Transportation Research Board Special Report 291

GREAT LAKES SHIPPING, TRADE, AND AQUATIC INVASIVE SPECIES

The Environmental Footprint of Surface Freight Transportation

Prepared for
Committee on the St. Lawrence Seaway:
Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes: Phase 2
Transportation Research Board and Division on Earth and Life Studies

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BACKGROUND

The “Statement of Task” for this paper prepared by the Committee included the following instructions:

> “This White Paper is to describe the environmental footprint of shipping, rail and truck modes of freight transport. The comparison should draw on information available internationally but the comparison should be made with reference to the types of traffic and other conditions associated with the trade of the ocean-going vessels trading into and out of the Great Lakes and the surface transport conditions of the region. Aspects of the environmental effects to be considered include, but are not necessarily confined to, air emissions, water contamination, area of land occupied, and quality-of-life effects such as noise, congestion and aesthetics.
>
> The Committee does not expect detailed or precise data, unless they are readily available; rather, deliberations can be based on relative comparisons or rankings that are supported by the literature. For example, concerning land use, by what order of magnitude do rail and highway transport outrank ports? A summary table or chart indicating the relative magnitude of the air, water, land, and quality-of-life footprints would be very helpful, along with a summary index of the overall magnitude of the environmental footprint for each transportation mode.
>
> The purpose of the paper is to enable the Committee to outline the environmental consequences of the options that it considers to eliminate the introduction of nonindigenous species into the Great Lakes. In its elaboration of the strengths and weaknesses of the options identified, the Committee will need to weigh the environmental impacts of any shift of transport from one mode to another.”

Effects to be Considered and Interpretation of “Footprint”

The research for the paper has followed the instructions in being brief and mainly based on secondary sources, i.e. the open literature and available databases, though supported by unpublished information available to the author from previous work, and some substantial new analysis and interpretation of available data to make the necessary comparisons. This is particularly true of the examination of emissions of greenhouse gases and criteria air contaminants from the three modes, which the author would argue are the most important aspects of the environmental impacts of the three modes, in the current government policy context, and certainly the aspects that are the subject of the most debate in public and professional circles. Part of the reason for the debate is that estimates available in the literature provide confusing variation and in some cases misleading findings. The author has re-examined available information, particularly for ship and truck freight, and has attempted to provide comparable estimates for the freight of interest, which is that currently carried by ocean-going ships through the St. Lawrence Seaway.

It will be clear from the paper that the quantitative research effort has focussed on emissions, with more qualitative assessment of other effects. The list of effects considered is as follows:

- Fuel use
- Greenhouse gas emissions
- Criteria air contaminant emissions
- Area of land occupied
- Water contamination (spills)
- Accidents
- Noise
- Congestion
- Aesthetics
- Introduction of nonindigenous species

This list adds consideration of accidents to the effects proposed in the Statement of Task, and also the introduction of nonindigenous species. The latter was added following discussion by the Committee of the initial findings from the work, at its meeting on February 5th, 2007. It was requested that the "footprint" of each mode should also mention its effects on the introduction of nonindigenous species, which is of course the main object of the Committee's deliberations.

The Statement proposed the effects be combined to describe and compare the "environmental footprint" of each mode. This invites analogy with the "ecological footprint" proposed by Rees to represent consumption of the earth's resources by communities,[1] or as estimated by the World Wildlife Fund for countries.[2] Such a footprint combines a number of the major components of consumption by the land area that their production consumes; and it ingeniously adds the use of energy from fossil fuels, by converting their carbon content into the amount of land needed for its fixation. It computes the "area of biologically productive land and water needed to provide ecological resources and services – food, fibre and timber, land on which to build and land to absorb CO_2 released by burning fossil fuels."[3] This is then compared to the actual land area of each country.

It seems immediately clear, however, that no such conversion into a single measure or index is possible for all the diverse dimensions of the freight mode impacts required in this paper. Instead it is proposed that the effects all be tabulated, with as much quantification as is possible, and qualitative rankings where necessary. To the extent possible, the quantitative measures should be standardised to comparable units of traffic. The customary units to represent transport services are tonne-kilometres, combining distance carried and weight of shipments, both of course crucial to the physical requirements for transportation.

It is recognised that tonne-kilometres (tonne-km or tkm) do not represent all aspects of transport demands and services provided, as there are other important differences in the "quality" of haulage services, notably for example their speed, reliability and security. Nor of course do comparisons among the modes of their total traffic in tonne-km represent the value of the commodities carried, and therefore the value of the services to customers. But for the present objective, which is to compare the environmental effects of the actual ocean-going traffic on the Great Lakes – St. Lawrence Seaway (GL/SLS) with the effects if that freight were instead carried by rail or truck, the measure of effects per tonne-km is the most convenient means of expressing the comparisons. (An alternative might be to estimate the total environmental effects of the current traffic, and predict the changes in those total effects if the freight was instead carried entirely by rail or by truck).

In passing, it should also be noted that a combined “footprint” of the modes might be attained through a “multi-criteria index”, in which the impacts were each weighted by their relative importance to policy-makers, or users, e.g. Such weighted indices have been attempted particularly in evaluations of transport infrastructure investments, but they clearly require agreement on the appropriate weights, which would be impractical in this project. Alternatively, perhaps the most precise version of such a weighted index would be one in which all effects were given a monetary value, and combined into a single environmental cost estimate for each mode. Considerable research has been undertaken to provide such monetary values, but estimates are certainly not available for all the dimensions considered here, and those available vary widely.[4]

In conclusion the report will attempt to include all the effects in quantitative or qualitative fashion as in the following outline table:

Effect	**Ship**	**Rail**	**Truck**
Fuel use – tonne-km per litre			
Greenhouse gas emissions – grammes per tonne-km			
NOx – g/tonne-km			
VOCs – g/tonne-km			
CO – g/tonne-km			
PM – g/tonne-km			
Land occupied			
Accidents & casualties per tonne-km			
Spills			
Noise – noise depreciation cost per tonne-km			
Congestion – delay time or $ per tonne-km			
Aesthetics			
Introduction of nonindigenous species			

FUEL CONSUMPTION AND EMISSIONS

Comparisons of fuel consumption and emissions among the three freight modes are made below, based on information from a number of US, Canadian and European sources. The intention is to provide estimates for comparable types of traffic – essentially the types currently carried by ship on the Great Lakes and Seaway. The estimates will therefore be standardised for presentation purposes as rates of fuel use and emissions per tonne-km. It must be recognised that the types of traffic carried by each mode differ substantially, in ways which affect their fuel use per tonne-km, notably in their distributions of commodities (which differ e.g. in volume and weight, affecting the vehicle type and propulsion required), shipment sizes (from small, light packages to many tonnes or cubic metres), and lengths of haul. Furthermore, the modes are complementary for much traffic, with e.g. water and rail combining in long-distance movements of grain and iron ore, and truck providing collection and distribution services for goods shipped by water or rail. In trucking in particular, fuel use per tonne-km differs substantially depending on the type of vehicle, mass and dimensions of load and trip distance, and the system-wide average rate of fuel use (and consequently emissions) would be very misleading in comparisons with water and rail. Consequently, an attempt will be made to provide estimates for trucks that are more appropriate for the long-distance carriage of bulk commodities currently provided by water in the GL/SLS.

The emissions of interest are the following:

- Greenhouse gases (GHG), of which the most important from transportation sources are:
    - Carbon dioxide (CO_2)
    - Nitrous oxide (N_2O)
    - Methane (CH_4)
- Criteria air contaminants (CACs), as follows:
    - Carbon monoxide
    - Volatile organic compounds (VOC) or hydrocarbons (HC)
    - Nitrogen oxides (NOx)
    - Sulphur oxides (SOx)
    - Particulate matter (PM)

CACs are regulated air pollutants in US and Canada, with standards for emissions by transport vehicles. Transport GHGs are not directly regulated as a class, though fuel consumption standards for cars and light trucks effectively regulate CO_2, given its direct relationship to fuel consumed.

Quantification Issues

Available data in US and Canada on freight traffic do not routinely include comparable estimates of fuel use and tonne-km by water and truck. Rail freight is exceptional, due to its history of data regulation, and the greater practicality of obtaining from the small number of carriers their total fuel use and total tonne-km derived from details of shipments. Otherwise, national statistics of fuel use are not directly comparable with the available estimates of tonne-km. Fuel use statistics are compiled from reports by refiners of sales by type of fuel and tax category, which differs at least slightly from fuel used nationally, to the extent for example that domestic carriers consume the fuels beyond national borders (and waters) and that foreign carriers use fuels purchased beyond those borders. Furthermore, refiners' fuel sales records are unable to distinguish final uses of fuels by type of vehicle, vessel or activity, separating for example the private use of road diesel fuel by cars and light trucks from commercial use by heavier trucks, or separating the use of marine diesel and residual fuel oils by fishing vessels, ferries, cruise ships, other recreational vessels or military vessels from commercial freighters. Such partitioning of fuels by type of use is attempted in both countries by government energy and transport analysts, but is acknowledged to be approximate.

Obtaining statistics of tonne-kilometres is even more problematic, necessitating complex record systems or sample surveys of the multitudes of carriers or shippers of freight. National statistics in both the US and Canada for water and truck transport rely on partial surveys and estimates of important parts of total traffic, but not the entire activity included in national fuel sales statistics. In the US, the Commodity Flow Surveys[5] in 1993, 1997 and 2002 have provided estimates of tonne-km in all modes, from samples of shipments by manufacturers, wholesalers and some retail businesses, but with the important omission (particularly for water) of all imports, and with other limitations that mean that tonne-km cannot match national sales of fuels for marine or trucking use. In Canada, Statistics Canada's Trucking Origin-Destination Survey [6] provides estimates of tonne-km for the largest for-hire truck carriers, but omitting all private (own-account) trucking and owner-operators, and similarly cannot explain all national sales of truck fuels. As will become clearer below, the central estimates made in this paper of fuel use per tonne-km for water and truck therefore rely on more limited survey data. Those estimates then form the basis for the paper's central estimates of GHG and CAC emissions.

GHG emissions per kilometre or per tonne-kilometre are relatively easily obtained from fuel use, as the relationship of CO_2 to fuel consumed is fixed, and dominates the total of greenhouse gas emissions. Total GHG is expressed in "CO_2-equivalent" (CO_2e), in which methane and nitrous oxide are weighted by their radiative-forcing capability, respectively 21 and 310 that of CO_2. Methane emissions from transport fuels are so small as to be negligible even when weighted. Nitrous oxide emissions are much more important, having contributed as much as 10% to total CO_2e from rail or marine diesel fuels, recently; though these proportions are falling over time due to the more stringent NOx controls being adopted for engines in all modes. The GHG emission factors of transport fuels used in the comparisons below, essentially for the fleets of vehicles/vessels and fuels used in the early part of this decade, are those provided by Natural Resources Canada for the Transportation Table in the development of Canada's National Climate Change Strategy Data,[7] as in Table 1, below.

CAC emissions are not measured directly from routine observations in real traffic conditions, as capture and analysis of exhaust gases is impractical. Instead they are normally estimated from laboratory testing of the engines, and then simulation in engineering models of their use in traffic conditions, with assumed loadings, etc. Estimates obtained are supported sometimes by limited samples from real traffic.

National inventories of GHG and CAC emissions are produced by both US EPA[8] and Canada's Department of the Environment,[9] with details by source, including estimates for nation-wide use by water, rail and truck freight. These rely on emission factors obtained as above, and also on attributions of diesel, fuel oil and gasoline use between transport services and other uses. Natural Resources Canada also produces estimates of energy use and greenhouse gas emissions from transport in its Energy Use Data Handbook,[10] based on that department's own interpretations of national fuel consumption data and its modelling of transport activities. The Handbook also provides that department's estimates of tonne-km for each transport mode,

TABLE 1 Greenhouse Gas Emission Factors Per Litre of Fuel

Fuel	CO_2	CH_4	N_2O	CO_2e
	grammes per litre			
Truck diesel	2360	0.331	0.34	2,471
Rail diesel	2730	0.150	1.10	3,074
Marine diesel	2730	0.150	1.00	3,043
Marine fuel oil	3090	0.300	0.08	3,121

Source: Natural Resources Canada, for the Transportation Table.

allowing simple computation of GHG emissions per tonne-km. The resulting rates appear reasonable for rail transport, agreeing with other sources for that industry, but are highly implausible for water transport.[11] It is tempting to make similar computations of emission rates per tonne-km for the US freight modes (as is sometimes done by researchers), by combining the EPA inventories with national statistics published by US DOT's Bureau of Transportation Statistics of tonne-km by mode.[12] These also, however, produce implausible results for water transport.[13] Instead, the estimates below rely on more specialised sources of data and studies of the specific transport modes, intended to represent the GL/SLS traffic with which we are concerned.

The intention, as stated in the introduction, is to provide indications of the relative impacts of the alternative freight modes, from information available readily. The estimates provided for emissions are from sources which offer measures often to several decimal places, with apparent precision, but it must be recognised that the sources are bound to differ somewhat in their methods, so that the comparisons are not exact. Furthermore, it is not necessarily the case that the emissions represented are those that are most significant from the point of view of harm to health, ecological systems or materials. An important gap in the comparisons is the absence of reporting of $PM_{2.5}$, recognised increasingly as of greater importance to health than the broader category of larger particulates, PM_{10}. The tables report estimates made during the last two decades, following conventional measurement processes, most of which estimated PM_{10} rather than $PM_{2.5}$. Consistent comparisons among the modes are therefore not possible. However, an exception is the recent study of ship emissions by Levelton which will be described below, which provides estimates of both PM_{10} and $PM_{2.5}$, and in which the latter are consistently about 80-85% of the mass of the former.

Ship Emissions

Table 2 illustrates estimates of ship emission rates per tonne-kilometre of different vintages, and for different countries, obtained from two prominent OECD studies and another by the European Conference of Ministers of Transport (ECMT),[14] together with studies by EPA for the US and Levelton consultants for Canada.

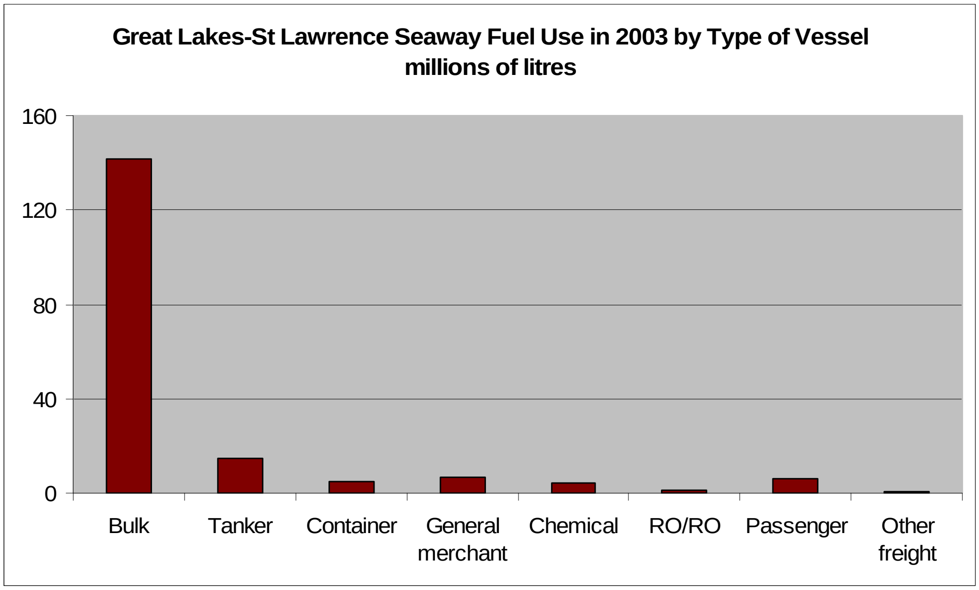
TABLE 2 Estimates of Emission Rates from Marine/Inland Water Freight Transport, Grammes Per Tonne-Kilometre of Freight

Study (year) / country	CO_2	CO	HC	NOx	SOx	PM_{10}
OECD (91) / EU[15]	40	0.018	0.08	0.05	0.05	0.03
Befahy (93) / Belgium[16]		0.2	0.08	0.58		0.04
SN (97) / Neths[17]	33	0.11	0.05	0.26	0.04	0.02
ECMT (98) / EU[18]	12		0.01	0.32	0.24	
EPA (98) / US Great Lakes[19]		0.012	0.006	0.163		0.012
Levelton (06) / Transportation Table / Eastern Canada[20]	(10)*	0.009	0.009	0.285	0.145	0.025
Levelton / TT SLS estimate	(10)*	0.011	0.008	0.253	0.144	0.021

* Estimate from the Transportation Table in Canada's National Climate Change Strategy development

It can be observed that the estimates vary substantially, for some of the emissions by a factor of 10 or more. That doubtless reflects differences in measurement or estimation methods, and also differences in the populations of vessels, engines and their activities represented – notably for example differences in inland barge traffic versus coastal or oceanic marine traffic. The EPA and Levelton-based estimates are clearly more relevant, being more recent and specifically for traffic on or including the Great Lakes. They are also very consistent, relative to the European estimates. This is partly because they are based on the same recent industry research on engine emission rates, though the manner in which they are related to tonne-km is very different. The EPA study used records of ship movements which included deadweight tonnage, and assumed they were loaded to 60% of that tonnage, to estimate total tonne-km. The Levelton study similarly obtained emissions from ship movement records, by estimating trip distances and vessel speeds, and applying emission factors for the specific engines. It provided great detail of emissions by type of vessel and location, for all movements in eastern Canadian inland and coastal waters in 2003, and by region such that the SLS could be distinguished. The study did not however estimate tonne-km. Therefore tonne-km were derived for this paper by calculating from the Levelton study's estimates of CO_2 emissions the implied fuel use, then applying the estimate of CO_2 emissions per tonne-km obtained by the Transportation Table, from a survey in 1998 of Eastern Canadian freight carriers – of 10 grammes per tonne-km.[21] That the resulting estimates of CAC emissions per tonne-km are so close to those produced by EPA gives confidence that this crude estimate of tonne-km is reasonable. The final row of the table then shows estimates of emissions for the SLS, derived from Levelton's volumes of CACs and CO_2, combined again with the Transportation Table's estimate of 10 grammes of CO_2 per tonne-km. In passing, it is relevant to the broader objectives of the committee to note that the fuel consumption estimates derived from the Levelton study can be tabulated by vessel type and region (within Canadian waters) allowing for example the presentation in Chart 1 of fuel use in the Great Lakes and Seaway by vessel type.

CHART 1



It is concluded that the estimated rates in the final row of the table, derived from the Levelton study, for the St Lawrence Seaway, together with the rate for CO_2 from the Transportation Table, are the most appropriate for the purposes of this paper.

Rail Emissions

Estimates of emission rates per tonne-km for CO_2 and CACs from rail freight are provided in Table 3. Comparing the rates for CO_2, which directly reflect fuel use per tonne-km, shows clearly that the European estimates are for very different equipment and services than those in Canada. The lowest of the European rates, for the UK, is nearly two and a half times greater than that in Canada, while the highest of those rates, for the Netherlands, is fully 6 times greater. These differences reflect the different locomotives and freight cars, shorter distances and lighter loads of shipments in Europe, compared to operations in Canada. They also reflect operational productivity, Canadian (and US) railways having the highest total factor productivity and lowest costs per unit of traffic among world freight railways.

The rates for Canada in the table are obtained through a Memorandum of Understanding between the Government of Canada and the Railway Association of Canada, under which emissions of GHGs and CACs are reported annually, together with tonne-km. The table shows rates for 2004. They are considered accurate by Environment Canada, and are used in the national inventories of GHGs and CACs. The GHG rate is also in close accord with the rate that can be derived for the US from national rail fuel use statistics and industry- produced tonne-km, of 18 grammes per tonne-km.[22] The rates are averages for all national traffic, not specific to the traffic in the region of the GL/SLS. However, it can be expected that the type of traffic currently carried by ocean-going ships in that region – primarily bulk commodities – is the dominant type in rail freight in Canada generally. Therefore it is concluded that the average rates in the final row of the table are appropriate for this paper.

Truck Emissions

Estimated rates for truck GHG and CAC emissions are presented in Table 4, again including European estimates, together with a recent estimate for Canada. The rates selected from the European studies are for the largest European trucks, and truck combinations, but it is recognised that those are still relatively smaller than the typical truck combination used for long-distance hauls in Canada, and that the average length of haul is probably much greater in Canada than in Europe. The figures provided for average Canadian trucks in the table are from the Transportation Table of the National Climate Change Strategy development, and refer to all for-hire trucking in Canada, both long- and short-haul, including all the local pick-up and delivery. It is evident from the CO_2 emission rate, which again directly reflects fuel use per tonne-km, that Canadian for-hire operations on average have been more fuel-efficient than the long-haul traffic in Europe (though the ECMT estimate for large long-haul trucks is essentially the same as the Canadian average).

TABLE 3 Estimates of Emission Rates from Rail Freight Transport, Grammes Per Tonne-Kilometre of Freight

Study (year) / country	CO_2	CO	HC	NOx	SOx	PM_{10}
OECD (91) / EU[14]	48	0.15	0.07	0.4	0.18	0.07
Schoemaker & Bouman (91) / Neths [23]	102	0.02	0.01	1.01	0.07	0.01
RCEP (94) / UK [24]	41	0.05	0.06	0.2		
ECMT (98) / EU[17]	69		0.07	1.22	0.08	
EC & RAC (05) / Can [25]	17	0.092	0.024	0.3	0.022	0.011

TABLE 4 Estimates of Emission Rates from Truck Freight Transport, Grammes Per Tonne-Kilometre of Freight

Study (year) / country	CO_2	CO	HC	NOx	SOx	PM_{10}
OECD (91) / EU[14]*	140	0.25	0.32	3	0.18	0.17
Schoemaker & Bouman (91) / Neths*	127	0.34	0.34	2.3	0.11	0.19
ECMT (98) / EU[17]*	100		0.05	1.2	0.03	
Transport Canada (00) / Canada – average for-hire trucks**[26]	103	1.52	0.14	2.6	0.05	0.11
Transport Canada (00) / Canada – 8-axle combination	33	0.49	0.04	0.83	0.02	0.04

*large EU trucks/tractor-trailers
** for-hire trucks

It will be noted that the emission rates in the table for average Canadian trucks are substantially higher for CO and NOx than are those for European trucks. The Canadian rates are derived from emissions per litre of truck diesel fuel recommended by Natural Resources Canada for the work of the Transportation Table, but it is recognised that they might be seriously out of date, particularly for NOx, for which increasingly stringent heavy truck engine standards in both US and Canada are changing average emissions of the truck fleet rapidly, and will continue to do so for at least the coming decade.

The table then also shows in its final row some estimated rates of emissions per tonne-km from the types of trucks that would be used in transporting the kinds of bulk commodities currently carried by ocean-going ships in the Seaway. These were derived by the author, from estimates produced for Transport Canada of truck costs by configuration and load, in 1996.[27] The fuel costs in those reports allow fuel consumption and therefore GHG to be calculated, producing the rates per tonne-km for various configurations and loadings in Chart 2. The rate from Table 4 for average emissions within all for-hire trucking is also shown, at 103 grammes per tonne-km. It can be seen that a number of smaller 2-axle trucks have rates much higher than that average, but the largest bulk-carrying combinations have much lower rates than the average. The 5-axle bulk dry tanker with a load of 30 tonnes – the typical large combination throughout the US – would have a rate of only 40 grammes per tonne-km, while the 8-axle "Super-B" dry bulk tanker with a load of about 44 tonnes – the large Canadian configuration – would have a rate as low as 33 grammes per tonne-km. It is proposed that this large truck would be the practical alternative for the freight currently carried by ocean-going freighters. The freight concerned is almost all bulk or containerised (as e.g. confirmed by the fuel use in Chart 1), for which the largest truck configurations provide the lowest cost option. CAC emission rates for these larger trucks are not available separately, therefore the rough assumption is made in the table that they would be proportional to fuel use, and therefore would be lower by the same proportion as CO_2 emissions relative to the average for-hire truck. These rates are proposed as appropriate for this paper.

Comparisons of Best Estimates for Bulk Freight Traffic by Mode

The estimates considered most appropriate by mode are compared in the following tables, first the rates expressing fuel use, actually inverted as tonne-kilometres per litre of fuel, a more intuitive comparison among the modes, in Table 5. The figures are not strictly for the same calendar year, nor determined with the same degree of certainty – as noted above, the ship figure was estimated from a survey in 1998, and the truck figure from data for 1996, while the rail figure represents the Canadian industry's statistics from 2004 and is clearly more reliable. The real rates will vary from year to year with the nature of the engine and equipment employed, and the load factors realised. It is proposed that, given this variability and the uncertainty in the estimates, they should not be considered as precise estimates, but as indicative of the relative situation among the modes for similar operations in the early part of this decade.

CHART 2

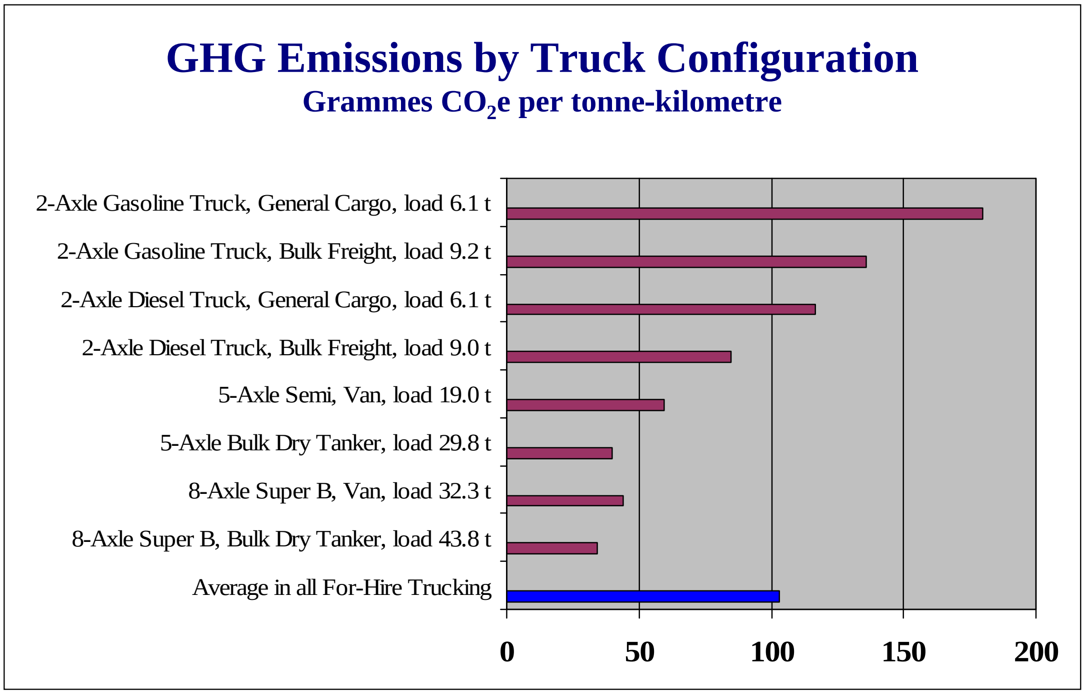


Table 5 suggests that ship was able to provide more than 70% more tonne-km per litre than rail, and four times more tonne-km per litre than the large combination trucks.

Then Table 6 provides the comparison of emissions of CO2 and CACs. As indicated, the rates are not strictly for the same year: the ship data were for 2003, and the rail numbers for 2004, while the truck rates are less certain estimates from the late 1990s.

It is apparent from the table that the rate of emissions of CO_2 per tonne-kilometre is estimated to be substantially lower for ship than for the other modes providing comparable services, some 40% lower than rail and 70% lower than trucks. Trucks would also have the highest NOx and CO emission rates – though, as mentioned, the NOx rate is declining particularly fast for trucks. Rail would have lower rates than ship for SOx and PM_{10}, with recent fuels, though recent and anticipated reductions in sulphur contents of fuels will reduce these emissions in all modes. The comparisons are presented graphically in Chart 3.

LAND AREA OCCUPIED

An attempt has been made, in accordance with the Statement of Task, to make rough estimates of the land area occupied by facilities required for freight transport by ship, rail and truck in the service area of the Great Lakes and St. Lawrence Seaway.

Land for Ship Facilities

For ship transport, the land area included is that of the 15 major GL-SLS ports in the US and 11 in Canada, plus the area of land occupied by the Seaway facilities themselves – the canals and locks. Using descriptions of the ports available from public sources, notably their individual websites and that of the Great Lakes-Seaway,[28] estimates have been obtained of the land area, as shown in the following Table 7. The estimates are certainly very rough – it is often not clear from their sources whether the area concerned represents the terminal facilities or the entire area occupied, and there is clearly a mixture of both in the table. Where figures are only for terminals, the full area occupied is obviously underestimated. Moreover, for those asterisked no information was obtained, therefore they were estimated based on their size relative to the others in the list. However, given the necessity also to estimate for the other modes using crude assumptions, the comparison can only be a very rough indication, for which these estimates are probably sufficient. The table shows a total of about 3,500 hectares, which, given the suspected underestimation involved, and the exclusion of smaller ports, should probably be expressed as 3,500-5,000 hectares of port land.

The area occupied by the Seaway canal and lock facilities is not available in published information on the Seaway. However, a small snippet is contained in the St. Lawrence Seaway Management Corporation’s description of the history of the Welland Canal, that the “By-Pass” section around Welland, a 13.4 km section, opened in 1973, required the purchase of 2,600 hectares of land.[29] The navigable section itself is itself just 106 metres wide, therefore covering an area of 1.42 million square metres, or 142 hectares. The land required was therefore about 18 times the area of the canal itself. The remainder of the Welland Canal is a further 30 km in length. Assuming the other sections, being built in earlier times, used only half the amount of land as the By-Pass, the area occupied would be a further 2,900 hectares.

TABLE 5 Estimates of Fuel Use Rates by Mode of Transport, in Tonne-Kilometres Per Litre of Fuel (Early in Decade Beginning in 2000)

Freight mode	Tonne-km per litre
Ship	312
Rail	181
Truck – 8-axle combination	75

TABLE 6 Estimates of Emission Rates by Mode of Transport, Grammes Per Tonne-Kilometre

Freight mode (year)	CO_2	CO	HC	NOx	SOx	PM_{10}
Ship (2003)	10	0.011	0.008	0.253	0.144	0.021
Rail (2004)	17	0.092	0.024	0.3	0.022	0.011
Truck – 8-axle combination (late 1990’s)	33	0.49	0.04	0.83	0.02	0.004

CHART 3

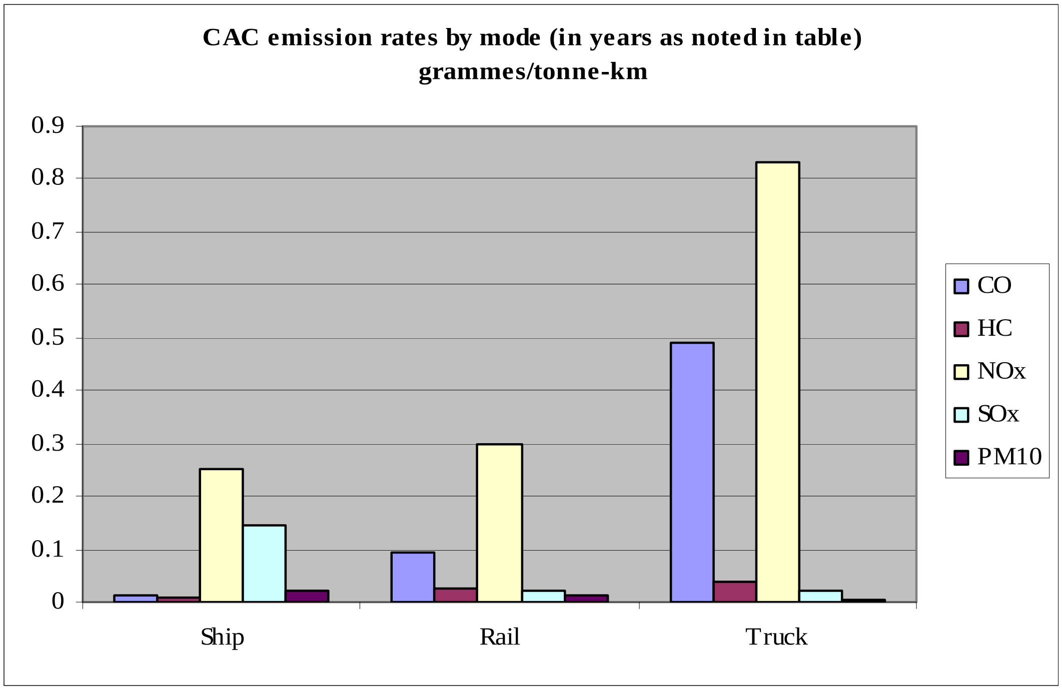


TABLE 7 Rough Indications of the Land Area Occupied by Port Facilities at the Main GL/SLS Ports

US	hectares	acres
Duluth	405	1000
Green Bay	40	100
Milwaukee	28	70
Chicago	684	1690
Burns Harbor	202	500
Detroit	16	40
Monroe	8	20
Toledo*	16	40
Cleveland	62	154
Ashtabula	81	200
Conneaut*	16	40
Erie	29	72
Buffalo	12	30
Oswego*	8	20
Ogdensburg	3	8

* no information – estimated.

Canada	hectares	acres
Thunder Bay	32	79
Sault Ste Marie*	12	30
Goderich*	8	20
Sarnia*	40	100
Windsor	59	145
Hamilton	195	482
Toronto	485	1,198
Oshawa	5	12
Prescott	35	86
Valleyfield	10	25
Montreal	977	2,178

Grand total	3,471	8,340

The Corporation also describes each of the seven locks in the Montreal-Lake Ontario section of the Seaway as being 233.5 metres long by 24.4 metres wide, an area of 0.57 hectares, or 4 hectares for the seven locks. Even if they required the same ratio of total land to canal as the Welland By-Pass, they would occupy only about 73 hectares. Including the US and Soo Locks would still mean the locks occupied less than 100 hectares.

Totalling these estimates, the Seaway and Great Lakes canals and locks would occupy roughly 5,600 hectares. Added to the estimate for the ports, of 3,500-5,000 hectares, the rough total estimate of land for ship transport is about 10,000 hectares.

Land for Roads

For roads, it is assumed that the relevant road network is that linking all of the 26 main GL-SLS ports with Montreal – i.e. those roads necessary to serve all those ports from Montreal if ship traffic were transferred to road. The length of each link was estimated using “Mapquest” together with the portions of each link that are limited-access highways as opposed to undivided roads. The total length concerned was estimated as 4,969 kilometres, of which 2,975 km is limited-access. Only a simple approximation of the area of land occupied is possible, of course. Assumptions were made of the average widths of roads (which the author had made in previous Canadian research[30]), namely that the right-of-way required for a limited-access highway is 100 metres, and that for an undivided interurban road is 30 metres. The resulting estimates are that the area occupied by freeways is 29,754 hectares, and the total occupied by undivided roads 5,981 hectares, for a rounded total of 36,000 hectares.

This does not of course consider the requirements for land for truck terminals, storage and transhipment of freight, equivalent to the terminal space in ports.

Land for Rail Track

The length of the rail network linking the main GL/SLS ports was not estimated precisely, but for rough indicative purposes was assumed to be the same as the road network – i.e. approximately 5,000 kilometres. The land required for the tracks can again be estimated from an assumed average width of the right-of-way owned by the rail carriers. This is expected to be less on average than for an undivided road, and guessed to be 20-30 metres. The resulting estimate of land occupied by railtracks is therefore between 10,000 and 15,000 hectares.

Again, this estimate does not consider land required for terminals for storage and transhipment.

Summary and Discussion

In summary, the rough orders of magnitude of land required for the facilities for ship, rail and truck transport for the GL/SLS are as shown in the Table 8. It seems clear that roads require the most and ship facilities the least.

However, as well as being based on rough approximations, the comparisons are dubious, for a number of reasons. Most obviously, the facilities for ship transport exist primarily to serve freight transport, while the road and rail networks also accommodate significant volumes of passenger traffic. Roads in particular provide most of their capacity to accommodate passenger vehicles, which of course dominate vehicle traffic. Railtracks also accommodate some passenger traffic, though it comprises only a small proportion of their total traffic. Second, the densities of traffic on the alternative road and rail networks in this region are also much greater than those on the Seaway – estimates of traffic provided to the Committee show that the Seaway between Montreal and Lake Ontario carried 29 million tonnes in 2003, compared to 37 million tonnes on the highways parallelling that section; the Welland Canal section of the Seaway carried 32 million tonnes, while the parallel highway between Toronto and Detroit carried 61 million tonnes.[31] Average rail volumes of 60 million tonnes were reported for CN alone between Montreal and Toronto.[32] If the land occupied were somehow standardised to traffic (square metres per tonne-km?) it would probably show rail occupying less than ship facilities, and would at least narrow the gap between roads and ship facilities. If somehow passenger traffic were also factored in, roads would probably show the lowest land requirement. On the other hand, if the cost of the land was estimated by valuing it at its alternative best use (i.e. opportunity cost), it seems likely that ship facilities would show the lowest costs and roads the highest, due to the difference in their use of highest-valued land in urban cores.

TABLE 8 Indicative Estimates of Land Area Occupied by Freight Facilities

Freight facilities	**Land area hectares**
GL/SLS ports, canals, locks	10,000
Railtrack	10-15,000
Roads	36,000

Third, and most important, the total amount of land used, and the average amounts per unit of current traffic (if we could agree how to measure them) cannot in any obvious way represent the implications of shifting traffic from ship to the other modes. Land requirements for transport facilities do not vary in any simple direct way with traffic: the area needed for a Seaway lock is the same for one ship or many, up to the number of ships that can be handled during the season, after which a duplicate lock would be needed. The need for land in ports for berths and terminals changes with large changes in traffic, but is still invariant over a range of numbers of ships and volumes of cargo. Similarly, railtracks and roads are able to accommodate wide ranges of traffic, and need duplication in numbers of tracks or lanes as traffic expands. The current average amount of land per unit of traffic is therefore not a direct measure of the incremental (or "marginal" in the economists' terminology) requirement for land as traffic expands or contracts.

We can conjecture what might be the implications for the amounts of land required if ocean-going traffic on the Seaway were transferred to other modes. The Seaway locks, channels and ports would still be needed to accommodate all the remaining non-ocean-going traffic. Land needed for terminals and berths might be reduced at the SLS/GL ports, but the freight would still need to be loaded/unloaded and transhipped between ships, rail and/or trucks at ocean ports (on the coast or in the Lower St. Lawrence), and the requirement for terminals and berths would presumably increase at those ports by approximately the same amount as it was reduced at the SLS/GL ports, so there would be no substantial net change in the requirement. Whether the transfers of freight to rail or truck would require expanded capacity and increased areas of land would depend on the capacity and existing traffic demands on the relevant links. On links for which the transferred traffic meant that capacity was exceeded, there would be a need to add tracks or lanes. In essence, requirements for expanded capacity would be related directly to the extent of existing congestion. As will be noted below in the section on congestion, most of the relevant rail network in the region probably has sufficient excess capacity to handle traffic transferred from ships, but there are links in and around Chicago which are currently congested and might need expansion to handle further traffic. Much of the relevant intercity highway network also has excess capacity, but there is serious congestion in and around the major cities in the region. Transferred traffic might again only be handled if those links were expanded.

In conclusion, the rough indications of land use estimated above will be presented in the final tabulation of effects, but they must be interpreted with great caution given the qualifications expressed. In particular, they cannot represent the incremental requirements for land if traffic were transferred from ships to rail or truck. Those incremental requirements are probably better represented by the qualitative ranking for congestion, discussed below.

ACCIDENTS

As noted in the introduction, it seems reasonable to include accident experience among the environmental effects of the freight transport modes, due to their similarity in ultimate effects – notably on health and well-being – to those of environmental emissions.

Accident definitions and reporting criteria differ somewhat by mode, and between Canada and the US. However, estimates of standardised frequencies of accidents and their consequences in deaths and injuries are published in the US, in the Bureau of Transportation Statistics' annual National Transportation Statistics.[33] The publication also provides the estimates of tonne-kilometres of freight described above in the examination of emission rates. Those are more consistent, and more readily available, than the estimates for Canada.

The US estimates of accidents, casualties and tonne-km for 2003 have been combined to provide the rates per tonne-km of freight in Table 9. These are nationwide rates for the US, rather than for the types of traffic currently carried by ocean-going ships in the Seaway. Distinguishing the relevant types of vehicles and loads is simply not possible, notably within truck accident records. It can be conjectured that the accident and casualty rates per tonne-km for the 8-axle combination trucks identified above as the potential competitors to ship transport by the Seaway would be lower than those for average trucks, as was indicated in the Canadian research that provided the basis for the regulatory decisions permitting such trucks. However, no precise estimate is available, so the average rate must be used an approximation.

The table also presents alternative estimates for rail, depending upon whether grade crossing accidents are included or not. No resolution of the debate over how such accidents should be attributed to roads or rails is offered here, but rather both alternatives are provided as indicators.

It can be seen from the table that ship transport has the lowest (reported) rates of casualties per tonne-km, and truck the highest. It should also be noted that the ratio of accidents to fatalities and injuries is much greater for trucks than for the other two modes, reflecting the fact that the proportion of road accidents involving trucks is much greater than the proportions of fatalities and injuries that are truck occupants.

It is simple to conclude from this evidence that the accident risks are lower for ship freight than rail freight, and much lower still than for truck freight.

SPILLS

“Spills” in our context is the popular term referring to harmful discharges or other contamination of natural systems, occurring as a consequence of freight transportation. It includes therefore leakages and accidental or deliberate spills and discharges of the cargo materials themselves, or other materials used in the transportation process – most prominently the fuels or lubricants of the vehicles or vessels.

TABLE 9 Accident and Casualty Rates Per Billion Tonne-Km, by Freight Modes, US 2003

Freight mode	Fatalities per billion tonne-km	Injuries per billion tonne-km	Accidents per billion tonne-km
Ship	0.05	0.23	5
Rail (exc crossings)	0.21	3.12	1
Rail (inc crossings)	0.34	3.52	2
Truck	0.36	13.22	214

Source: US BTS: National Transportation Statistics 2006.

Regulations in both the US and Canada specify procedures for the safe transportation of hazardous materials, and require that harmful discharges be reported to authorities, prescribing the materials (known as “hazardous materials” in the US and “dangerous goods” in Canada), and the minimum conditions under which discharges become reportable. These include any incident in which death or injury requiring hospital admission occurs, or members of the public are evacuated from the area for an hour, or a major transport artery is closed for an hour; or releases of specified quantities of materials posing immediate dangers to health. For marine incidents, releases of smaller quantities of some contaminants are reportable recognising their greater potential for harm when dispersed in water.[34]

It seems very likely that such incident reporting regulations are evaded and otherwise not applied consistently, given the potential consequences. It is also possible that the quality of reporting varies between the modes of transport, given for example the great differences in the number of operators between trucking and rail transport. Nevertheless, large numbers of incidents are reported annually, particularly in the U.S., and the published statistics can at least allow some indication of the numbers of incidents by severity, and their distribution among the modes. Table 10 provides statistics from the US for the 5 years 2001-2005 combined, by transport mode and severity, including reported estimates of the value of damage.

The lower half of the table provides total figures for the entire US, showing that the number of incidents in water transport was only a small fraction of one percent of the total for all modes, with incidents in rail being nearly 40 times more frequent, and those in highway transport over 600 times more frequent. Furthermore, there were no injuries or fatalities reported during the 5 years in marine transport, while there were 17 fatalities and 879 injuries reported in rail and 66 fatalities and 659 injuries reported in truck transport.

The upper half of the table provides the figures for the 8 States that border the Great Lakes.[35] It can be seen that these together were responsible for about 34% of the total transportation incidents reported throughout the US, about 22% of reported fatalities and 17% of reported injuries. The disparity among the modes is even more striking, with only 12 marine incidents reported, of a total of nearly 25,000 for the 3 modes over the 5 years; and 18 fatalities and 265 injuries reported in the other two modes while none were reported in marine transport.

TABLE 10 US Hazardous Materials Incidents During 2001-2005, by Mode of Transport and Severity

	Incidents	Major Injuries	Minor Injuries	Fatalities	$ Damages
Great Lakes States					
Water	12	0	0	0	0
Rail	906	2	35	3	12,799,273
Highway	23,795	25	201	15	48,956,026
US Totals					
Water	109	0	0	0	2,296,729
Rail	4,062	125	754	17	60,936,541
Highway	69,242	107	552	66	217,040,140

Source: Pipelines and Hazardous Materials Safety Administration (www.hazmat.dot.gov)

These figures are of course not standardised to the amounts of traffic carried by the alternative modes, and there were doubtless considerably greater volumes of freight carried by rail and truck than by ships within the whole of those Great Lakes States. Statistics describing those amounts of traffic have not been available for this project (if indeed they are available from any source),[36] but it seems clear that the disparity in incidents reported among the modes could not be explained by the larger shares of road and rail, and that the incidents and casualties per tonne-km of freight have been much lower for marine transport than for rail or truck.

Statistics of reported dangerous goods incidents are also published for Canada by mode of transport at the national level (i.e. not by Province). Table 11 shows the results for marine, rail and road during the same five-year period 2001-5. In these national statistics, marine incidents were about 3% of those reported for the three modes over the period, with rail and road incidents being similar in frequency, both about 18 times greater than the marine figures.

These figures again cannot be standardised to traffic, as tonne-km figures by mode are not available for truck and marine for all the traffic represented in these incident figures. But again, it seems clear that the disparity in incidents could not be explained by the differences in tonne-km among the three modes, and that the incident rates must be lower per tonne-km for marine than for the other modes. Whether rail or truck would have the higher rate cannot be guessed without more information on their tonne-km.

NOISE

Noise from transport is commonly held to be a nuisance, particularly by those exposed to frequent loud noises of aircraft near airport, of trains in marshalling yards and of road vehicles near urban highways. Noise is however difficult to measure in ways which represent the nuisance it produces. Physically, noise is measured conventionally by pressure in decibels, and as an index of relative loudness by dB(A) which is pressure weighted differentially at different frequencies. The pressure depends on such factors as the nature of the source (or transport equipment, in our case), the distance to the recipient, and absorption properties of surrounding materials. The subjective experience by recipients depends on their tolerance and mood, and appears to be affected by the background (ambient) noise, the duration of each episode, frequency of episodes, and relative intensity.[37]

TABLE 11 Canada - CANUTEC Reports of Hazardous Materials Incidents by Mode of Transport, 2001-2005

Mode	2001	2002	2003	2004	2005	5-year total
Marine	20	9	9	8	16	62
Rail	266	255	219	189	205	1,134
Road	222	247	224	215	221	1,129
Totals	488	502	443	404	426	2,263

Source: Transport Canada, Dangerous Goods Directorate, CANUTEC
http://www.tc.gc.ca/emergencies/menu.htm

Transport noise measurements are common at airports, often to meet regulatory requirements, and less frequently at railyards and along urban highways. For aviation, a “Noise Exposure Forecast” has been used, combining numbers of events and their intensity over a specified time period. Research into monetary valuations of noise costs have also been undertaken relatively frequently, particularly for transport noise, again mostly at airports. Estimates based on the depreciation in value of properties with increasing exposure to airport noise have been undertaken for a number of airports in the developed world. In a recent survey of such estimates, Gillen describes the “Noise Depreciation Index” as the percentage reduction in property values per dB(A), and suggests it has been found to be in the range of 0.3-2.3% in several airport studies.[38]

However, measures of noise nuisance and valuations of noise costs are very uncommon for the other modes of transport. None of any immediate relevance for ship and rail freight noise have been found. One estimate for truck freight is quoted by Gillen, from a study in Switzerland by INFRAS, estimating from a Noise Depreciation Index that reductions in property value from truck noise amounted to $0.0163 per tonne-km. Such an index could conceivably be estimated in the US or Canada, with different vehicles, traffic conditions and ambient noise than in Europe, but this has apparently not been undertaken.

In the absence of any quantitative evidence, it can only be conjectured how noise nuisance differs among the three freight modes. However, in view of the relative proximity of the operations to residential areas, as well as the nature of the transport equipment and engines, it is proposed that the relative ranking would be that truck would impose the greatest noise nuisance per tonne-km, and ship the least.

CONGESTION

Congestion is potentially important to freight traffic particularly due to the delays in shipment deliveries, and the costs of the delays in equipment, operators’ salaries, and fuel. It can also increase emissions of GHG and CACs, and exacerbate noise nuisance, considered earlier.

Traffic congestion has been the object of very extensive research, particularly for roads, by generations of traffic engineers concerned to understand and model the effects of traffic volumes on capacity. Research into the economics of traffic congestion also has a very long provenance, including extensive efforts to value delays to users, and to understand the external costs of congestion. Most of that work has been concerned with passenger travel time, and very little for freight. And research into congestion delays and their costs in modes other than road is also much more rare.

The recent examination by University of British Columbia staff of social costs of transport reviews the congestion estimation literature, and summarises a number of estimates of freight transport delay costs. All are expressed in values per shipment – a curiously non-standardised measure, peculiar to the traffic considered in each study.[39] Truck delay values reported from the various studies ranged from $45 to $200 per shipment – but those cannot be transformed into costs per tonne-km for all truck shipments.

In the absence of quantified estimates for average traffic conditions in the GL/SLS region for any of the three modes, again only conjecture of qualitative rankings is possible. First, it is clear from the nature of the traffic that there are few if any delays to ship traffic that might warrant the title of congestion. For rail traffic, knowledge of the track capacity in Canada linking the Seaway and great lakes ports suggests there is no serious congestion issue except through Toronto, and it would for example be possible to accommodate the ocean-going freight if it shifted from the Seaway to rail with adjustments to scheduling and no serious delays. In the US rail network, there is serious congestion in and around Chicago, the largest US rail hub, and location of transhipment activity. Additional traffic transferred from ship would presumably impose some additional congestion if its routing took it to Chicago. For truck traffic, there is severe congestion during rush hours in all the major cities involved, and some, such as Toronto, are experiencing increasing congestion in the daytime period between peaks.[40]

It seems relatively clear again that the rankings of the three modes in terms of congestion would be truck highest and ship lowest.

AESTHETIC AND OTHER ENVIRONMENTAL DEGRADATION

Other aspects of degradation of the natural environment that raise concerns among the public and interest groups include some specific nuisances, for example vibration from heavy vehicles and trains (frequently mentioned in Europe, for example, with older buildings close to transport facilities), or the disruption of communities from the inability to cross roads with high traffic volumes. They also include some more nebulous feelings of distress at the visual intrusion of transport facilities and traffic, and loss of aesthetic pleasure in the natural landscape. These concerns are often recognised in the studies of the "full costs" of transport, which attempt to estimate monetary values for all the negative effects that normally have no market value, but are almost never quantified or monetised.

For example, the recent review of social costs by the University of British Columbia for Transport Canada noted potential costs from "vibration damage to structures adjacent to transportation facilities; visual intrusion, i.e. transport facilities or operation may interfere with people's ability to enjoy their surroundings and scenery," but argued they were less important, and did not review them.[41]

In the most comprehensive costing of US motor vehicle use, by Delucchi[42], the following effects were identified, but considered impossible to quantify and value:

- Vibration
- Habitat destruction and species loss due to highways
- Socially-divisive effects of roads as physical barriers in communities
- Aesthetics of highways.

Some research in Switzerland has suggested solutions to the valuation of "nature and landscape". In the major European social costing study in 1995 (updated in 2004),[43] by the consulting company INFRAS and University of Karslruhe, the novel valuation of landscape degradation was included, from the proposition that the value is the cost that would be required to remove transport structures (roads, railways, airports) and reinstate the former natural beauty. Then the Swiss Federal Office for Spatial Development adopted a similar approach in estimating national costs of transport, specifically estimating the value of loss of beauty and habitat by the costs needed to replace the natural conditions. That agency reported official estimates of total costs for Switzerland in 2006 as shown in Table 12 (converted to millions of $US at an exchange rate of 1 Swiss franc = $0.82):[44]

TABLE 12 Valuation of Loss of Beauty and Habitat, Switzerland 2006 ($ Million US)

	Road	Rail	Total
Passenger	453	55	508
Freight	90	30	120
Total	543	84	627

The basis for this monetary valuation is very debatable, but as these relative costs are indicative of the quantities and intensity of the degradation, they support the expectation that road imposes greater aesthetic losses than rail, even in a country such as Switzerland, with an unusually extensive national rail network.

It can also be conjectured that these other nuisances of community disruption and aesthetic degradation are likely to be causally related to congestion; but no information other than complaints and laments exists for such nuisances in North America. Those would also support a ranking with truck having the greatest negative impacts and ship the least.

INTRODUCTION OF NONINDIGENOUS SPECIES

For completeness, the comparison of “environmental footprints” among the modes should include their relative importance in the introduction of nonindigenous species. This is of course the main issue before the committee in the case of freight transportation by ship in the St. Lawrence Seaway and Great Lakes, and is examined extensively in the Committee’s other White Papers and reference materials. All that remains to be considered here is the relative contribution of the three modes, ship, rail and truck, in introducing nonindigenous species.

The published literature reviewed on invasive species includes extensive consideration of pathways, or vectors, by which species are introduced, but does not include any quantitative comparison among the three freight modes. A comprehensive recent taxonomy of pathways was included in the report of the US Invasive Species Advisory Committee, Pathways Team.[45] That identified all modes of transport as potential pathways, and proposed how pathways should be evaluated, but it did not achieve the next step (as proposed in its terms of reference) of assigning priorities to pathways.

The Management Plan of the US National Invasive Species Council[46] notes the extensive responsibilities for control of transportation of invasive species, including those of the US Department of Transportation, covering all modes of international and interstate transportation. However, it mentions no specific control measures or programs for rail or truck transport, while transport by ship and aircraft are clearly identified as the objects of programs. Similarly, the US Geological Survey’s description of its Invasive Species Program[47] includes specific action on ship ballast water and aviation, but none on other modes of transport.

Canada’s programs directed at invasive species, including an Action Plan on Aquatic Invasive Species, but no specific programs directed at land transport modes.[48]

The work of Pimentel and collaborators in describing the extent and costs of nonindigenous species in the US includes some indications of pathways of introduction, both deliberate and accidental.[49] Identifying the pathways is not a focus of the work, however, and the only transport modes mentioned are again shipping and aviation.

In assessing the relative contributions of the modes as pathways, a key point is that the primary concern is about intercontinental transfer of species. Historically, shipping bore all the responsibility for such transfer. Aviation has been added in the last few decades, but shipping remains by far the most important pathway due to the greater volume of traded commodities for which it is responsible, as well as the relative nature of the operations. The land modes clearly can bear none of the responsibility for original inter-continental transfers, but play a role in transporting species, deliberately or accidentally, within the continent, when the species are within trade packaging or containers. Introduction of non-native aquatic species via land transport modes has been documented in Europe.[50] Inter-regional trade has expanded rapidly in recent decades, stimulated by liberalised trade rules and liberalised freight carrier regulation, and consequent improvements in productivity of trucking and rail. Their potential contribution to the continent-wide spread of non-indigenous species has therefore also expanded. However, quantitative estimates are not available, and it seems likely that the risks posed by those modes are minor compared to the risks from ocean-going shipping on inland waters, as in the GL-SLS.

In summary, it seems qualitatively clear that ship scores substantially worse than the other two freight modes in the dimension of introduction of nonindigenous species. In the absence of information on the risks posed by truck and rail, any ranking between them would be entirely conjectural, therefore it is proposed that they be ranked equally.

SUMMARY OF FINDINGS

Table 13 below summarises the “footprint” assessment for the three modes.

TABLE 13 Summary of Estimated Environmental Effects of Freight Transport by Ship in the St. Lawrence Seaway and Great Lakes, and by Alternative Modes

Effect	Ship	Rail	Truck
Fuel use – tonne-km per litre	312	181	75
Greenhouse gas emissions – grammes per tonne-km	10	17	33
NOx – g/tonne-km	0.253	0.3	0.83
VOCs – g/tonne-km	0.008	0.024	0.04
CO – g/tonne-km	0.011	0.092	0.49
PM_{10} – g/tonne-km	0.021	0.011	0.004
Land occupied - hectares	10,000	10-15,000	36,000
Accidents: injuries per tonne-km	0.23	3.12	13.22
Spills	L	greater than ship	
Noise – noise depreciation cost per tonne-km	L	M	H
Congestion – delay time or $ per tonne-km	L	M	H
Aesthetics	L	M	H
Introduction of nonindigenous species	H	less than ship	

Notes:

Letters refer to subjective rankings of relative environmental effects or nuisance, L = lowest, M = medium, H = highest.

Rates of fuel use, emissions and accidents are from slightly different recent years, and estimated with different degrees of certainty for the three modes: see text sections for more details.

The figures provided of rates per tonne-km, and absolute numbers for land occupied, come directly from the sections above. The figure for accidents provided is the rate of injuries, as an approximate indicator of the rather different experiences in fatality rates and accident rates. For spills and introduction of nonindigenous species, no attempt is made to resolve the relative rates for rail and truck. For the remaining effects, only subjective rankings are provided, with L = lowest and H = highest.

In light of the uncertainties in data and estimations methods,[51] as noted in the text, the figures should be considered indicative rather than precise, and the judgements conjectural rather than consensual. The differences are sufficiently great in most of the dimensions however, that the relative rankings are clear.

ANNEX: NOTE ON REQUIREMENTS FOR DATA AND RESEARCH

The paper notes repeatedly the necessity to estimate data on freight traffic and impacts on the environment. Data collection and research to satisfy all the needs would be extensive and expensive, and it will probably remain impractical for routine statistical systems to satisfy objectives as specialised as those of this paper. However, data describing traffic in greater detail have many potential uses, and the following requirement is proposed as a practical addition to routine systems, for the medium term.

The key requirement to improve the estimates of emission rates would be that estimates of tonne-kilometres be available for the regions of interest, from sources that also provide estimates of fuel consumption. In both US and Canada, such compatible estimates are available for rail freight transport, reported by the carriers concerned. For ship and truck transport, estimates are available in the US at the national level of tonne-km (ton-miles), but not from sources from which fuel consumption is also available, leading to confusion over the computation of fuel consumption and emission rates even among federal agencies, as well as among researchers. In Canada, estimates of both tonne-km and fuel use are available for part of trucking – the for-hire carriers – but not for all trucking, including the large private sector and owner-operators. For water transport, Canadian statistics can provide tonne-km, but not compatible fuel consumption. For studies of a particular region, which is the object of this paper, the estimates would also need to be available on a regional basis.

It is also clear from the assessments in the paper that a number of the dimensions of the “footprint” of freight transport have not been quantified to any serious extent in North America, including nuisance from noise, visual intrusion, community disruption and aesthetic degradation, and even congestion effects (in which research has focussed on passenger transport). Understanding and quantifying these effects is of increasing interest for policy purposes, and requires research in both concepts and measurement.

ENDNOTES

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[1] See Rees, WE: “Ecological footprints and appropriate carrying capacity: what urban economics leaves out,” *Environment and Urbanization*, 4 (2), 121-130, 1992.

[2] See World Wildlife Fund: *Living Planet Report 2006*.

[3] *Ibid*, p.2.

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[4] The research literature on valuations of environmental effects is very extensive, but for a recent summary of some of the most prominent, see a recent study by researchers at the University of British Columbia's Centre for Transport Studies: Zhang, A, Boardman, AE, Gillen, D and Waters, WG II: "Towards Estimating the Social and Environmental Costs of Transportation in Canada", report for Transport Canada, September 2005.

[5] See US Bureau of the Census: http://www.census.gov/svsd/www/cfsdat/cfsoverview.htm

[6] See Statistics Canada: *Trucking in Canada*, catalogue no. 53-222, at http://www.statcan.ca/bsolc/english/bsolc?catno=53-222-XIE

[7] See "Transportation and Climate Change: Options for Action – Options Paper of the Transportation Climate Change Table", Transport Canada, Ottawa, November 1999.

[8] EPA's latest GHG inventory appears in *Inventory of US Greenhouse Gas Emissions and Sinks*, April 15, 2006, and the latest CAC emissions inventory, for 2002, is available at http://www.epa.gov/ttn/chief/net/2002inventory.html. GHG from the transport sector are provided in greater detail in *Greenhouse Gas Emissions from the U.S. Transportation Sector*, 1990-2003, March 2006.

[9] See Environment Canada: *National Inventory Report Greenhouse Gas Sources and Sinks in Canada, 1990–2004*, April 2006, and the CAC inventory in the National Pollution Release Inventory annual report for 2002, and 2005 database at http://www.ec.gc.ca/pdb/npri/npri_dat_rep_e.cfm#annual2002.

[10] See the 2004 Data at http://oee1.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tables.cfm.

[11] The emission rates produced from the Natural Resources Canada (NRCan) data for 2004 appear in the following table. The rate for rail is essentially the same as that provided directly by the Railway Association of Canada. The rate for marine transport being nearly twice as great as that for rail is implausible, compared for example to the other estimates from international research cited in this paper, likely resulting from combining total GHG emissions from all water transport fuel sales, including sales for all uses other than domestic freight carriage, with tonne-km estimated just for domestic freight carriage. The emission rate for truck transport is supposed by NRCan to apply to all truck use, and is also substantially greater than the estimates cited later in this paper, which are intended to represent specifically for-hire carriage by heavy trucks. In the absence of comprehensive tonne-km recording for all types of trucks, it is possible that the NRCan tonne-km estimate is too low, and the average emission rate therefore too high.

GHG emission rates by freight modes from national GHG inventory data and available estimates of national freight tonne-km

	GHG Mt CO2e	Billion tonne-km	GHG g/tonne-km
Canada – 2004			
Marine	8.7	262	33
Rail	5.8	324	18
Truck	36.8	198	185
US – 2002			
Ships and boats	57.8	893	65
Rail	41.5	2,343	18
Truck	329.3	1,832	180

[12] See http://www.bts.gov/publications/transportation_statistics_annual_report/2003/html/chapter_02/domestic_freight_ton-miles.html.

[13] For illustrative purposes, the table in note 7 also shows results of similar calculations for the US in 2002, combining EPA estimates of GHG with BTS estimates of freight tonne-km. Again, the rail rate seems reasonable, but the marine rate implausible – and even more so than is the case with the NRCan data – again likely because the GHG represent all fuels used for water transport and recreation, while the tonne-km are just from domestic freight carriage.

[14] The European references in this table for ship emissions rates, and those in subsequent tables for rail and truck freight, are among those cited in the recent study by Zhang *et al*, *op. cit.*

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[15] OECD: *Environmental Policy: How to Apply Economic Instruments*, Paris, 1991.
[16] Befahy, F., (1993): “Environment, Global and Local Effects”, cited in OECD 1997.
[17] Statistics Netherlands/Centraal Bureau voor de Statistiek: Schoemaker and Bourman, p. 57. , 1997. cited in OECD 1997a
[18] European Conference of Ministers of Transport: *Efficient Transport for Europe, Policies for Internalisation of External Costs*, Paris, 1998.
[19] EPA: “Commercial Marine Emissions Inventory for EPA Category 2 and 3 Compression Ignition Marine Engines in the United States Continental and Inland Waterways”, report EPA420-R-98-020, August 1998.
[20] Levelton Consultants Ltd., Maritime Innovation and Dr. J. Corbett: “Marine Emission Inventory Study: Eastern Canada and Great Lakes”, prepared for Transportation Development Centre, Transport Canada, Report TP 14564E, March 2006.
[21] See Transportation Table of Canada’s National Climate Change Process: *Foundation Paper on Climate Change*, December 1998, Appendix B.
[22] See earlier note on derivation of GHG emission rates from national statistics.
[23] Schoemaker, T, and Bouman, P: “Facts and Figures on Environmental Effects of Freight Transport in the Netherlands”, 1991, cited in OECD 1997.
[24] Royal Commission on Environmental Pollution, UK: *Transport and Environment*, October 1994.
[25] Environment Canada and Railway Association of Canada: Locomotive Emissions Monitoring Program 2004, Report EPS 2/TS/19, December 2005.
[26] See Options Paper of the Transportation Climate Change Table, *op. cit.*
[27] Trimac Canada: Truck Operating Costs in Canada, 1996, Transport Canada.
[28] See http://www.greatlakes-seaway.com/en/seawaymap/index.html
[29] St. Lawrence Seaway Management Corporation: “The Welland Canal Section of the St. Lawrence Seaway.” Pamphlet available from the above website.
[30] See Royal Commission on National Passenger Transportion, *Final report, Volume 2*, Ottawa, Supply and Services Canada, 1992.
[31] Tardif, R: “Trucking Activity Current Status, Hwy Limitations, Future Opportunities” presentation to National Academies/TRB Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Montreal, Sept 28, 2004.
[32] Lemieux, Y: “Modal Competitive Dynamics Along the St.Lawrence Seaway and Great Lakes”, presentation to National Academies/TRB Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Montreal, Sept 28, 2004.
[33] US Bureau of Transportation Statistics: *National Transportation Statistics 2006*.
[34] See U.S. Hazardous Materials Regulations (Title 49 CFR Parts 100-185), ss 171.15 and 171.16; and Canada’s Transportation of Dangerous Goods Act, and Part 8 regulations: Accidental Release and Imminent Accidental Release Report Requirements,
[35] Illinois, Indiana, Ohio, Michigan, Minnesota, New York, Pennsylvania, Wisconsin.
[36] The US Bureau of the Census’ Commodity Flow Surveys, undertaken for DOT, could provide estimates of tonne-km for the sampled population of freight, notably excluding imports and agricultural products.
[37] Gillen, D, Chapter 5 in Zhang *et al, op. cit.*
[38] *Ibid*.
[39] See von Wartburg, M and Waters, WG II, Chapter 2 in Zhang *et al, op cit*.
[40] See Tardif, R: presentation to the Committee, Sept 28, 2004, cited above.
[41] Zhang *et al, op. cit.*
[42] Among the large number of reports from the project, see Delucchi, M: “The Annualized Social Cost of Motor Vehicle Use in the US 1990-91: Summary of Theory, Data, Methods and Results,” University of California Transportation Centre, UC Berkeley, report UCTC 311, June 1997.
[43] INFRAS (Zurich), IWW (University of Karlsruhe): *External Costs of Transport: Update Study, Final Report*, October 2004.
[44] See Swiss federal Office for Spatial Development http://www.are.admin.ch/are/en/verkehr/kosten_nutzen/unterseite24/unterseite12/index.html
[45] Invasive Species Pathways Team: Final report, October 2003, at www.**invasivespecies**info.gov/docs/toolkit/**pathways**.doc

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[46] National Invasive Species Council: *National Management Plan: Meeting the Invasive Species Challenge* January 18, 2001.

[47] US Geological Survey: Microbes to Mammals – Invasive Species Program, at biology.usgs.gov/invasive/Publications/invasivespecies-brochure.pdf.

[48] See for example Environment Canada: Canada's "Response to the Recommendations In the Twelfth Biennial Report on Great Lakes Water Quality of the International Joint Commission," at http://www.on.ec.gc.ca/greatlakes/default.asp?lang=En&n=F09D81D4-1

[49] Pimentel, D, Lach, L, Zuniga, R and Morrison, D: "Environmental and Economic Costs of Nonindigenous Species in the United States, *BioScience*, 50 (1), 53-64 (Jan 2000).

[50] See Minchin, D: "The transport and spread of living aquatic species", Chapter 5 in Davenport, J and Davenport, JL: *The Ecology of Transportation: Managing Mobility for the Environment*, Springer, 2006.

[51] The most important and practical requirements for additional data and research into the environmental effects of freight transport are noted in the Annex to this paper.