from previous years.

7.3 Locomotive Emissions Measurements

To calculate the weight of emissions for each chemical compound, it was necessary to determine, from published sources, the emissions levels for each type of locomotive in the Canadian fleet (12 to 25). The emissions values shown in Table 7 are for freight locomotives and were taken from AAR, Southwest Research Institute and US EPA reports.

7.3.1 Freight Service

Freight locomotives consume approximately 90 percent of the railway diesel fuel in Canada. The types of locomotives used in Canada have been grouped together in Table 8 with the corresponding number of locomotives for each category and the emissions values for each pollutant. The brake specific duty cycle has been calculated in both lb/bhp-hr and IG/bhp-hr.

Table 9 shows the conversion to an emissions factor for each pollutant. The emissions factor is the amount of pollutant, in grams per Imperial gallon (g/IG), generated over the operational duty cycle of the locomotive. Table 10 shows the amount of emissions, in kilo-tonnes, calculated by locomotive type. In Table 11, the values have been converted to percentage weighted average. The weighting has been calculated from the percentage of fuel consumed per locomotive type.

As can be seen, the SD-40 type locomotives still represent a large percentage of the Canadian fleet and are responsible for approximately 50 percent of the locomotive emissions load of every pollutant type except for particulate matter, for which they represent over 60 percent.

As new fuel-efficient locomotives that meet Tier 1 standards or higher are purchased in Canada, the SD-40 fleet will be reduced in number. The new locomotives have lower fuel consumption and lower NOx levels. The rate of locomotive replacement will determine how quickly the overall level of NOx decreases from the current cap of 155 kilo-tonnes. At the current rate of locomotive replacement of 40 to 100 per year, it could take a minimum of 10 years to replace the SD-40 fleet.

Table 8: Freight Engines and Emissions Values

Model	Engine	HP	Number in Fleet	bsfc lb/bhp-hr	bsfc IG/bhp-hr	Reported Emissions Levels NOx (g/bhp-hr)	CO	HC	PM
EMD SD-40	645E3B	3000	1006	0.4052	0.0479	11.8	1.5	0.27	0.20
EMD SD-60	710G3	3800	63	(0.3600)	0.0420	10.3	2.0	0.26	0.24
EMD SD-70	710G3C	4000	26	0.3500	0.0409	13.0	0.6	0.28	0.23
EMD SD-75	710G3EC	4300	223	0.3380	0.0402	13.3	1.0	0.30	0.20
GE Dash 8	7FDL	3800	61	(0.3600)	0.0420	12.4	4.8	0.48	nd
GE Dash 9	7FDL	4400	325	0.3530	0.0416	11.3	1.4	0.21	0.11
GE Dash 9	7FDL (Tier 0)	4400	40	0.3530	0.0416	9.5	1.4	0.21	0.11
		Total	1744						

Table 9: Calculated Emissions Factors – Freight Locomotives

Model	Engine	Emissions Factor NOx (g/IG)	CO	HC	PM
EMD SD-40	645E3B	246.3	31.3	5.64	4.18
EMD SD-60	710G3	245.2	47.6	6.19	5.71
EMD SD-70	710G3C	317.8	14.7	6.85	5.62
EMD SD-75	710G3EC	330.8	24.9	7.46	4.98
GE Dash 8	7FDL	295.2	114.3	11.43	nd
GE Dash 9	7FDL	271.6	33.7	5.05	2.64
GE Dash 9	7FDL (Tier 0)	228.4	33.7	5.05	2.64

Table 10: Annual Tonnage of Emissions by Locomotive Type (Weighted)

Model	Engine	HP	Number in Fleet*	Fuel Cons. Lb/hr	Fuel Cons. IG/hr	Fuel Cons. IG/yr** (MM)	Atmospheric Load NOx	CO	HC	PM
							Kilo-tonnes			
EMD SD-40	645E3B	3000	1006	297	35	211	52	6.60	1.19	0.88
EMD SD-60	710G3	3800	63	330	39	19	5	0.90	0.12	0.11
EMD SD-70	710G3C	4000	26	337	40	6	2	0.09	0.04	0.03
EMD SD-75	710G3EC	4300	223	346	41	48	16	1.04	0.31	0.21
GE Dash 8	7FDL	3800	61	350	41	15	5	1.76	0.18	nd
GE Dash 9	7FDL	4400	325	363	43	73	20	2.44	0.37	0.19
GE Dash 9	7FDL (Tier 0)	4400	40	363	43	10	2	0.35	0.05	0.03
					Totals	382	102	13.18	2.26	1.45

* 2000 survey of fleet
** Assume 70% utilization

Table 11: Percent of Emissions by Locomotive Type (Weighted)

			Number in Fleet*	Fuel Cons. Lb/hr	Fuel Cons. IG/hr	Fuel Cons. IG/yr (MM)	Atmospheric Load NOx	CO	HC	PM
							Weighted Average (percent)			
EMD SD-40	645E3B	3000	1006	297	35	211	51	50	53	61
EMD SD-60	710G3	3800	63	330	39	19	5	7	5	8
EMD SD-70	710G3C	4000	26	337	40	6	2	1	2	2
EMD SD-75	710G3EC	4400	223	346	41	48	15	8	14	14
GE Dash 8	7FDL	3800	61	350	41	15	5	13	8	nd
GE Dash 9	7FDL	4400	325	363	43	73	20	19	16	13
GE Dash 9	7FDL (Tier 0)	4400	40	363	43	10	2	3	2	2

*Source: Private survey by author

8.0 CONCLUSIONS

Canadian railways in freight service have taken advantage of the tolerance of their locomotive engines to some diesel fuel properties. Consequently, diesel fuel, with lower cetane number and higher aromatics content, is standard for freight locomotives. Sulfur content could be regulated by the end of 2010. This would have an impact on the current use of heating oil (furnace oil) by some Canadian railways because home heating oil and railway diesel fuel could be regulated at different levels.

The Canadian locomotive fleet has changed significantly in the past 10 years to higher horsepower, more fuel-efficient engines. The fuel consumption of freight locomotives has dropped significantly even though freight tonnage has increased. This has kept locomotive emissions, particularly NOx, at 1989 levels. The railways are therefore meeting their commitment as outlined in the MOU with EC regarding locomotive emissions.

Locomotive emissions from older locomotives (1980s manufacture) represent approximately 50 percent of the emissions from the Canadian locomotive fleet. A continuous reduction in locomotive emissions should take place, depending on traffic increase and modal shift, as the railways replace their fleets on a 2 for 3 basis at a rate of 40 to 100 per year, with locomotives meeting US EPA Tier 1 or Tier 2 regulations.

9.0 RECOMMENDATIONS

The recommendations stemming from this review are:

a. Transport Canada should be an active participant in US EPA, U.S. Department of Energy and AAR initiatives in developing future Tier 3 and Tier 4 locomotive emissions standards.

b. Discussions should be held with RAC to develop future Canadian locomotive emissions objectives and a strategy to achieve these objectives.

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Appendix A: Canadian Locomotive Fleet – Mainline and Branchline – 1998

Engine	**HP**		**Year**	**Total**	CN	CP	VIA Rail	BC Rail	GO Transit	Other
ROAD LOCOMOTIVES										
EMD										
20V645E3	3200			6						6
16V710G3B	4300	EFI	96-99	167	139	28				
16V-710G3B	4000	EFI	90-92	26	26					
16V-710G3B	3800	EFI	85-89	63	63					
16V-710G3(A)	3600	EFI	88-95	45					45	
16V-645F3B	3600		85-94	66	60					6
16V-645E3B	3000		85-87	23				23		
16V-645E3C	3000			58			58			
16V-645E3M	3000		1988	0						
16V-645E3	3000		66-80	1140	523	569				48
16V-645D3A	2250		64-66	18		2				16
16V-645D3	2250		1963	0						
Subtotal EMD				1612	811	599	58	23	45	76
MLW										
16V-251F	3700		70-84	7			7			
16V-251F	3600		69-82	24						24
16V-251E	3000		67-76	9						9
16V-251B	2400		63-66	1		1				
Subtotal MLW				41	0	1	7	0	0	33
GE										
16V-7FDL-16	4400		94-95	317	103	184		30		
16V-7FDL-16	4000		90-94	58	55					3
16V-FDL-16	3600		1980	3				3		
12V-7FDL-12	2250		89-90	5				5		
12V-7FDL-12	3000		1979	0				10		3
Subtotal GE				383	158	184	0	48	0	6
Caterpillar										
3516	2075		1994	3						3
Subtotal Caterpillar				3						3
BUDD-RDC				21			6	9		6
Total Mainline & Branchline				2060	969	784	71	80	45	124

Source: Locomotive Emissions Monitoring Program – 1998. Compiled and published jointly by Environment Canada and the Railway Association of Canada.

Appendix B: Canadian Locomotives Fleet – Yard and Switcher – 1998

Engine	**HP**	**Year**	**Total**	CN	CP	VIA Rail	BC Rail	GO Transit	Other
SWITCHER									
EMD									
16V-645E	2000	71-75, 86	288	110	129				49
16V-645C	1800	54-67	175	162		7			6
16V-645C	1750	75-81	202		202				
16V-645B/C	1500	81-94	10		10				
16V-645D	1500	52	0						
16V-567C	1750	51-53	59		3				56
16V-567B	1500	51-52, 78	9						9
12V-645E	1500	71-80	4						4
12V-645C	1350	87-89	117	117					
12V-645C	1200	81-85	24		24				
12V-567C	1200	55-60	103	61	33				9
8V-645E	1000	66-67	2			2			
8V-645C	1000	67-69	0						
8V-567C	900	51-64	13		1				12
8V-567B	800	51-54	1						1
Total EMD			1007	450	402	9	0	0	146
MLW									
12V-251C3	2000	73-81	2						2
12V-251C	2000	64-76	24				4		20
12V-251C	1800	66	2				2		
12V-251B	1800	56-65	52						52
12V-251B	1400	59-60	2						2
6I-251B/C	1000	59-60	18						18
6I-539	1000	48-58	0						
Total MLW			100	0	0	0	6	0	94
Caterpillar									
12V-3512	2000		33		6		27		
Total Caterpillar			33		6		27		
Total Yard & Switcher			1140	450	408	9	33	0	240

Source: Locomotive Emissions Monitoring Program – 1998. Compiled and published jointly by Environment Canada and the Railway Association of Canada.