Trucks and Air Emissions

September 2001
Final Report

EPS 2/TS/14 - September 2001
Air Pollution Prevention Directorate
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Introduction

This document brings together an assortment of facts and figures about trucks, their activities and the impact of those activities on the Canadian environment. It is designed as a general primer on the subject. Readers who wish to learn more are encouraged to access the referenced documents and agencies.

Trucks play a key role in our society and are important in maintaining our standard of living. They are responsible for virtually all final deliveries of everything we buy, from cars to food. In addition, all our municipal service providers rely on trucks to build and repair roads and to install and maintain telephone and electricity lines. The technology that is designed into trucks is often leading edge: advanced electronic controls and diagnostics, driver management systems and satellite communications are commonplace in large fleets. This technology has been introduced not just for operational efficiency but also to control the engine's performance and reduce vehicle emissions. Since the 1970s, trucks have reduced their emissions by over 80%, decreased their fuel consumption rate by 50% and increased their payload efficiency, as measured in litres/tonnes per kilometre (L/t-km), by 300%.

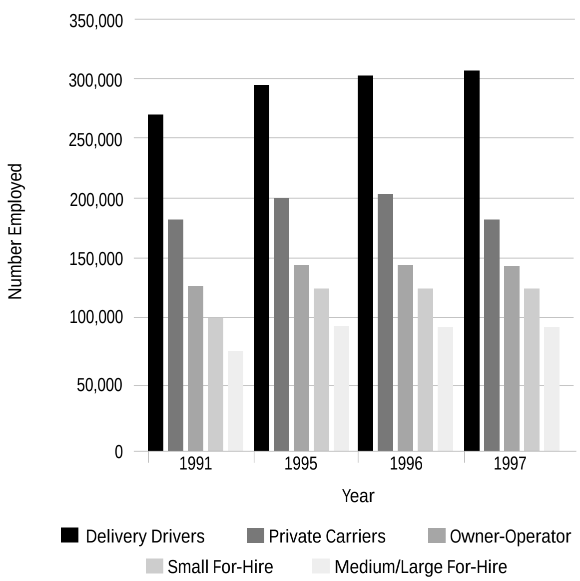
Despite these advances, trucks are still contributing a significant portion of air emissions in Canada. To reduce the impact, governments at all levels are continuing to tighten the standards for both new and in-service vehicles. Trucks in the future will be used even more and will pollute less through the adoption of new technologies and fuels. The resulting increased costs of owning and operating vehicles will flow through the economy as slightly higher transportation costs. However, the benefits will be tangible in cleaner air in our cities and a reduction in the health costs imposed by air pollution.

Trucks and Trucking in Canada

Economic Importance

Currently, trucking in Canada is a $40-billion industry that employs close to 400,000 Canadians. As seen in **Figure 1**, over 300,000 of these are employed directly in the trucking industry; the balance are employed in the heavy vehicle industry, in manufacturing, sales, support and parts[1]. Trucks move 90% of all consumer products and foodstuffs within Canada.

Figure 1 | **Employment in the Canadian Trucking Industry**



Trade is a major factor in Canada's economic growth, and Canada's trade with the United States represents 80% of our total international trade. With most major centres in the U.S. industrial heartland often less than one day's truck drive away, it is not surprising that trucks haul the vast majority of Canada's exports and imports. More than 70%, by value, of Canada's trade with the United States is shipped by truck. Without trucking, our standard of living would be lower and Canadians would be unable to enjoy many of their favourite consumer products.

Other facts about trucking in Canada are:

- Truck traffic across the Canada-United States border averages one truck every three seconds.
- Trucks carry more than $30 million in exports and imports across the border every hour.
- There are over 12,500 Canadian trucks using satellite communications.
- "Truck driver" was the most frequently listed occupation for males in the last census.
- Trucks carry 75%, by value, of all Canadian manufactured goods.
- There are over 612,000 truck trips a week on Canada's main highway network.

All forecasts point to an even greater reliance on trucks in the future. Transport Canada research suggests that for-hire truck traffic will increase by twice the rate of the rail and marine modes in the coming decade[2]. The overall market share of trucking could rise by 12% over the same period, while the shares of the rail and marine modes will decline.

Vehicle Populations and Demographics

Vehicle population data are derived from vehicle registration files, and as weight is a key defining factor in both the fees paid and operational characteristics, the gross vehicle weight (GVW)[3] is used to classify trucks. **Figure 2** presents the standard eight-class GVW segmentation system used throughout North America and illustrates some of the types of truck bodies and applications that are typical of the weight classes.

[1] Transport Canada, *Transportation in Canada 1999*, Annual Report, TP13198E.

[2] Transport Canada, Economic Analysis Branch, Marine and Surface Statistics and Forecasts (ACAC).

[3] This is the maximum allowable weight of the truck and includes the tare or empty weight plus payload weight.

Figure 2 | **Vehicle Weight Classification System**

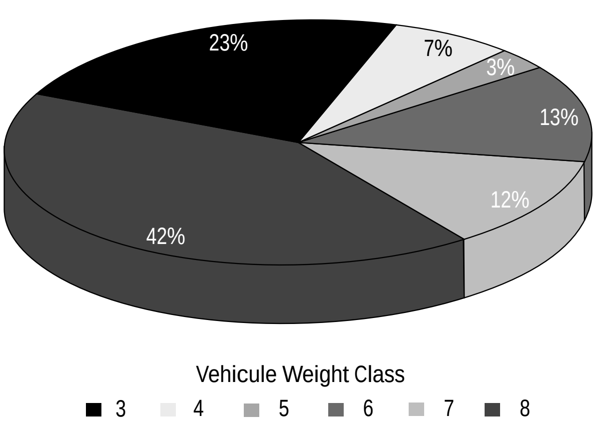
Gross Vehicle Weight (lbs) *	Weight Classes	VIUS ** Categories	Vehicle Type
33,001 or greater	Class 8	Heavy-Heavy	Dump; Cement; Heavy Tandem Conventional
26,001-33,000	Class 7	“	Fuel; Recycling; Medium Conventional
19,501-26,000	Class 6	Light-Heavy	Stake; Beverage; Single-Axle Van
16,001-19,500	Class 5	Medium-Duty	Short-Nose Conventional with Van Body; Cab Forward with Van Body; Wide-in Van
14,001-16,000	Class 4	“	
10,001-14,000	Class 3	“	
6,001-10,000	Class 2	Light-Duty	Pickup; Cargo Van; Mini Van
6,000 or less	Class 1	“	

* Includes weight of empty vehicle plus payload.
** VIUS • U.S. Department of Transportation Vehicle Inventory and Use Survey.

Registered Commercial Vehicles

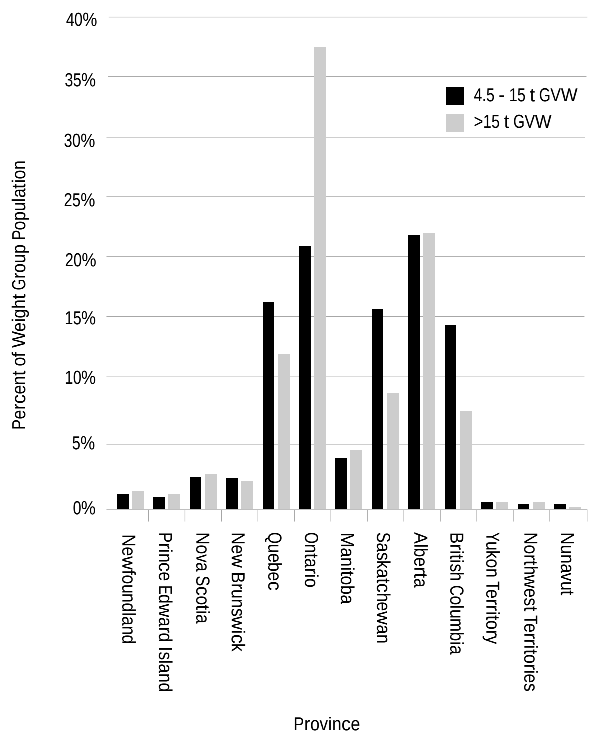
Commercial trucks are usually defined as vehicles over 10,000 pounds or 4.5 tonnes (Class 3). Trucks below this weight limit, while they may be used for commercial purposes, are most often privately owned vans or pick-up trucks. These lighter vehicles fall within the emissions and safety regulations of light-duty vehicles. Commercial vehicle populations in 1998 – the most recent year for which estimates (derived from provincial vehicle registration files) are available – stood at approximately 711,000. As seen in **Figure 3**, the majority of these (54%) are large vehicles in the Class 7 and 8 weight range.

Figure 3 | **Percentage Distribution by Weight of Canadian. Medium- and Heavy-Duty Trucks**



As trucks are directly related to economic activity, it is not surprising that the population distribution of vehicles within Canada mirrors the size and economic wealth of Canada's provinces. As seen in **Figure 4**, Ontario has the largest truck fleet, followed by Alberta. Ontario is the clear leader in the big Class 8 trucks, with 38% of the entire Canadian population. However, when the smaller trucks are segmented, Alberta and Ontario are essentially tied, at 22% for Ontario and 23% for Alberta, and Quebec and Saskatchewan are a close second at 16% each.[4] Most of these smaller trucks are used for agricultural purposes in the prairie region.

Figure 4 | **Truck Population Distribution by Province**



The age of trucks is important in assessing their environmental and energy impact. New vehicles are manufactured to higher performance standards and thus have a relatively lower impact on both air pollution and energy use. The operating fleet can be broadly divided into three main types of operations:

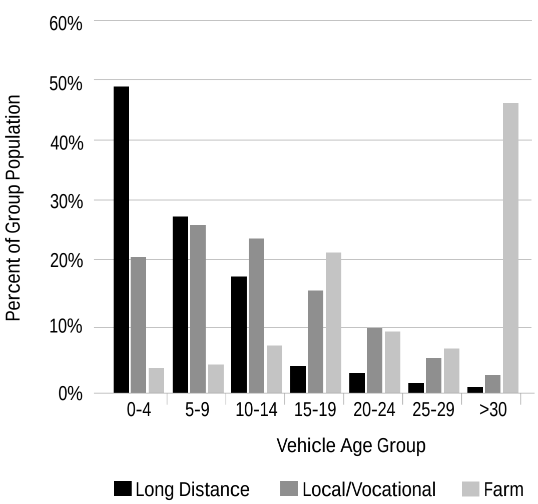
- commercial carriers engaged in long-distance freight movement;

[4] Statistics Canada, *Canadian Vehicle Survey*, 4th quarter, 1999.

- locally operating trucks such as dump trucks and municipal vehicles; and
- agricultural vehicles used for hauling fertilizers, grains and produce.

Each of these groups has different age and operational characteristics. The long-haul truckers work in a fiercely competitive marketplace and thus have to have the best and most efficient equipment possible to keep their operating costs low. In part they have done this by owning a relatively young stock of vehicles. As can be seen in **Figure 5**, almost 50% of long-haul trucks are less than four years old. In comparison, only 20% of local/vocational vehicles are less than four years old, and 56% are more than 10 years old. The agricultural sector has the oldest trucks, with an estimated 90% more than 10 years old.

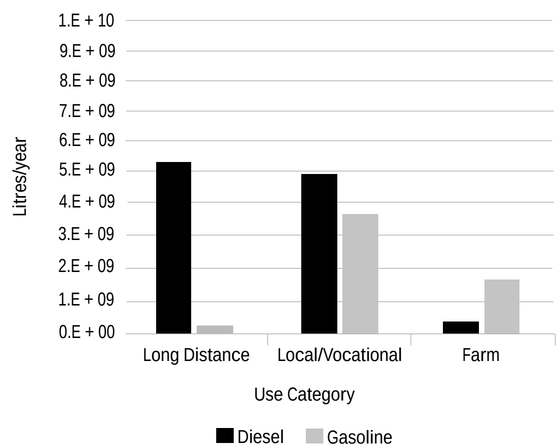
Figure 5 | **Age Distribution of Trucks**



Fortunately, the farm vehicles are used only about one tenth as much as the long-haul trucks, which average over 160,000 km a year. When the age, size, fuel and usage data on trucks are integrated into an estimate of the fuel use by each of these three groups, the results (see **Figure 6**) show that:[5]

- local and vocational trucks use the most fuel at 54% of the total;
- 64% of all trucking fuel used is diesel;
- 93% of all long-haul truck fuel is diesel (51% of all diesel);
- 66% of all truck gasoline is used by local/ vocational trucks; and
- over 80% of the fuel used in farming is gasoline.

Figure 6 | **Estimated Distribution of Fuel Use by Commercial Vehicle Use**



Freight Movements

Highly accurate numbers on the use of trucks in freight transport are difficult to assemble in Canada as the private trucking community is not well surveyed. There is substantially more information about the for-hire sector.

Table 1 shows that 429 million tonnes of freight were moved within Canada in 1998.[6] Rail and marine realized over 70% of their activity in the shipping of primary goods and crude materials, while for-hire trucking realized about the same but in manufactured and fabricated materials.

[5] Taylor, G., *The Potential for GHG Reductions from Scrappage Programs for Older Trucks and Engines*, National Climate Change Program, Transportation Table, Trucking Sub-Group, 1999.

[6] Transport Canada, *Transportation in Canada, 1999*, TP13198E.

Table 1 Freight Movement in Canada, 1998

Commodity	Domestic Transportation Flows (Millions of Tonnes)				
	Rail	Marine	For-Hire Trucks	Air	Total
Primary Products					
Grains	26.0	5.2	4.7	-	35.9
Forest Products	19.6	8.7	27.5	-	55.8
Metallic Ores	49.2	7.1	1.3	-	57.6
Non-metallic Minerals	21.5	10.7	13.8	-	46.0
Minerals Fuels	38.8	1.7	5.2	-	45.7
Sub-Total	**155.1**	**33.4**	**52.5**	-	**241.0**
Manufacured Products	47.3	14.9	125.3	0.5	188.0
Total, All Products	**202.4**	**48.3**	**177.8**	**0.5**	**429.0**

Table 2 For-Hire Trucking Activity by Commodity, 1998

Commodity	For-Hire Trucking Activity Revenues					
	Domestic		International		Total	
	(Millions)	%	(Millions)	%	(Millions)	%
General Freight	$2,657.10	41.5	$2,243.10	46.3	$4,900.20	43.6
Food Products	1,186.50	18.5	633.20	13.1	1,819.60	16.2
Forest Products	871.20	13.6	735.40	15.2	1,606.60	14.3
Automotive Products	350.50	5.5	561.30	11.6	911.80	8.1
Steel & Alloys	395.80	6.2	359.70	7.4	755.40	6.7
Chemical Products	368.30	5.8	220.30	4.5	588.50	5.2
Petroleum Products	343.60	5.4	42.00	0.9	385.60	3.4
Non-metallic Minerals	205.40	3.2	44.90	0.9	250.30	2.2
Metals/Ores	22.90	0.4	7.30	0.1	30.20	0.3
Total Revenues	**$6,401.20**	**100**	**$4,847.20**	**100**	**$11,248.40**	**100**

The trucking share would be higher if the activities of small for-hire carriers, private trucking carriers and owner-operators could be taken into account. One study has estimated that the private trucking industry had revenues of $15.4 billion in 1993.[7] Of this total, $12 billion, or 78%, was in urban areas. In addition, in urban areas such as Montreal, 37% of all the private trucks were municipal or utility vehicles that deliver services as opposed to goods. It is important to note that long-haul highway trucks tend to be newer than the urban fleet, as mentioned above, and thus the highway fleet not only incorporates the best and latest technology for fuel efficiency but also has the newest emissions control systems.

In terms of long-distance traffic volume measured by tonne-kilometres (t-km), general freight accounted for 26.4 billion t-km domestically, or 34.5% of all domestic traffic, and 24.3 billion t-km to the United States and Mexico, or 39.5% of all international traffic. Combined, this represented almost 37% of total tonne-kilometres in 1998.

In aggregate, general freight, food products and forest products accounted for almost 75% of long-distance carriers' total tonne-kilometres in 1998. **Table 2** shows the volume of for-hire trucking traffic by major commodity group for 1998.

Vehicle Manufacture

The truck manufacturing industry is also an important aspect of the Canadian economy. While the truck manufacturing industry is global in nature, a number of assembly plants in Canada supply truck products to Canadians and to our NAFTA trading partners. These companies include:

- Freightliner Corporation – a division of Daimler-Chrysler;
- International Transportation Equipment Corp. (Navistar);
- Kenworth Trucks – a division of the Paccar Group; and
- Western Star Trucks – recently acquired by Freightliner Corp.

In addition to these manufacturers of basic truck chassis, there are over 2,000 companies involved in manufacturing finishing components for trucks such as dump bodies, van bodies, etc., and trailers that are pulled by the truck "tractor." These trailers can be in a variety of configurations including a dry freight van, refrigerated van, flat deck, stake van, etc. These manufacturers are located throughout Canada and provide local product manufacturing, service and support. There are no manufacturing facilities for large diesel engines at present in Canada.

[7] ADI Ltd., *Profile of Canada's Private Trucking*, Industry Canada, Automotive Branch, 1995.

Emissions from Trucks

Engines that power trucks are designed to operate on gasoline or diesel fuel. Diesel is the fuel of choice for vehicles with high utilization, such as long-distance trucks, because the diesel engine is the most efficient of all known types of internal combustion engine. All over the world, heavy trucks, urban buses and industrial equipment are powered almost exclusively by diesel engines. Although the diesel engine currently has significant environmental impacts, there will be some important progress in diesel emission control over the next decade, and the diesel engine is likely to remain the dominant engine in the future.

Emission Fundamentals

Internal combustion engines are large contributors to air pollution, which has a damaging impact on our health and the environment and is suspected of causing global climate changes. All internal combustion engines produce emissions of:

- hydrocarbons (HC), which are partially burned fuel – these are also called volatile organic compounds (VOCs);
- carbon monoxide (CO), which is a product of an incomplete combustion of carbon;
- nitrogen oxides (NOx), which are the product of high-temperature combustion of nitrogen (present in air);
- particulates or particulate matter (PM), which are agglomerations of fuel soot and sulphur particulates caused by incomplete combustion;
- carbon dioxide (CO_2), which is the complete combustion product of carbon in the fuel;
- sulphur oxides (SOx), which are created by the combustion of the sulphur contained in fuel, especially diesel fuel; and
- greenhouse gases (GHGs), which include CO_2, CO and NOx.

The first four of these pollutants are regulated under the current emission standards throughout the world. The other pollutants have been considered for regulations, as have other constituents of emissions that have toxic environmental effects.

Current Emission Estimates

Emissions from vehicles are the result of vehicle use; thus, the number of vehicles, their vintage, fuel, type, usage pattern and location (terrain and climate) all affect emissions. Environment Canada, through modelling of the vehicle fleet, has developed estimates of the total annual emissions from trucks in Canada. Emissions from all gasoline- and diesel-powered vehicles are a major source of air pollution, on a national basis contributing 32% of CO, 32% of NOx and 16% of VOCs. Trucks, however, produce only a small portion of this total. **Figure 7** indicates the percentage contribution of heavy vehicles to transportation emissions and shows that the major pollutants from trucks are particulates, SOx and NOx, while VOCs and CO are a relatively small portion of total truck emissions. In the National Emissions Inventory for 1995, heavy-duty vehicles accounted for 0.2% of particulate emissions, 1.7% of hydrocarbons (VOCs), 2.3% of CO, 2% of SOx and 16% of NOx.[8] **Table 3** includes a breakdown of these estimates for road vehicles.

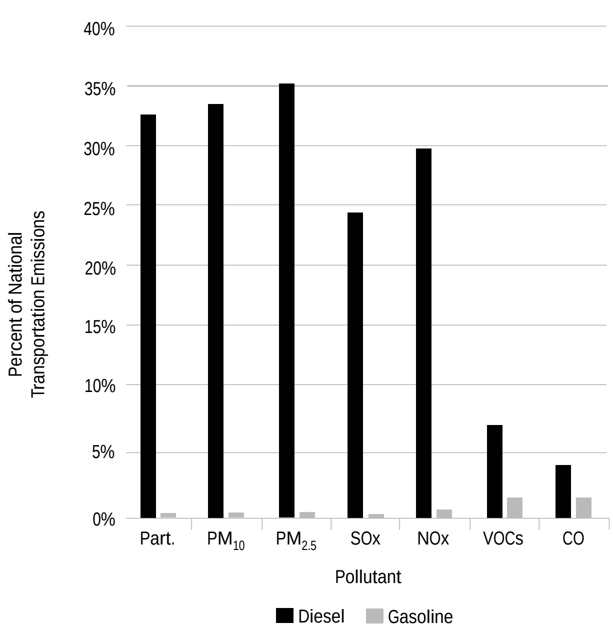
[8] Environment Canada, *1995 Emissions Inventory of Criteria Air Contaminants*, Ottawa, 1998.

Table 3 | 1995 Estimates of Total Canadian Emissions

Vehicle and Fuel Class	Annual Emissions (Tonnes)						
	Part.	PM_{10}	$PM_{2.5}$	SOx	NOx	VOCs	CO
Air Transportation	2,018	1,115	787	2,263	34,026	11,636	61,758
Heavy-Duty Diesel Vehicles	32,075	32,075	29,498	32,807	378,300	48,540	224,438
Heavy-Duty Gasoline Trucks	545	528	414	588	15,073	11,814	164,787
Light-Duty Diesel Trucks	1,304	1,304	1,203	1,535	5,567	2,600	4,626
Light-Duty Diesel Vehicles	379	379	347	632	1,978	747	1,667
Light-Duty Gasoline Trucks	2,586	2,509	1,986	4,399	112,437	142,425	1,461,808
Light-Duty Gasoline Vehicles	4,870	4,717	3,256	11,048	273,396	355,873	3,558,667
Marine Transportation	8,438	8,129	7,379	58,000	118,578	37,449	103,310
Motorcycles	16	16	11	34	630	2,027	10,873
Off-Road Use of Diesel	17,081	17,081	15,714	16,149	209,231	22,581	66,365
Off-Road Use of Gasoline	4,414	3,867	3,393	1,005	25,395	93,111	1,027,393
Rail Transportation	19,492	19,492	17,933	7,226	115,604	5,608	22,022
Tire Wear and Brake Lining	4,362	4,313	1,353	–	–	–	–
Total Transportation	**97,580**	**95,524**	**83,276**	**135,686**	**1,290,214**	**734,412**	**6,707,715**

PM_{10} = particles with aerodynamic diameter less than or equal to 10 micrometres.
$PM_{2.5}$ = particles with aerodynamic diameter less than or equal to 2.5 micrometres.

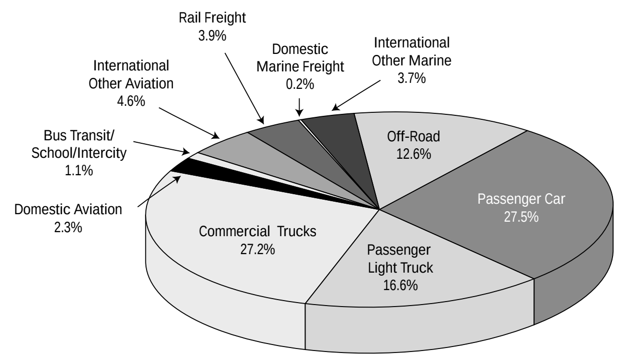
Figure 7 | Heavy-Duty Truck Emission Contributions



In 1996, diesel engines in trucks, and a few other vehicles, used 10.9 billion litres of diesel. This constitutes 5% of the demand for energy in Canada, 12.5% of the demand for refined petroleum products, and 24% of the demand for energy by road users.

Trucks contributed an estimated 27% of the total transportation emissions of greenhouse gases in 1997, as seen in **Figure 8**.

Figure 8 | Source of Transportation Greenhouse Gas Emissions, 1997



Source: *Transportation and Climate Change: Options for Action.* National Climate Change Program, Transportation Table, November, 1999.

Inter-modal Emission Comparisons

Freight transportation services in Canada are provided by road vehicles, railways, ships and aircraft. Discussions about which mode pollutes the least are fraught with methodological problems. The four modes compete for the freight transport market, and each mode has its own service characteristics that determine in which goods and regions it is most economically competitive.

Air freight, for instance, tends to be restricted to very light or high-value cargo. On the other end of the spectrum, inland marine freight consists of bulk commodities such as iron ore, coal and oil. Marine is also the prime mode for North American imports and exports. Trucks, because of their high mobility and relatively small unit size, are the preferred shipping mode for most manufactured goods and foods. Finally, rail competes best on long-haul routes and for bulk resource movements. For most industrial goods and produce, rail cannot operate without trucks, which deliver the goods to and from the railhead. Because of this, often road and rail collaborate by providing an intermodal shipping service, such as Canadian Pacific Railway's “Expressway,” which is targeted at short – and medium-distance transport.

Which mode – road or rail – has the lowest emissions on a particular route? The complexity of the transport chain makes simple comparisons faulty. While rail has usually been found to be the most energy efficient or lowest emitter on single long-distance links, this type of route represents only a small portion of the total transport flow and the finding ignores the distribution issues at the rail end points. It also does not account for such confounding issues as:

- the nature of the cargo (e.g. lettuce versus gravel) – not all commodities have the same density or value;
- circuitry – not all routes are direct, and data exist that indicate that as much as 31% of rail or 15% of truck kilometres are extra due to route circuitry;
- service speed and/or frequency; and
- shipment loss and/or damage.

The basic emission standards for the two modes are compared in **Table 4**. Truck emission rates are significantly lower for PM and NOx but higher for HC and CO. The higher values for HC and CO are caused by the differences in test cycle – the truck driving cycle is much more dynamic than that of a train, which has more constant speed operations. The higher speed variability causes higher emissions over the test cycle; however, in constant load tests, the truck CO and HC emissions would be at or below those of rail.

Truck fuel efficiency has more than doubled in the last 20 years, while emissions have been reduced. Thus a 34,000-kilogram (kg) truck can squeeze 2.3 times as many kilometres out of a litre of fuel in 2001 as it could in 1975.[10]

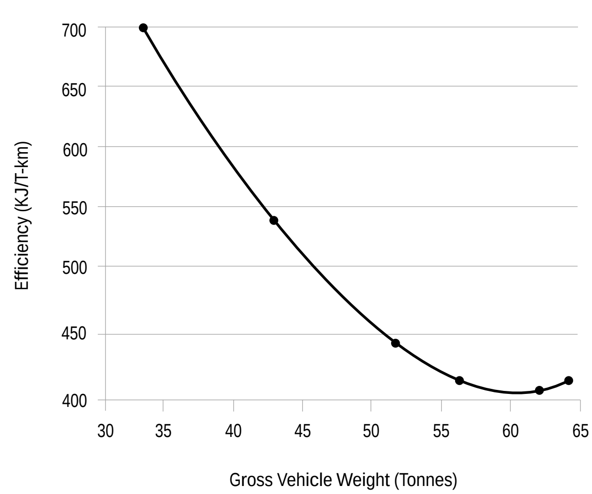
Table 4 | Truck versus Locomotive Emission Rate Comparison

Engine Type	Test Cycle	Emission Rates for 2000 Engines (g/bhp-hr)[9]			
		HC	CO	NOx	PM
Truck Engines	Transient Cycle	1.30	15.50	4.00	0.10
Locomotives	Line-haul	0.48	1.28	8.60	0.32
Locomotives	Switch	1.01	1.83	12.60	0.44

But this is only half the story. While trucks have become more fuel efficient, they have also become larger. In 1975, most of the freight in Canada moved on five-axle tractor-semitrailers with 35- or 40-foot trailers. Today, while five-axle tractor-semitrailers are still common, a great deal of domestic freight is handled by trucks with six or more axles. Trailer lengths are now much longer – the standard for much of the industry is 16.2 metres (53 feet) – and there are double- and even triple-trailer units in use in some places. To put this improvement in fuel consumption in context, consider that, in 1975, a typical load of a little over 20 tonnes could be handled for about 36.1 litres of fuel per thousand tonne-kilometres. In 1995, a typical load of 30 tonnes can be handled with 13.3 litres per thousand tonne-kilometres. This is almost a threefold increase, and the comparison considers only typical loads.

There are many really big trucks today that do considerably better. **Figure 9** demonstrates how fuel consumption rates decrease as truck weight increases. These data are for reasonably dense freight (over 200 kg per cubic metre). Freight on an eight-axle B-train (a long combination vehicle made up of a tractor pulling two semitrailers) operating at 62,500 kg uses 36% less fuel per tonne hauled than it would on a four-axle tractor-semitrailer operating at 31,600 kg.

Figure 9 | Truck Weight and Efficiency



[9] G/bhp-hr = grams per brake horsepower per hour. Based on U.S. Environmental Protection Agency new vehicle and locomotive standards.

[10] Portions of the material in this section were extracted with permission from Nix, F. and LeBlanc, M, *Trucking in Canada*, Canadian Trucking Research Institute, Ottawa, 1995.

[11] Nix, F., *Trucks and Energy Use*, Canadian Trucking Association, Ottawa, 1991.

Emissions Control Programs

The California government in 1959 started the control of vehicle emissions. Canada adopted its first set of vehicle standards in the early 1970s, following the lead of the U.S. Environmental Protection Agency (EPA). Since that time, Canadian standards have closely paralleled U.S. standards. There have been some differences, however, due to regulatory process delays or decisions to wait for control technology to be developed and validated before it is imposed on Canadian new-vehicle purchasers.

Vehicle emissions are controlled through both vehicle manufacturing standards and in-service performance tests. Before the vehicle or engine can be sold, it must be certified by the manufacturer as meeting the emission standards in force at the time of its manufacture. The standards are defined in terms of the maximum mass of emissions per distance travelled in the case of light-duty vehicles (less than 3,855 kg) or brake horsepower per hour (bhp-hr) in the case of heavy-duty vehicles. The federal government regulates the emission standards for new vehicles, while the provinces have jurisdiction over in-service vehicles. The standards for new-vehicle emissions were originally set out under regulations in the Motor Vehicle Safety Act, which is administered by Transport Canada, with the emissions components of the act administered by Environment Canada. Recently, full responsibility for emission regulations has been transferred to Environment Canada under the *Canadian Environmental Protection Act, 1999*.

It is difficult for Canada to have significantly different standards from the United States because of the concentration of vehicle design and manufacture in U.S. plants and the large amount of cross-border trade, which demands compliance with U.S. standards.

North American Standards

The following emission standards[12] apply to new diesel engines used in heavy-duty highway vehicles. Virtually all large trucks use diesel engines. The current definition of a compression-ignition (diesel) engine is based on the engine cycle, rather than the ignition mechanism, with the presence of a throttle as an indicator to distinguish between diesel-cycle (compression-ignition) and Otto-cycle (spark-ignited) operation. Regulating power by controlling the fuel supply in lieu of a throttle corresponds with fuel lean combustion and the diesel-cycle operation. (This allows a natural gas-fuelled engine equipped with a spark plug to be considered a compression-ignition engine.)

In the U.S. and Canadian standards, heavy-duty vehicles are defined as vehicles of gross vehicle weight (GVW) above 3,855 kg. In the United States, under the light-duty Tier 2 regulation (to be phased in beginning in 2004), some vehicles of GVW up to 4,545 kg have been reclassified as “medium-duty passenger vehicles” and are subject to the light-duty vehicle legislation.

As with light-duty passenger vehicles, the regulations are based on collecting and measuring the total emissions from a vehicle or engine over a driving cycle. The driving cycles used have been developed and refined to provide a reasonable estimate of the total operating regime in which the vehicle will be operated. The idea is to control emissions in all possible operating modes and thus reduce the total emissions. For light-duty vehicles, the whole vehicle is tested on a dynamometer that simulates road driving conditions. For heavy-duty vehicles, because of the historical lack of truck-size dynamometers and the fact that truck engines are used in stationary as well as mobile applications, only the engine is tested on an engine dynamometer. As a consequence of this testing difference, the basic standards for engine-based certification are expressed in g/bhp-hr and require emission testing over the transient federal test procedure (FTP) engine dynamometer cycle that simulates actual use. However, chassis certification may be required for complete heavy-duty gasoline vehicles, with pertinent emission standards expressed in g/mile.

[12] Portions of the material in this section were supplied by and used with the permission of DieselNet.com.

The emission standards are designed to try to ensure compliance with emission standards throughout the "useful life" of the engine. Thus, manufacturers must test engines for durability, which has been defined as follows:

- light heavy-duty diesel engines – 8 years or 176,000 km (whichever occurs first);
- medium heavy-duty diesel engines – 8 years or 296,000 km; and
- heavy heavy-duty diesel engines – 8 years or 464,000 km.[13]

Additional emission testing requirements, which were introduced in 1998 for signees of the Consent Decree (discussed later) and which are part of the standards for 2004 and later, include the following:

1. The supplemental steady-state test was introduced to help ensure that heavy-duty engine emissions are controlled during steady-state type driving, such as a line-haul truck operating on a freeway. The test is identical to the European Union's 13-mode European Stationary Cycle (ESC) schedule (commonly referred to in the United States as the "Euro III" cycle). The supplemental steady-state test has the same numerical emission limits as the FTP standards.

2. The "not to exceed" (NTE) limits have been introduced as an additional instrument to make sure that heavy-duty engine emissions are controlled over the full range of speed and load combinations commonly experienced in use. The NTE approach establishes an area (the "NTE zone") under the torque curve of an engine where emissions must not exceed a specified value for any of the regulated pollutants.

   The NTE test procedure does not involve a driving cycle of any specific length (mileage or time). Rather, it involves driving of any type that could occur within the bounds of the NTE control area, including operation under steady-state or transient conditions and under varying ambient conditions. Emissions are averaged over a minimum time of 30 seconds and then compared to the applicable NTE emission limits. Under the EPA proposal, the specified value under which emissions must remain is 1.25 times the FTP standards.

Model years 1987-2003

Model years 1987-2003 Canadian, U.S. federal, and California emission standards for heavy-duty diesel truck and bus engines are summarized in **Tables 5 and 6**. Applicable to the standards for 1994 and subsequent years, sulphur content in the certification fuel has been reduced to 500 parts per million (ppm) by weight.

Table 5 | U.S. and Canadian Emission Standards for Heavy-Duty Diesel Engines, g/bhp-hr

Year	HC	CO	NOx	HC+NOx	PM
1974	-	40.0	-	16.0	-
1979	-	25.0	-	10.0	-
1985	1.3	15.5	10.7	-	-
1987	1.3	15.5	10.7	-	0.60
1990	1.3	15.5	6.0	-	0.60
1991	1.3	15.5	5.0	-	0.25
1994	1.3	15.5	5.0	-	0.10
1998	1.3	15.5	4.0	-	0.10

Table 6 | California Emission Standards for Heavy-Duty Diesel Engines, g/bhp-hr

Year	NMHC	THC	CO	NOx	PM
1987	-	1.3	15.5	6.0	0.60
1991	1.2	1.3	15.5	5.0	0.25
1994	1.2	1.3	15.5	5.0	0.10

NMHC = non-methane hydrocarbons.
THC = total hydrocarbons

[13] U.S. federal "useful life" requirements were later increased to 10 years for the urban bus PM standard (1994+) and for the NOx standard (1998+), with no change to the above mileage numbers.

Model Year 2004 and Later

In October 1997, the EPA adopted new emission standards for model year 2004 and later heavy-duty diesel truck and bus engines. These standards reflect the provisions of the Statement of Principles signed in 1995 by the EPA, the California Air Resources Board (ARB) and the manufacturers of heavy-duty diesel engines. The goal was to reduce NOx emissions from highway heavy-duty engines to levels of approximately 2.0 g/bhp-hr beginning in 2004. Manufacturers have the flexibility to certify their engines to one of the two options shown in **Table 7**.

Table 7 | U.S. Emission Standards for Model Year 2004 and Later Heavy-Duty Diesel Engines, g/bhp-hr

Option	NMHC+NOx	NMHC
1	2.4	N/A
2	2.5	0.5

All emission standards, other than those for NMHC and NOx, applying to 1998 and later model year heavy-duty engines will continue at their 1998 levels. However, the EPA has extended the definition of "useful life" for the heavy-duty diesel engine service class of 696,000 km, 22,000 hours or 10 years, whichever occurs first, for all pollutants beginning in model year 2004.

The U.S. federal 2004 standards for highway trucks are harmonized with the Canadian and California standards, so manufacturers can use a single engine or machine design for all markets.

Consent Decree

In October 1998, a court settlement was reached between the EPA, U.S. Department of Justice, California ARB and engine manufacturers (Caterpillar, Cummins, Detroit Diesel, Volvo, Mack Trucks/Renault and Navistar) over the issue of high NOx emissions from heavy-duty diesel engines during certain driving modes. Since the early 1990s, the manufacturers had used engine control software that caused engines to switch to a more fuel-efficient (but higher NOx) driving mode during steady highway cruising. The EPA considered this engine control strategy an illegal "emission defeat device."

Provisions of the Consent Decree included the following:

- civil penalties for engine manufacturers and requirements to allocate funds for pollution research;
- a requirement to upgrade existing engines to lower NOx emissions;
- certification of engines on both the transient FTP and the supplemental steady-state test; and
- a requirement to meet 2004 emission standards by October 2002, 15 months ahead of time.

Model Year 2007 and Later

On December 21, 2000, the EPA issued its final rulemaking on emission standards for model year 2007 and later heavy-duty highway engines. The standards were signed into effect that month. The new rules include two components:

- diesel fuel regulation; and
- emission standards.

The fuel regulation limits the sulphur content in on-highway diesel fuel to 15 ppm (by weight), down from the previous 500 ppm. The fuel provisions would go into effect in June 2006. This ultra low sulphur diesel fuel is seen as a "technology enabler" to pave the way for advanced sulphur-intolerant exhaust emission control technologies, such as diesel particulate filters and deNOx catalysts, which will be necessary to meet the 2007 emission standards.

The second part of the new standards introduces new, very stringent emission standards. The new PM emission standard of 0.01 g/bhp-hr is to take full effect in the 2007 heavy-duty engine model year. As well, the new rules have reduced standards for NOx and NMHC to 0.20 g/bhp-hr and 0.14 g/bhp-hr, respectively. These NOx and NMHC standards would be phased in between 2007 and 2010. The phase-in would be on a percent-of-sales basis: 25% in 2007, 50% in 2008, 75% in 2009 and 100% in 2010. The EPA has also imposed a formaldehyde emission standard of 0.016 g/bhp-hr to ensure that this gas is not emitted when the expected shift to catalyst exhaust aftertreatment occurs in the next decade.

Europe

The European regulations for medium and heavy-duty diesel engines are commonly referred to as Euro I through Euro V. The Euro I standards for medium and heavy-duty engines were introduced in 1992. The Euro II regulations came into effect in 1996. These standards applied to both heavy-duty highway diesel engines and urban buses.

In 1999, the European Parliament and the Council of Environment Ministers adopted the final Euro III standard (Directive 1999/96/EC of December 13, 1999, amending Directive 88/77/EEC) and also adopted Euro IV and V standards for the years 2005 to 2008. The standards also set specific, stricter values for extra low emission vehicles (also known as "enhanced environmentally friendly vehicles" or EEVs) in view of their contribution to reducing atmospheric pollution in cities. **Table 8** contains a summary of the emission standards and their implementation dates.

Table 8 | **European Union Emission Standards for Heavy-Duty Diesel Engines, g/kWh (smoke in m^{-1})**

Tier	Date & Category	Test Cycle	CO	HC	NOx	PM	Smoke
Euro I	1992, <85 kW	A.	4.5	1.10	8.0	0.612	
	1992, >85 kW	A.	4.5	1.10	8.0	0.36	
Euro II	1996.10	-	4.0	1.10	7.0	0.25	
	1998.10	-	4.0	1.10	7.0	0.15	
Euro III	1999.10, EEVs only	B.	1.5	0.25	2.0	0.02	0.15
	2000.10	B.	2.1	0.66	5.0	0.10 0.13 *	0.8
Euro IV	2005.10	-	1.5	0.46	3.5	0.02	0.5
Euro V	2008.10	-	1.5	0.46	2.0	0.02	0.5

A. http://www.dieselnet.com/standards/cycles/ece_r49.html

B. http://www.dieselnet.com/standards/cycles/esc.html
http://www.dieselnet.com/standards/cycles/elr.html

g/kWh = grams per kilowatt hour.

* For engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3,000 rev/min.

It is expected that the emission limit values set for 2005 and 2008 will require all new diesel-powered heavy-duty vehicles to be fitted with exhaust gas aftertreatment devices, such as particulate traps and deNOx catalysts. The 2008 NOx standard will be reviewed by December 31, 2002, and either confirmed or modified, depending on the available emission control technology.

Changes in the engine test cycles have been introduced in the Euro III standard (year 2000). The old steady-state engine test cycle ECE (Economic Commission of Europe) R-49 will be replaced by two cycles: a stationary cycle ESC (European Stationary Cycle) and a transient cycle ETC (European Transient Cycle). Smoke opacity is measured on the ELR (European Load Response) test.

For type approval of new vehicles with diesel engines according to the Euro III standard (year 2000), manufacturers have the choice of either of these tests. For type approval according to the Euro IV (year 2005) limit values and for EEVs, the emissions have to be determined on both the ETC and the ESC/ELR tests.

Emission standards for diesel engines that are tested on the ETC test cycle, as well as for heavy-duty gas engines, are summarized in **Table 9**.

Table 9 | **Emission Standards for Diesel and Gas Engines, ETC Test, g/kWh**

Tier	Date & Category	Test Cycle	CO	NMHC	CH_4 [a]	NOx	PM [b]
Euro III	1999.10, EEVs only	ETC	3.0	0.40	0.65	2.0	0.02
	2000.10	ETC	5.45	0.78	1.6	5.0	0.16 0.21 [c]
Euro IV	2005.10	-	4.0	0.55	1.1	3.5	0.03
Euro V	2008.10	-	4.0	0.55	1.1	2.0	0.03

a For natural gas engines only (CH_4 = methane).

b Not applicable for gas-fuelled engines at the year 2000 and 2005 stages.

c For engines of less than 0.75 dm^3 swept volume per cylinder and a related power speed of more than 3,000 rev/min.

Importantly, the current EU regulations have no provisions for proof of emission control durability. This is to be corrected in upcoming legislation to take effect in 2005.

The Rest of the World

The U.S. or EU standards are used as the basis for standards – or in some cases de facto standards – throughout much of the world. Japan has developed its own standards (see **Table 10**) based on driving patterns characteristic of that very urbanized country. In many lower-income countries, the cost of legislating and enforcing new vehicle standards is prohibitive. For this reason there is a United Nations-led program to establish an international standards program that would provide blanket quality assurance for imported vehicles. These standards are likely to be based on either the EU or U.S. standards and test procedures.

Table 10 | Japanese Heavy Vehicle Emission Standards

Gross Vehicle Weight	Date	Test	Unit	CO		HC		NOx		PM	
				max	mean	max	mean	max	mean	max	mean
< 1,700 kg	1988	10-15 mode	g/km	2.7	2.1	0.62	0.40	1.26	0.90		
	1993			2.7	2.1	0.62	0.40	0.84	0.60	0.34	0.20
	1997			2.7	2.1	0.62	0.40	0.55	0.40	0.14	0.08
	2002[a]				0.63		0.12		0.28		0.052
1,700 - 2,500 kg	1988	6 mode	ppm	980	790	670	510	500 DI 350 IDI	380 DI 260 IDI		
	1993	10-15 mode	g/km	2.7	2.1	0.62	0.40	1.82	1.30	0.43	0.25
	1997-98			2.7	2.1	0.62	0.40	0.97	0.70	0.18	0.09
	2003[a]				0.63		0.12		0.49		0.06
> 2,500 kg	1988-89	6 mode	ppm	980	790	670	510	520 DI 350 IDI	400 DI 260 IDI		
	1994	13 mode	g/kWh	9.20	7.40	3.80	2.90	7.80 DI 6.80 IDI	6.00 DI 5.00 IDI	0.96	0.70
	1997-99[b]			9.20	7.40	3.80	2.90	5.80	4.50	0.49	0.25
	2004[a]				2.22		0.87		3.38		0.18

"Max": to be met as a type approval limit if sales are fewer than 2,000 per vehicle model year and generally as an individual limit in series production.

"Mean": to be met as a type approval limit and as a production average.

DI = direct injection
IDI = indirect injection

a New short-term targets issued by the Central Council for Environmental Pollution Control on 1998.12.14.

b 1997: GVW 2,500-3,500 kg; 1998: GVW 3,500-12,000 kg; 1999: GVW>12,000 kg.

[14] Environment Canada, Transportation Systems Division, *The State of Heavy-Duty Vehicle Emission Inspection and Maintenance in Canada and the United States*, EPS 2/TS/12, March 2000.

In-Service Inspection, Maintenance and Retrofit Programs

Once vehicles are manufactured and sold, the enforcement of the maintenance of the emission control systems is the jurisdiction of the provinces in Canada. Emission control systems degrade in performance over their useful life. However, proper maintenance of the vehicle will ensure that the minimum emissions are generated.

Vehicle Inspection

One indicator of a poorly maintained engine, either gasoline or diesel fuelled, is the emission of visible smoke. For diesel engines, the generation of smoke is a clear indication of potential problems with the fuel, air induction system, fuel injectors, or cylinder condition. For this reason, the measurement of smoke (opacity) has been used as an in-service test to identify high emitters. The test, while not perfect – it can miss some high emitters – is relatively inexpensive and operationally easy. Some 20 U.S. states, along with British Columbia and Ontario, have instituted in-service testing as a way to ensure the continued compliance of vehicles with their emission control capabilities.[14] These programs call for mandatory periodic inspections, as in Ontario, or rely on random roadside inspections, as in British Columbia (Ontario also undertakes random roadside inspections).

Vehicle Age Management

New vehicles are designed and manufactured better than older vehicles. Improvement of the fuel efficiency of trucks has been a constant goal, and over the last 15 years truck emissions of particulates and NOx have been more than halved. Thus, ensuring that vehicles are exchanged for new models as frequently as possible can have a significant effect on reducing emissions. As discussed in the demographics section, long-haul truckers generally have modern equipment. Urban fleets, however, tend to be older vehicles with higher emissions. Farm vehicles, while they have the oldest age profile, are usually not operated near major urban areas and their higher emissions have minimal air quality impact. Therefore, the focus of most vehicle age management programs has been on school, transit, urban or agricultural fleets, where incentives are provided to scrap and replace the vehicle or to upgrade its emissions technology.

The first voluntary scrappage program of older, high polluting light-duty vehicles (not trucks) was conducted in 1990 by Union Oil of California (UNOCAL). The program offered US$700 for old vehicles; 3,000 vehicles were offered in the first two days. Since then, the various California programs have scrapped about 30,000 light-duty vehicles.

Heavy trucks have been in involved in very few scrappage programs and none in Canada. As the incentive to scrap is a financial one, it is unlikely that large enough fiscal incentives could be offered to solicit much interest. Trucks have, however, been involved in upgrading programs.

Retrofit Programs

The rationale for retrofit programs is similar to that for scrappage programs – to move the age distribution of the vehicles to a more modern emission control technology. In the case of retrofits, the owner is required to change or add equipment to the vehicle to reduce its polluting capability.

In the United States, this approach was first used for urban transit buses in 1993, and now several states are trying a voluntary program aimed at heavy trucks. The guidelines for these programs target particulate matter reduction and require that retrofit equipment get type approval in reducing PM by 25% or 0.1 g/bhp-h.

An engine "retrofit" includes (but is not limited to) any of these activities:

- addition of new or better pollution control aftertreatment equipment to certified engines;
- upgrading of a certified engine to a cleaner certified configuration;
- upgrading of an uncertified engine to a cleaner "certified-like" configuration;
- conversion of any engine to a cleaner fuel;
- early replacement of older engines with newer (presumably cleaner) engines (in lieu of regular expected rebuilding); and
- use of cleaner fuel and/or emission reducing fuel additive (without engine conversion).

The South Coast Air Quality Management Department (SCAQMD) in California operates perhaps the most active program. The initiative,[15] part of the statewide Carl Moyer Memorial Air Quality Standards Attainment Program, aims to speed up the introduction of low-emission heavy-duty engines in trucks, transit and school buses, marine vessels and off-road vehicles such as forklifts and construction equipment. In the 2000-2001 fiscal year, the state expects to provide US$28.5 million in grants under the program.

Alternative-fuelled engines such as those using compressed natural gas, liquefied natural gas, propane and electricity are given the highest priority. Cleaner diesel engines are considered in some cases. Program funds can be used to help purchase new vehicles, new engines or retrofits to existing engines. Some funding also is available for alternative fuel and electric charging stations. In general, new vehicles and equipment must achieve a 30% reduction in NO_x emissions compared to current emission standards, and retrofits must achieve a 15% reduction. Vehicles and equipment funded must operate for at least five years, and 75% of their use must be within SCAQMD's jurisdiction.

A similar type of program has been developed in Sweden. The three biggest cities in Sweden – Stockholm, Goteburg and Malmo – introduced "environmental zones" in the centre of each city in order to improve the ambient air quality. The environmental zones regulations are not harmonized with the European Union's emission standards and are made possible by local legislation dealing with in-service vehicles and the use of vehicles. The law makes it possible for communities in Sweden to introduce limitations on heavy-duty vehicles in environmentally sensitive areas. Vehicles of a certain age have to be retrofitted with an approved emission control device in order to receive an exemption and to be allowed to travel in the environmental zones.

[15] http://www.arb.ca.gov

A general exemption from the regulation has been granted for vehicles aged eight years or less. All vehicles older than 15 years are banned. Vehicles aged from 9 to 15 years must be retrofitted with an emission control device. The required emission reductions for the retrofit kits are listed in **Table 11**.

Table 11 | Swedish Retrofit Requirements

Pollutant	Emission Reduction
Diesel Particulate Matter (DPM)	80% *
Hydrocarbons (HC)	60%
Nitrogen Oxides (NOx)	No increase
Noise	No increase

* "Type A" systems of 20% DPM reduction were also allowed at the initial stage of the program. Starting in 1999, vehicles equipped with Type A systems are not permitted in the environmental zones.

The approved emission control devices are catalytic converters in combination with particulate traps. The systems are effective due to the widespread use of low sulphur diesel fuel in Sweden. Low sulphur diesel fuel, with a maximum of 0.10 ppm sulphur, accounts for more than 90% of total diesel use in all heavy-duty vehicles.

An evaluation of the program's effectiveness, carried out one year after its introduction, showed the following emission reductions from heavy-duty vehicles:

- PM – 20%;
- HC – 10%;
- NOx – 8% (mainly due to renewal of the vehicle fleet); and
- a reduction in total noise level, despite increasing traffic.

Another consequence of the program is an increasing population of heavy-duty vehicles fuelled with compressed natural gas and alcohol in the zones. An estimated 3,000 vehicles have been retrofitted with emission control systems over the first three years of the program.

Technological Solutions and Options

Engine Technologies

The dominant engine technology used in trucks is the diesel engine. It is highly probable that it will continue in its dominant role and even expand further into lighter duty trucks. The reasons that diesel engines are used include:

1. *Energy efficiency.* The single most important reason that diesel engines are used in most applications is their superior energy efficiency. Where both diesel engines and spark-ignition engines have reasonably equivalent power output characteristics, the diesel will consume less fuel in performing the same work. How much less fuel the diesel engine will use varies with the application, but typical estimates range between 25% and 35%.
2. *Packaging efficiency*. Spark-ignition engines are not a viable alternative to diesel engines for applications requiring high power output at low speeds. All internal combustion engines produce waste heat, but spark-ignition engines produce relatively more, generally, than compression-ignition engines and therefore require more cooling. Generally speaking, spark-ignition engines do not exceed 10 litres in displacement and are not used in applications where power requirements exceed about 400 horsepower.
3. *Durability and reliability*. Diesel engines are legendary for their durability and reliability. One major diesel engine manufacturer recently tore down a randomly selected 412-horsepower heavy truck engine that had been driven 1.28 million km. The engine was a 1996 model that had been hauling average loads of 36,400 kg at an average driving speed of 100 km/h. The engine was judged to be capable of going another 400,000 km before an overhaul would be needed.[16]
4. *Fuel safety*. Diesel fuels generally are less volatile and are therefore safer to store and handle than the fuels used in spark-ignition engines. This lower fuel volatility is another characteristic that dictates the use of diesel engines in certain applications. Fire-fighting equipment, ambulances, military vehicles, boats, school buses, and engines used in certain stationary applications rely on diesel power, at least in part, because of the low volatility and, hence, greater safety of diesel-type fuels.

Diesel emission control technology has been centred on improving control of the combustion process itself – so-called in-cylinder control. This has resulted in significant changes to the engines, including:

- use of electronics for more precise control of fuel injection;
- changes in cylinder components, making the piston rings tighter, increasing the fuel mixing, etc.;
- large increases to the pressure at which fuel is injected, which has a marked effect on efficiency and smoke production; and
- control of NOx through the use of engine load sensors.

Unlike gasoline engine technology, the aftertreatment of engine emissions through the use of catalysts has not yet been extensively used on diesels. This is because the engines were able to meet the standards without resorting to these techniques and also because the durability of the catalysts is poor, primarily owing to the presence of sulphur in the fuel. Sulphur coats or “poisons” the catalyst surfaces, rendering them ineffective after a short time.

As the standards are changed, engine manufacturers will probably need to use aftertreatment technologies to meet the new emission levels. These technologies will consist of:

- particulate traps, which reduce the amount of particulates released;
- oxidation catalysts, which ensure the complete combustion of HC and CO; and
- deNOx catalysts, which remove NOx.

[16] “Caterpillar C-12 Tear-Down Inspection Confirms Engine’s Durability,” Press Release, September 8, 1999.

Virtually all the catalyst technologies that will be employed are, as mentioned above, sensitive to sulphur. The future sulphur content regulations for diesel fuel will be “technology enabling” – in much the same way that the elimination of lead in gasoline was required for light-duty vehicles in the 1970s. The cost of these technologies – without factoring in the extra cost of low-sulphur fuel – will be significant. Current cost estimates per new vehicle[17] range from $600-$1,600 for oxidation catalysts to $5,000-$6,000 for particulate traps, and $7,000-$15,000 for mixed fuel systems. The cost of sulphur removal will also be significant but is technically possible, as Sweden has requirements in place now that are in fact lower than the proposed U.S. and Canadian fuel content standards.

These technologies will reduce truck emissions by a further 90% (PM moving from 0.1 g/bhp-h to 0.01 g/bhp-h) and will improve the durability of the emission control systems.

Diesel Fuel Properties

The quality and constituents of fuel affect emissions. The two most significant properties of diesel fuel are cetane and sulphur content. Other characteristics, such as carbon content, can be affected by only a complete change of the type of fuel, as discussed later in the alternative fuels section.

Cetane

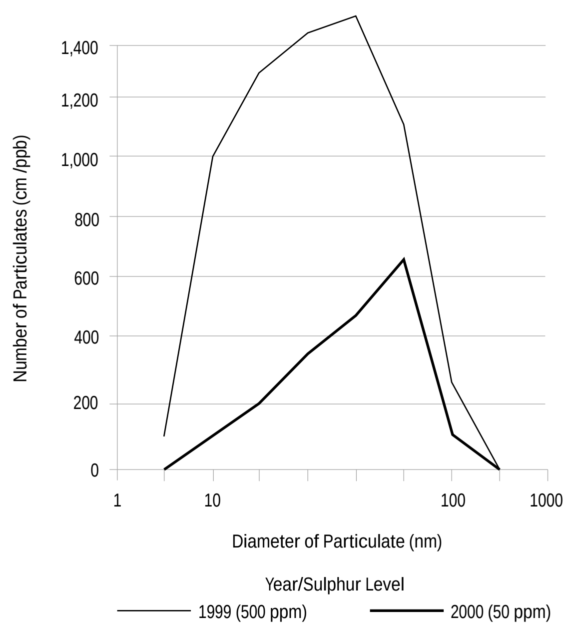
Cetane is a measure of a fuel’s combustibility, in much the same way that octane is used for gasoline. A lower cetane number generally can be associated with less efficient combustion and thus can change the emissions of CO, HC and particulates.[18] Cetane is not regulated in the marketplace, but operational demands place consumer acceptance limits on products produced by the refiners.

Sulphur

Sulphur content is a function of the source of the crude stock from which the fuel was refined plus the refining processes used. The sulphur, when combusted, forms oxides of sulphur (SOx), which have significant health, vegetation damage, water acidification and materials corrosion effects. The sulphur also contaminates exhaust aftertreatment catalysts, similar to the effect of lead in gasoline, and thus restricts the level of emission control that can be achieved.

Sulphur content has also been linked to the generation of particulates in the cylinder. Thus, the effect of sulphur reduction in diesel fuel can have an immediate and dramatic effect on local air quality, as has been documented by the Danish government, which reduced the sulphur content of fuels to 50 ppm in 1999.[19] **Figure 10** shows that peak particulate concentration dropped from 1,500 cm^3/ppb to 700 cm^3/ppb within a one-year period as the regulations came into effect. As well, the graph shows the large shift in the size distribution from small particulates to larger particulates, which cause less health damage.

Figure 10 | Particulate Levels on Street in Copenhagen



[17] Manufacturers of Emission Controls Association, *Independent Cost Survey for Emission Control Retrofit Technologies*, Washington, D.C., December 2000.

[18] Mitchell, Ken, “Effects of Fuel Properties and Source on Emissions from Five Different Heavy Duty Diesel Engines,” SAE Paper 2000-01-2890, Society of Automotive Engineers, Warrendale, PA, 2000.

[19] Olivastri, B. and Williamson, M., “A Review of International Initiatives to Accelerate the Reduction of Sulphur in Diesel Fuel,” Oil, Gas & Energy Branch, Air Pollution Prevention Directorate, Environmental Protection Service, Environment Canada, December 2000.

In 1993, the average sulphur level for the total diesel pool in Canada was 1,800 ppm.[20] By 1997, the average level had been reduced to 1,200 ppm. This reduction was brought about by a memorandum of understanding between Environment Canada and most domestic refiners on providing low sulphur diesel fuel for on-road uses at the retail level. The implementation of the federal Diesel Fuel Regulations (1997), which became effective in 1998 for all on-road uses, is expected to further reduce that average. In 1997, the average sulphur levels for on-road diesel and regular (off-road) diesel were 300 ppm and 2,400 ppm respectively.

Current regulations require that sulphur content be no more than 50 ppm by 2006. If Canada follows the U.S. lead, the requirement will be changed to 15 ppm by 2006. The U.S. EPA has estimated that the overall cost associated with lowering the sulphur cap from the current level of 500 ppm to the 15 ppm level proposed today will be approximately 1.3 to 1.6 cents per litre.[21] This estimate comprises approximately 1.6 cents per litre in increased costs to produce and distribute the fuel, and a cost offset of about 0.4 cents per litre or more from the vehicle maintenance savings that would result from the use of the cleaner fuel. The refinery industry, however, has made significantly higher estimates of these costs.

Some countries, such as Sweden, have gone further in sulphur reduction. Sweden first introduced an environmental tax on sulphur in diesel in 1991; subsequent adjustments in 1992 and 1996 resulted in an almost 100% market share for urban diesel fuel of 10 ppm sulphur.

Alternative Fuels

Changing the type of fuel used in trucks is also an option for emission control. A switch in fuel, however, is very complicated and expensive, as most alternative fuels will not combust in a diesel cycle (without spark) and if a spark ignition is used there is a large energy efficiency penalty. A recent analysis[22] estimated that replacing diesel technology with the “next best” alternative fuel would increase the total cost (direct plus indirect) of providing bus, rail and truck transportation by:

- 24% for urban bus transportation;
- 48% for rail; and
- 56% for trucking and warehousing.

However, in some situations and fleets these costs can be much smaller or even represent a saving, usually because of the lack of road tax on the alternative fuel.

Natural Gas

Because of its gaseous form and lower carbon content, natural gas has a dramatic effect on CO, HC and particulate emissions, with reductions of 50%-60% possible without aftertreatment. However, as the combustion temperatures tend to be higher, the amount of NOx produced increases by 20%-30%. Natural gas historically has required a spark ignition, but a Canadian company[23] recently developed a dual fuel injector that allows for the continuous mixing of diesel and natural gas. This eliminates the energy efficiency losses and still maintains much of the emission benefits. In medium-duty trucks that have gasoline engines, the conversion to natural gas is more competitive because the efficiency reduction is much less significant.

Ethanol

Ethanol, which can be made from corn or agricultural wastes, has been tried with poor success in diesel engines. However, it is advantageous from a GHG perspective as an additive in gasoline. Normally, it is blended to a 10%-15% ethanol level. Emissions from medium-duty trucks that have no catalyst aftertreatment can be reduced – mostly for CO. Higher levels from ethanol use require purpose-designed engines, which are currently available only in light-duty models.

[20] Environment Canada, *Final Report of the Government Working Group on Sulphur in Gasoline and Diesel Fuel*, Ottawa, July 1998 (http://www.ec.gc.ca).

[21] U.S. Environmental Protection Agency, “Proposed Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements,” regulatory announcement, EPA420-F-00-022, May 2000.

[22] *Diesel Technology and the American Economy*, prepared for Diesel Technology Forum, Herndon, VA, by Charles River Associates, Washington, D.C., October 2000.

[23] Westport Technologies Ltd. of Vancouver (http://www.westport.com).

Biodiesel

This product is formulated from agricultural crops – mostly soybeans – and is a substitute for regular diesel fuel. Its primary benefit is its lower GHG rating because of the short-cycle carbon that is contained in it. Further, because biodiesel has a very low sulphur content, the particulate levels from biodiesel-fuelled trucks are lower. Currently, in part because of low production rates, biodiesel is more expensive than regular diesel. In the cost-sensitive trucking industry, this means that it has had limited uptake by the market.

Hydrogen

Hydrogen is seen by some as the ultimate fuel. It can be extracted from water and it behaves much like natural gas, but because of the lack of carbon it is even cleaner burning. However, it is an extremely difficult fuel to use in an engine. Moreover, the fuel must be stored in very high pressure tanks or in liquid form at very low temperatures in large insulated tanks. Both systems add weight to the vehicle, thus decreasing payload, and both entail high costs for the supply and compression or liquefaction of the fuel. Furthermore, the fuel in pure form must be spark-ignited, which reduces efficiency.

An alternative way of using hydrogen is in a fuel cell. With this technology, the fuel is used to feed the fuel cell, which converts the chemical energy into electrical energy. Canada is a world leader in the development of fuel cell technology (see http://www.nrcan.gc.ca for more information), which is being commercially tested for all sizes of vehicles by the major vehicle manufacturers. The fuel cell option presents an opportunity for very low emission vehicles. However, fuel cells are not expected to reach the marketplace for many years, as the technology has a number of significant market entry barriers. For example:

- Powerplant systems are more expensive and less compact, as the vehicle drive systems must be converted to electric drives.
- Fuel storage is a major problem, because the fuel used is either hydrogen or a liquid fuel, such as gasoline or methanol, which must be re-formed into hydrogen.
- Supplying adequate amounts of fuel and developing a new network of fuelling depots both pose problems.
- There is no significant net energy benefit compared to some of the advanced diesel and diesel hybrid systems.

Other Technologies

Other technologies can be employed to make the vehicle operate more efficiently and thus lower emissions. One set of technologies tries to lower the force needed to move the truck. These include:

- low rolling resistance tires, which can reduce rolling drag and improve fuel efficiency and emissions by 1%-3%;
- aerodynamic devices that “smooth” the truck; these are especially effective for trucks in highway operations, where they can improve fuel efficiency and emissions by 2%-5%; and
- lightweight structures, which can save fuel and emissions in two ways: first by reducing the weight of the vehicle when it is not fully loaded, and second by allowing the vehicle to carry more payload, thus decreasing the number of trucks required to move freight.

A second set of technologies is aimed at more optimal use of the engine output. This group includes:

- fully electronic transmissions to ensure that the proper gear set is used;
- driver management systems that can control the amount of idling, acceleration rates and maximum speed of the truck; and
- advanced lubricants that reduce the internal friction of the engine so that more of the energy goes to the road and not to heat.

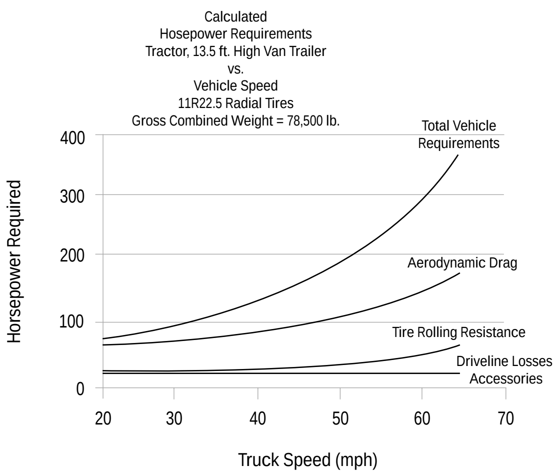
Finally, there are new technologies that are focused on recovering and reusing braking energy. The energy is stored electrically in batteries or mechanically in flywheels or hydraulic accumulators, and then this energy is fed back into the drivetrain when the vehicle needs more power. These systems have been shown to be capable of reducing fuel consumption by 25%-30% in urban driving and decreasing emissions by 50%-60%. Although the systems are expensive and complex, they do allow the continued use of conventional diesel engines and fuel.

Vehicle Operation Options

Speed Control

The control of truck speed is a significant factor affecting emissions and fuel consumption. The force that an engine must generate to move the vehicle down the road is a function of powertrain losses, rolling resistance, and aerodynamic drag. All of these are a function of speed, as seen in **Figure 11**.

Figure 11 | Power Requirements versus Road Speed



Source: Goodyear, *Factors Affecting Truck Fuel Economy*, 492700-3/93

Because aerodynamic drag is an exponential function of speed, the total force required – and thus the power and fuel use – is a non-linear function of speed. Note that these relationships are for steady-state conditions, which are rare in actual operations. When the speed variation (acceleration or deceleration) is added to the mix, the influence of mass, or gross vehicle weight, typically has a larger impact on the power demand from the engine. For a typical truck, aerodynamic drag is the majority of the road load at speeds over 90 km/hr (56 mph), as shown in **Figure 11**.

The simple fact is that as trucks (and cars) travel faster they require higher power levels from the engine. This increases fuel consumption rates and emissions, most notably of NOx. Thus, controlling vehicle speeds can play a significant role in reducing both emissions and fuel consumption. As seen in **Table 12**, smaller trucks are more sensitive to changes in speed than larger trucks, with a 13,600 kg truck increasing its fuel consumption rate by 28% for a change in speed from 90 km/h to 105 km/h, and by 50% for a change in speed from 90 km/hr to 120 km/h. Estimates of the changes in fuel consumption that could be achieved in Canada if the current speeds on the roads were strictly controlled to either 105 km/h or 90 km/h indicate that 1% and 4%, respectively, of truck fuel use could be reduced.[24] As NOx emissions are essentially proportional to fuel use at these high engine speeds, similar reductions in that pollutant could be expected.

Table 12 | Effect of Speed on Truck Fuel Consumption (L/100 km)

Speed (km/h)	Gross Vehicle Weight (000 kg)						
	13.6	**18.2**	**22.7**	**27.3**	**31.8**	**36.4**	**40.9**
120	29	32	34	35	37	38	39
105	25	26	28	30	31	33	34
90	20	21	23	25	26	28	29
% change from 90 km/h							
120	50%	49%	46%	42%	41%	37%	33%
105	28%	22%	20%	20%	18%	20%	16%
% change from 105 km/h							
120	18%	22%	21%	18%	19%	15%	15%

Congestion

Emissions and energy use would be dramatically decreased if vehicles could operate at steady speeds and never have to stop. This obviously is an unachievable target, but the goal of decreasing delays on our network of roads is what transportation engineers spend a lot of time and money on. When a vehicle accelerates to a given road speed, a substantial amount of energy is transferred into the momentum of the vehicle. When the vehicle slows or stops, this energy is consumed, either through vehicle drag or through the application of the vehicle's brakes. Once lost, this energy cannot be regained. Further, when the vehicle is stopped the engine is still running and thus still generating emissions and using fuel.

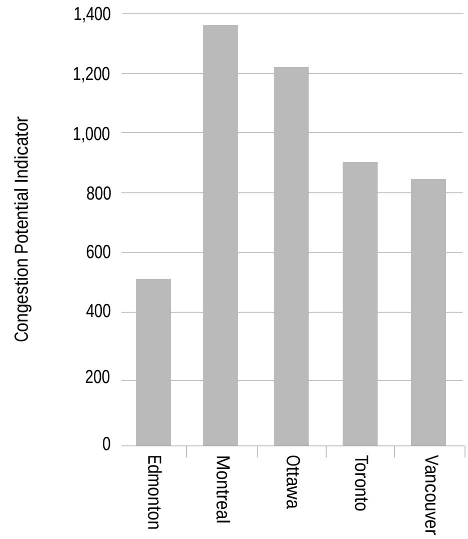
[24] Taylor, G. et al., *The Potential for GHG Reductions from Improved Use of Existing and New Truck Technology in the Trucking Industry*, National Climate Change Program, Transportation Table, TruckingSub-Group, 1999.

Road networks are designed to minimize the need to stop. The introduction of the limited-access highway in the 1950s was a major development in reducing emissions and energy use. But by improving speeds, these roads also encouraged people to reside longer distances from their workplace. Slowly, as populations and car ownership increased, the capacity of our road networks was exceeded. Today, there is more congestion and unplanned delays than ever.

Congestion is difficult to measure, as it tends to be a local problem reflecting an undersupply of roads. The Transportation Association of Canada has devised a "congestion potential indicator" for eight urban areas within Canada.[25] This measure is defined by the average trip distance, multiplied by the number of vehicle trips, divided by the number of arterial and expressway lane-kilometres. The results are shown in **Figure 12** These data indicate considerable differences among the urban centres included. The indexes for Montreal, Ottawa, Toronto and Vancouver are many times higher than for the other urban areas.

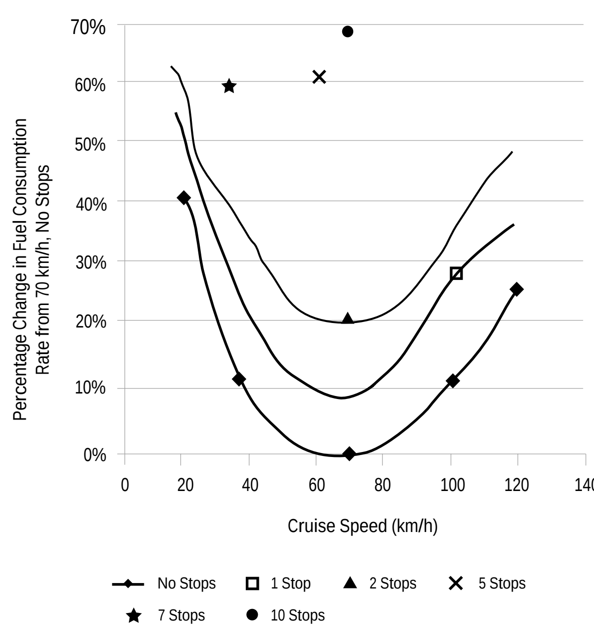
The consequences of congestion were reviewed in a recent report funded by Natural Resources Canada.[26] One study reviewed in the report compared the fuel consumption rates of a passenger car at various steady-state cruise speeds and with a varying number of stops on the route.[27] The data, presented in **Figure 13**, show that the lowest consumption rate is achieved with no stops. Fuel consumption is lowest and is relatively constant in the speed range of 50-80 km/h. Below this range, fuel consumption increases because the vehicle's drivetrain is not optimized for low speeds and tire resistance is a larger influence on energy demand. As cruise speeds increase, fuel consumption rises with the increased aerodynamic drag.

Figure 12 | **Congestion Potential Indicators for Canadian Cities**



When a single stop is introduced, energy consumption increases by 14%. This penalty increases as the number of stops increases, reaching a penalty of 68% when there are 10 stops on a 10 km route. Penalties for heavy-duty trucks, while not explicitly measured in the study, would be in proportion to those for passenger cars.

Figure 13 | **Effect of Stops on Light-Duty Vehicle Fuel Consumption**



25 Transportation Association of Canada, *Urban Transportation Indicators in Eight Canadian Urban Areas*, Ottawa, June 1996.

26 DELCAN Ltd., *Traffic Congestion Impact on CO_2 Emissions in Canada*, Ottawa, Natural Resources Canada, Office of Energy Efficiency, 1999.

27 Baker, M., *Fuel Consumption and Emission Models for Evaluating Traffic Control and Route Guidance Strategies*, Kingston, Queen's University, 1994.

Thus, reducing congestion is a key strategy in reducing air emissions. Increasing road capacity, restricting demand, better traffic control, and the use of non-stop intersections such as roundabouts all are techniques that can be employed to smooth the flow of traffic and thereby reduce the generation of excess emissions.

Vehicle Weights and Dimensions

Canada has had a history of undertaking technical and economic analyses on which our standards for the weights and dimensions of trucks are based. This has led to the allowance of larger or heavier trucks on our roads than is typical in much of the United States. These higher limits have raised productivity for truckers in Canada and lowered transportation costs. The energy and emission incentives for heavier trucks was seen in **Figure 9**, which shows that the energy consumption rate is a strong function of gross vehicle weight. Currently, Canada allows vehicles up to 38 metres long on our roads, carrying loads up to 62,500 kg. However, most highway trucks are much smaller than this limit, with the bulk of the market served by a tractor with a 16-metre trailer.

The question of changing and harmonizing the weight and dimensions of trucks is a chronic issue with the Canadian Council of Motor Transport Administrators (CCMTA). Significant increases to the limits have been introduced over the last decade, and there are still compatability issues between some provinces. It is unlikely that the weight limits will be further increased, as doing this would directly add to bridge and pavement damage.

Allowing more long “truck trains,” as has been done in the United States, is more likely.[28] However, this would affect a relatively small portion of all trucking, as these vehicles are restricted to roadways that have adequate geometric design (large shoulders and turning diameters, etc.). Based on 1995 data, it is estimated that about 6.1% of truck activity on the main highways (mostly freeways) in the four main jurisdictions where they are allowed (the three Prairie provinces and Quebec) consists of truck trains.[29]

The benefit of the long trains is not only lower operational costs for the operator but also lower overall energy use and emissions; as well, there is a net reduction in the number of truck units on the road. If the current network were expanded, it has been estimated that approximately 6.1% of all truck activity on the main roads in British Columbia, Ontario and Nova Scotia would be long trucks. Approximately 1.3 million vehicle kilometres of travel (vkt) would be generated between Ontario and Quebec, replacing 2.6 million vkt if the standard 16-metre (53-foot) equipment now in use on that link were retained. Estimates of the energy savings are that diesel use could be reduced by just under 0.1% and that NOx would be reduced by a similar amount.

Road Construction and Maintenance

The design and quality of road pavements affect vehicle emissions by changing the amount of power required to move the vehicle along the road. A smoother and harder surface will have lower rolling resistance than a rough or soft road. The roads in Canada’s urban areas are generally of high quality and are constructed using asphalt or concrete. In winter these two types of roadway behave identically, as both are rigid. However, at elevated summer temperatures, asphalt surfaces can become more plastic and increase the rolling resistance, especially of heavily loaded trucks and buses. The effect of this plasticity may be seen in the rutting that occurs on some of our main asphalt-constructed roads.

The differences in hardness between asphalt pavements and concrete pavements have been assessed on sections of intercity highway in steady highway speed conditions.[30] In most temperature conditions, there were only small differences between the two pavement types. However, in warm weather, reductions of up to 8% in fuel consumption were measured for concrete

[28] The United States, however, has not increased axle weight limits, as Canada has done.

[29] Taylor, G. et al., *The Potential for GHG Reductions from Improved Use of Existing and New Truck Technology in the Trucking Industry*, National Climate Change Program, Transportation Table, Trucking Sub-Group, 1999.

[30] National Research Council of Canada, *Effect of Pavement Surface on Heavy Truck Fuel Consumption*, undertaken for the Cement Association of Canada, Ottawa, 1999.

versus asphalt surfaces. The effect of the pavement difference at the lower speeds typical of urban driving has not been measured but is probably more pronounced, as urban asphalt pavement has more time to deform.

In a similar manner, the roughness of the road surface increases the rolling resistance and therefore increases fuel consumption and emissions. In the same set of tests, a smooth road reduced fuel consumption by 10% compared with a rough road. Thus, maintaining the quality of the road surface through frequent repair or repaving can play a significant role in cutting emissions. As the benefits occur year-round, a smooth road is a more important factor than the type of road pavement.

Driver Training

While the intent of emission regulations is to control and minimize the level of emissions in all driving regimes, independent of the driver, the driver's performance can still have a large impact on both the truck's emissions and fuel consumption. As has been shown, the management of speed and the minimization of stops – through route planning and anticipatory driving – can significantly reduce the energy and emissions involved. Studies have shown that the "driver effect" (e.g. the difference between passive and aggressive driving), even when driving very prescribed driving patterns such as the official emission test cycle, can change energy and emissions by 5%. When this effect is coupled with the controls on maximum speed and idling, it has been estimated that better training of the driver and better vehicle management by the driver could save an average of 10% in energy and emissions.[31]

Much of these potential savings in fuel and emissions will come about as on-board "smart" driver control computers and real-time vehicle-to-head-office data links become increasingly common. These technologies will automatically limit the operational envelope of the driver or increase the monitoring capabilities of management. In addition, powertrain systems will continue to become less sensitive to driver mistakes in gear selection. In the meantime, truck owners and operators need training support and simple and effective management methods to control not only who drives but how that person drives the vehicle. In this way, they will be able to minimize the production of emissions and the use of energy.

[31] National Climate Change Program, Transportation Table, Trucking Sub-Group, *Environmental Awareness and Outreach Measures to Reduce GHG Emissions from the Trucking Sector*, August 1999.

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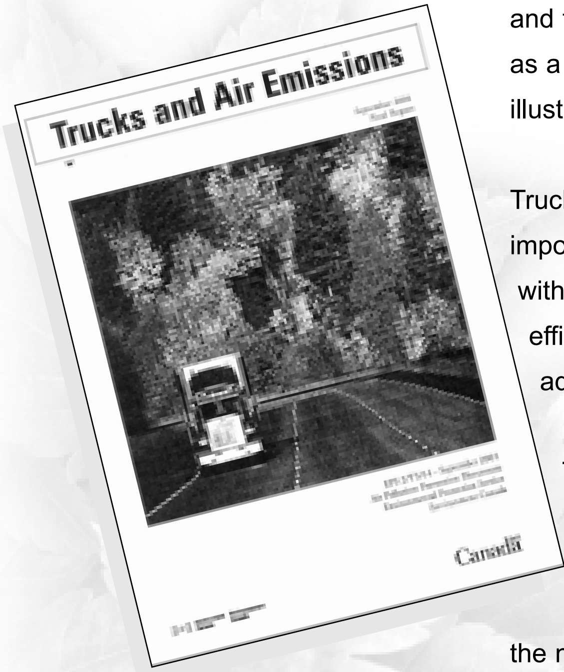
Trucks and Air Emissions



This report presents important facts and figures about trucks, their activities, and the impact of those activities on the Canadian environment. It is designed as a general primer on the subject, and the clearly written text is well illustrated with figures and tables.

Trucks play a key role in many aspects of Canadian society and are important in maintaining our standard of living. Modern trucks are equipped with leading-edge technology that has greatly increased their operational efficiency and reduced air emissions over the last 20 years. Despite these advances, trucks still contribute significantly to air pollution in Canada.

The report provides essential information on trucks and their emissions in Canada, and describes emission control programs in North America and elsewhere. It shows how governments at all levels are continuing to tighten standards to control heavy-duty vehicle emissions, and it outlines the new technologies, alternative fuels and operational advances that will result in reduced pollution and cleaner air for Canadians.

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