Environmental and Social Impacts of Marine Transport

in the Great Lakes-St. Lawrence Seaway Region

Prepared by:

Research and Traffic Group

January 2013

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About the Study Authors and Acknowledgements

For more than two decades **Research and Traffic Group** has provided advice and assistance to clients, and undertaken important studies, particularly in transportation. Brief resumes of the qualifications and experience of the Partners are provided below:

Gordon English (B.Sc., M.B.A., P.Eng.)

Gordon English has been a partner at Research and Traffic Group since 1999, and an active associate since 1994, leading projects focused on energy, safety and techno-economic feasibility evaluations, including five climate change evaluations, two energy/emissions modal comparison projects, several transportation safety impact assessments and a discussion paper on internalizing social costs in the transportation sector. English has more than 37 years' experience conducting transportation-related research. He is also currently the President of TranSys Research Ltd, which has focused on safety and techno-economic analyses for projects such as the economic viability of railway operations in an asset devolution assessment for the St. Lawrence Seaway and recommendations to the Republic of China on proposals for high-speed rail passenger service between Taipei and Kaohsiung. He also previously worked as the Director of Research for the Canadian Transportation Safety Board Act Review Commission and in various positions at the Canadian Institute of Guided Ground Transport at Queen's University.

David C. Hackston (B.Comm., B.Arts, FCILT)

David Hackston has been a partner at Research and Traffic Group since 1988, assisting clients with analyses related to rail transportation, intermodal and Great Lakes-Seaway issues. He has more than 40 years' experience in the transportation sector, including providing the *Canada Transportation Act Review* with expert advice on rail freight and passenger (intercity and urban) issues. From 1974 to 1987, he served with the Canadian Transport Commission as Executive Director, Traffic and Tariffs, advising on rates and public interest issues for rail, motor vehicle and marine (Great Lakes and Northern resupply). As chairman of the Ad Hoc Rates Committee and of the Sub Committee on Data, he advised on the drafting of the Western Grain Transportation Act and represented the CTC on the Steering Committee overseeing Transport Canada's review of the Atlantic Region Freight Assistance program. He also managed and conducted studies into various aspects of Canadian transportation flowing from initiatives agreed upon at the Western Economic Opportunities Conference, as well as the relationship between transportation and various Canadian industries. This followed a nine-year career in the marketing and sales department of CP Rail.

Acknowledgments

The study, *Environmental and Social Impacts of Marine Transport in the Great Lakes-St. Lawrence Seaway Region*, was commissioned and produced in collaboration with the Chamber of Marine Commerce, the Canadian Shipowners Association, the St. Lawrence Seaway Management Corporation and the Saint Lawrence Seaway Development Corporation.

The authors would like to thank the following participating marine carriers for providing confidential operating data and project steering committee members for the guidance and valuable feedback provided in the preparation of this report:

- Algoma Central Corporation
- American Great Lakes Ports Association
- American Steamship Company
- Canada Steamship Lines
- Canadian Shipowners Association
- Chamber of Marine Commerce
- Fednav Limited
- Great Lakes Fleet / Key Lakes Inc.
- Interlake Steamship Company
- Lake Carriers Association
- Saint Lawrence Seaway Development Corporation
- St. Lawrence Seaway Management Corporation
- Transport Canada
- World Wildlife Fund (Canada)

We commend the steering committee members for setting the guiding principles for this study — to make modal comparisons in as accurate and equitable a way as was possible within the limitations of data and analytic tools available. There have been many previous modal comparison studies. Those dealing with the fleets operating in the Great Lakes-Seaway System have suffered from the lack of publicly available data on fuel and operational activity for the vessels operating on the system. Most modal comparison studies involving the Great Lakes-Seaway System and other marine segments have drawn comparisons between modes based on system average performance of each mode carrying its own mix of cargo, rather than making a like-for-like comparison based on each mode carrying the same cargo mix. We commend the Great Lakes-Seaway marine carriers and the study sponsors for their search for a like-for-like comparison and their commitment to accept the results — whether the results placed marine at higher or lower performance ratios than prior modal comparison studies.

Finally, we thank the three peer reviewers of the draft final report. Valuable comments were made and specific comments and suggested improvements were either incorporated into this final report or responded to.

Gordon English
Partner, Research and Traffic Group

David C. Hackston
Partner, Research and Traffic Group

Study Peer Review

Introduction

A final draft version of this analysis was submitted to three Canadian and U.S. experts in transport logistics, economics and environmental sciences, for independent peer review. The review was intended to ensure that the methodology used by Research and Traffic Group to measure and compare the impacts for marine, rail and trucking modes of transportation was sound and met generally accepted precepts of environmental analysis. Research and Traffic Group responded in writing to all peer reviewer comments to the satisfaction of all three reviewers. Based on these comments, several minor adjustments were made to the analysis prior to final release. Letters from each of the three peer reviewers confirming their overall satisfaction with the analysis are included in this section.

Peer Reviewers

Dr. Bradley Z. Hull (B.S., M.S., Ph.D.)

Dr. Hull is Associate Professor and Reid Chair in the Department of Management Marketing and Logistics at John Carroll University (Cleveland, Ohio), where he teaches undergraduate and MBA courses in logistics and transportation. He researches transportation topics related to the Great Lakes and Seaway, and has hosted several conferences and given many presentations on opportunities for increased commercial use of this system. Dr. Hull has a business background that includes 28 years with British Petroleum with experience directing logistics operations for BP Oil Company and BP Chemicals, utilizing multiple transportation modes, including rail, truck, barge, pipeline and ship. With a PhD in Operations Research, Mr. Hull also directed and performed many quantitative supply chain analyses while working for BP.

John Lawson (B.A., M.A.)

Mr. Lawson is a recognized transport economist with nearly 40 years' experience, initially with the UK Department of Transport in the early 1970s, then from the mid-1970s to 2005 at Transport Canada. As Transport Canada's Director for Economic Analysis and Research, Mr. Lawson was responsible for analysis of policy issues, development of analytical methods and data. Retired from Transport Canada in 2005, Mr. Lawson is now an independent transport economics researcher and consultant, and Research Associate of the University of British Columbia Centre for Transport Studies. He consults for public and private sectors, in Canada and internationally, particularly on transport energy and emissions.

Captain James R. Parsons (MM, BMS, BEd, MSc, FCIP, PhD)

Capt. Parsons is the academic director for an online Masters of Maritime Management program at the Marine Institute of Memorial University in Newfoundland. He consults for the public and private sectors, most recently with WWF Canada, Transport Canada and NATO. His company Global Marine Solutions also provides marine consultancy, logistics, risk management and formal safety assessments for vessels, ports and terminals among other services. Capt. Parsons is a Master Mariner with extensive experience working in the Western, Central, and Eastern Canadian Arctic.

Peer Review Endorsement Letter from Dr. Bradley Hull

John Carroll
UNIVERSITY

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November 18, 2012

Mr. Raymond Johnston
President
Chamber of Marine Commerce
350 Sparks Street, Suite 700
Ottawa, Ontario, K1R 7S8

Re: Peer Review of "A Social/Environmental Impacts Comparison of the Surface Freight Transport Modes in the Great Lakes-Seaway Region" conducted by the Research and Traffic Group

Dear Mr. Johnston:

The RTG study is a detailed multi-tiered analysis that compares Great Lakes St. Lawrence Seaway transportation by ship, with the rail and truck alternatives. The comparison focuses on fuel efficiency and emissions generation, but also includes comparisons of modal capacity, congestion, and infrastructure. The study is based on confidential information provided by many waterborne carriers, data for specific Great Lakes Seaway railroads, and RTG simulations of rail and truck operations. It examines the impact of potentially transferring Great Lakes/Seaway cargos from water to rail and truck – both at present and in the future.

Per your request, I have spent considerable time reviewing the RTG study. Due to confidentiality of the waterborne data and the simulations, I cannot validate the results of the study. However, the methodology behind the study appears sound. The authors have detailed knowledge of the rail, truck and Great Lakes/Seaway shipping industries, and spent a great deal of time and effort developing data sources and structuring their analysis. During my review, I found the authors responsive at addressing my observations and suggestions, and incorporating the results into the study.

Respectfully,

Bradley Hull

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Peer Review Endorsement Letter from John Lawson

LAWSON ECONOMICS RESEARCH INC.
Independent Transport and Economics Research, Ottawa, Canada

Mr Raymond Johnston
President
Chamber of Marine Commerce
350 Sparks Street, Suite 700
Ottawa, Ontario
K1R 7S8

Dear Mr. Johnston:

Re: Peer Review of "A Social/Environmental Impacts Comparison of the Surface Freight Transport Modes in the Great Lakes-Seaway Region: Draft Final Report," prepared for The Chamber of Marine Commerce by the Research and Traffic Group, September 2012.

As requested, I undertook and reported on my "Peer Review" of the above report, interpreting my task as primarily to comment on the validity of the methods and results based on my experience as a transport economist and my knowledge of North American transportation, and also to make editorial suggestions about the clarity and accuracy of the text. As I had provided some of the material used in the safety comparisons as a minor sub-contractor to the Research & Traffic Group, I excused myself from commenting on the safety component of the report.

My overall assessment is that the study offers a substantial improvement over previous comparisons of the impacts of freight modes, through its use of improved information and its application of improved engineering models and simulations to estimate activities in the three modes, and to examine the marginal impacts if GL-S marine freight were shifted to the competing modes of rail or truck. Major improvements were achieved particularly through RTG's access to new information on marine movements and fuel consumption, also to RTG's new model of truck energy use and emissions, and simulation model of rail energy use and emissions.

The study provides more information on the particular GL-S traffic, and a more appropriate comparison of the modal characteristics of the traffic, than any previously published, either in Canada or the US. Comparisons of modal freight traffic impacts have often been attempted, but typically use nationally-reported statistics with important limitations on their comparability among the modes, and on the consistency between different dimensions of impacts. The basic traffic measures, of tonnes of cargo shifted and trip distances, and therefore freight tonne-kilometres, are not reported nationally in Canada for trucks or marine vessels; and while national statistics are reported in the US, they rely to some extent on assumption and inference. Calculations combining those tonne-km estimates with national statistics of system-wide fuel consumption, emissions, accidents, spills etc, to produce rates per tonne-kilometre for comparisons among the modes therefore suffer from those uncertainties. Researchers (and even Government departments) have in fact unknowingly calculated incorrect rates, using tonne-km estimates from only a segment of national traffic that happened to be reported in national statistics (in Canada, for example, estimates of tonne-km in domestic marine freight and in for-hire trucking have been compared respectively to total marine fuel and total truck fuel refinery sales, producing gross overestimates of fuel use per tonne-km in both cases).

Furthermore, even if such problems could be avoided, it has normally been possible using published statistics to make estimates of average rates of freight impacts only at the national, network-wide levels. Traffic diversity means such estimates are hardly appropriate for any region, and certainly not for the GL-S region with its particular mix of commodities, trip O-Ds and equipment types. Attempts in previous studies to adjust available statistics to represent GL-S traffic have relied on assumptions to provide rough approximations. The current study is I believe unique particularly in describing the marine mode traffic impacts, and considering the marginal effects if that traffic were diverted to the competing rail or truck modes.

The report correctly spends most effort and space on fuel consumption and emissions of GHGs and CACs as the impacts of most current interest and debate, and the greatest research challenges due to the data and modelling requirements. The study is impressive in its development of consistent measures of activity in freight movements in the three modes, including tonne-kilometres, and comparable estimates of fuel consumption, to enable estimation of rates of GHG and CAC emissions. Comparisons of those rates are the major achievement of the study, but it also provides valuable information on the effects on congestion, infrastructure requirements, and noise from hypothetical transfers of freight from marine to the other two modes.

In my review I provided a number of comments and questions for clarification, which were all addressed in the finalized report.

Sincerely,

John Lawson

John Lawson
President and Principal of Lawson Economics Research, Inc.

2012-11-13

Peer Review Endorsement Letter from Captain James Parsons

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17 November 2012

Mr. Raymond Johnston
President
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350 Sparks Street, Suite 700
Ottawa, Ontario, K1R 7S8

RE: A Peer Review of "A Social/Environmental Impacts Comparison of the Surface Freight Transport Modes in the Great Lakes-Seaway Region" conducted by Research and Traffic Group

Dear Mr. Johnston:

As per your request, I have reviewed the RTG report with great interest, paying particular attention to the validity of the methodology employed. As the various freight carriers had provided confidential data to RTG, it was not possible to validate the findings of the report.

Overall the report does a very fair, rigorous, and thorough examination and comparison of three unique modes of transport with respect to the external impacts of a mode shift of GL-S cargo to or from marine carriage relative to rail and road carriage. A direct comparison of three unique modes of transport occurring within and throughout several states and provinces of two different countries, each with its own restrictions, is not straightforward. In many cases were data sets were not collected, complied and presented in similar fashion, the report takes a very fair, honest, and open approach at making like-for-like comparisons. Simulation and sensitivity analysis are undertaken where data is absent, vague, or inconsistent so as to provide scientific rigour to the report. With respect to the social and environmental impacts of the three modes of carriage, the report is thorough in the selection of the areas of focus ranging from greenhouse gas emissions to the provision and maintenance of infrastructure. The methodological approach to the study is valid and reliable.

During my careful examination of the draft report I did note several minor and major observations, all of which were satisfactorily addressed by the RTG in the final report. In light of data limitations, scientific uncertainty and a lack of consensus from the scientific community on matters such as futuristic water levels and impacts on infrastructure, RTG delivered as per their project scope.

Respectfully Submitted,

Parsons

Captain James R. Parsons, PhD
Global Marine Solutions

Executive Summary

1. Introduction

For more than 200 years, the marine shipping industry has been an integral part of the Great Lakes economy.

The Great Lakes and the St. Lawrence River combine to form the longest deep-draft navigation system in the world, extending 3,700 kilometers (2,300 miles) into the North American heartland (see Figure ES1). The system includes the five Great Lakes and their connecting channels, as well as the St. Lawrence River to the Gulf of St. Lawrence. A series of locks either lift or lower vessels to overcome elevation changes. These include:

- Seven locks on the Montreal-Lake Ontario (MLO) section of the St. Lawrence Seaway, which lift/lower ships 68.8 meters (226 feet);
- Eight locks on the Welland Canal (Welland) section of the St. Lawrence Seaway, which lift/lower ships 99.4 meters (326 feet):
- One lock at Sault Ste. Marie, Michigan, which lifts/lowers ships 9.2 meters (30 feet).

Three distinct vessel-operator groups serve the waterway. These include American and Canadian domestic carriers transporting cargo between ports within the system, and international ocean-going vessel operators that operate between ports within the system and ports located overseas.

Figure ES1. Great Lakes-Seaway System

Source: RTG with data from U.S. DOT-NTAD and NRCan-Geogratis.

Every year, more than 160 million metric tons of raw materials, agricultural commodities and manufactured products are moved on the Great Lakes-St. Lawrence Seaway System. Dominant cargoes include iron ore for steel production, coal for power generation, limestone and cement for construction, and grain for both domestic consumption and export.

This marine highway supports the activities of more than 100 ports and commercial docks located in each of the eight Great Lakes states, and the provinces of Ontario and Quebec. It is also a crucial transportation network for commerce moving between North America and more than 59 overseas markets.

2. Scope

This report is designed to provide marine stakeholders, transportation planners and government policy makers with an assessment of the potential environmental and social impacts that could occur, if cargo carried by marine vessels on the Great Lakes-St. Lawrence Seaway navigation system shifted to road and/or rail modes of transport.

The study examines the external impacts that can be compared between rail, truck and vessel, including the following:

- Fuel efficiency;
- Greenhouse Gas (GHG) emissions;
- Criteria Air Contaminant (CAC) emissions;
- Traffic congestion;
- Infrastructure impacts;
- Noise impacts.

The external impacts included in this study are not intended to be an exhaustive list, but rather, represent key impacts common to each of the three surface transportation modes, enabling comparison. All modes have had historic impacts that are not included in a marginal impact assessment of future traffic shifts. For example, the marine mode's past impacts related to invasive aquatic species were significant and are being addressed to prevent future occurrences. Similarly, the impacts of road and rail infrastructure on wildlife habitats were significant historic influences but are not significant marginal impacts for future traffic changes and are not included in this study. The ongoing loss of animal life on roads and railways, the infrequent instigation of forest fires from rail activity and the uncertain impact of marine activity on shore erosion are examples of external impacts that are related to changes in traffic but are not quantified in this study due to data limitations and/or scientific uncertainty.

To accomplish this analysis, a bi-national consortium of public and private sector Great Lakes-Seaway System stakeholders retained transportation consultants Research and Traffic Group of Ontario, Canada. Research and Traffic Group has conducted numerous safety and environmental studies related to rail, road and marine on behalf of Canadian federal and provincial government agencies, as well as governments abroad. The project was overseen by a steering committee of stakeholders, including WWF-Canada and Transport Canada.

3. Methodology — Current Conditions Comparison

Within the limitations of data and analytic models, the three freight transport modes are compared using 2010 characteristics that are representative of each mode's current operations in the Great Lakes-St. Lawrence region when carrying the existing mix of marine cargo.

The geographic focus was on cargo movements on the Great Lakes, including travel through the Seaway locks system to/from St. Lawrence River ports and overseas locations. All cargo movements handled by Canadian domestic, U.S. domestic, and international ocean-going vessels within the Great Lakes-Seaway System are included in the study; movements on the lower St. Lawrence River are only included if the vessel transits the MLO section of the Seaway.

The data used for marine analysis was compiled from a sample of U.S., Canadian and international carriers representing 79% of the 2010 cargo carried on the Great Lakes-Seaway System. To provide the most meaningful analysis of the marine mode, findings are presented for three categories:

- ***Seaway-size Fleet*** — the Seaway-size fleet consists of Canadian domestic carriers and Seaway-sized international vessels, which can navigate the narrower and shorter Seaway locks (the Welland Canal between Lake Erie and Lake Ontario, and the Montreal-Lake Ontario (MLO) locks between Lake Ontario and the lower St. Lawrence River.)
- ***U.S. Fleet*** — the U.S. domestic fleet predominantly operates in the Upper Great Lakes (above or west of the Welland Canal). The modal comparisons are based on the cargo that the U.S. Fleet carries and recognize the operational characteristics of the three modes in the U.S.
- ***Combined Great Lakes-Seaway Fleet*** — the Combined Great Lakes-Seaway Fleet includes all categories of vessels operating within the Great Lakes-Seaway System, i.e., Canadian domestic carriers, U.S. domestic carriers and international vessels.

This is the first time a study has examined the external impacts of the U.S., Canadian and international fleets operating on the navigation system, using actual data from all three categories of shipowners.

The rail and truck characterizations are based on publicly available data and simulation models developed by Research and Traffic Group to assess the specific performance in transporting cargo.

Where possible, the modal comparisons were based on the equipment type actually used in transporting cargo. Energy consumption associated with engine idling and vessel hotel power was included, but adjustments were made to attain a like-for-like comparison. Wayside energy associated with loading/unloading was excluded for all modes and auxiliary energy used by self-unloading vessels to unload cargo was also excluded. In addition, 10% of every vessel's hotel power (i.e., power used for crew accommodation) used while at port was excluded, in recognition of the absence of data about the wayside energy used by the ground modes for similar purposes. The other 90% of hotel power used while at port and 100% used by vessels while underway are included.

The rail network included in the study area involves CN and Canadian Pacific (CP) on both sides of the border, and CSX Transportation (CSXT) and Norfolk Southern Railway (NS) more principally within the U.S. but also with short border crossings into Canada. Due to data availability, rail mode characterization is based on the complete rail networks of these railways, not just those rail segments located in the Great Lakes-Seaway region.

The highway network included in the study area involves the Interstate Highway System in the states bordering the Great Lakes and the strategic highway network in Ontario and Quebec. Unlike the rail mode, truck operations differ significantly between the U.S. and Canada. The related truck performance analyses were segmented by country due to differences mainly in truck axle load limits and body-style configurations.

4. Methodology — Future Conditions Comparison

An additional assessment of long-term modal potential was provided by comparing marine, rail and truck energy efficiency after meeting the regulatory conditions, and the technology and fuel-use improvements that would be economically available over the time frame 2012–2025. The technologies used in the year 2010 baseline comparison can be expected to change over time for each of the modes. However, the magnitude of change will be much greater for the marine mode than for the two ground modes.

Domestic vessels in the Great Lakes-Seaway Fleet are over 30 years old, whereas the rail mode's mainline locomotive fleet and the truck mode's long-haul tractor fleet are newer than 20 years old. The delay in renewal of the domestic marine fleet has been influenced by the 25% duty on foreign-built vessels brought into Canadian domestic trade, and the *Jones Act* restrictions prohibiting foreign-built vessels in the U.S. domestic trade. The recent repeal of the Canadian 25% import duty and the introduction of the Environmental Protection Agency's (EPA's) assistance program for new power plants on existing U.S. vessels are stimulating fleet and power plant renewal that will significantly improve the efficiency of both Canadian and U.S. domestic fleets.

Current EPA and Canadian government regulatory initiatives will also lead to reductions in CAC emissions intensity for marine over the interval 2012 to 2025 and for rail by 2016. As the least emissions-efficient mode, trucking was the target of early CAC regulatory initiatives and is not expected to see further reduction in CAC emissions intensity on a gram-emitted per liter of fuel basis. However, there are regulatory initiatives to reduce truck GHG emissions over the 2014 to 2017 timeframe. Energy-efficiency improvements made to meet these regulations will have an equivalent reduction for the truck mode's engine-based CAC emissions.

Similarly, there are longer-term efficiency improvements in proposed regulations for the marine mode. International Marine Organization (IMO) initiatives for ocean vessels built after 2013 will lead to further opportunities (and in some jurisdictions, requirements) for efficiency advances in ship design/operations. If Canada and the U.S. extend the IMO regulations to the domestic fleets, efficiency improvements of 30% over 2010 baseline technology will be required for newly purchased vessels.

In order to assess the long-term potential performance of each mode, a "post-renewal" scenario has been developed for each mode, under the assumption that 100% of each mode's fleet is comprised of equipment that meets circa-2016 regulations.

Marine Mode's Post-renewal Framework

The basic post-renewal comparison is based on the following assumed conditions for the fleets operating on the Great Lakes-Seaway System:

- The Canadian Fleet is renewed (engine and vessel-design) at an estimated 36.5% average improvement from the present technology being used on newly ordered vessels (with 2013/2014 deliveries).
- The U.S. Fleet is repowered to attain the performance exhibited by the "Best-in-Fleet" vessel in the U.S. carriers' data, but with a 90% effectiveness ratio to account for trade-specific differences (e.g., shorter distances, smaller vessels). This results in a 33.4% average improvement for the U.S. Fleet.
- The International Fleet sees an average 10% efficiency improvement and meets Emission Control Area (ECA)-2015 emissions requirements while in the Great Lakes-Seaway.
- All Fleets use 100% marine diesel oil (MDO) fuel — with auxiliary engines meeting EPA-C2 regulations and propulsion engines meeting EPA-C3 regulations for ECA-2015 (involving a phase-in of sulfur dioxide (SO2) reductions by 2020 to 2025).

The study notes that the load capacity and related energy efficiency of the marine mode, and the deeper draft U.S. Fleet in particular, are sensitive to water-level variations on the Upper Great Lakes. The baseline data reflect the conditions of 2010, which was reasonably representative of the previous decade; however, the 2001-2010 decade was lower than the long-term average. There is no consensus forecast of future water levels; however, the performance of the marine mode, and the deeper draft U.S. Fleet in particular, could improve or worsen in the post-renewal scenario depending on future changes in water levels.

It should be noted that both the U.S. and Canadian fleets would see initial efficiency improvements much greater than the above fleet-wide averages, as the lowest efficiency vessels would be the first to be displaced by the newer vessels/engines.

Rail Mode's Post-renewal Framework

In recent years, rail has been renewing its long-haul fleet, while its local yard-switching fleet remains quite old. The study assumes that there is little scope for additional cost-effective rail engine efficiencies over the 2010 engine by 2015.

Rail mode engines will be subject to more stringent CAC emissions regulations in 2015 and sulfur content of railway diesel fuel will also be reduced in 2016. Post-renewal performance for rail is expected to exceed the 2010 performance as all locomotives in the 2010 fleet are replaced with engines that meet the circa-2016 regulations. The 2010 fleet had a distribution of ages, including many older, less efficient engines with higher emissions intensities. In the post-renewal scenario, the line-haul fleet is comprised of 100% new equipment meeting 2016 standards.

Investment opportunities to reduce fuel consumption exist for all modes and it is difficult to forecast how many will get adopted. For rail, it is assumed that the following operating efficiency improvements will be economical in the "post-renewal" scenario:

- Locomotive fleet updated to 100% new engines attaining 2016 emissions regulatory compliance and efficiency performance estimated by the EPA for the 2040 locomotive fleet;
- Coal car average load increased to 115 tons;
- Grain and other bulk cargo average load increased to 100 tons;
- Train length increased by 10%;
- Layover-idle decreased by 20%.

Truck Mode's Post-renewal Framework

All existing CAC regulations for trucks were in effect in 2010. While the EPA has not published notices of new CAC regulations for trucks, it has introduced a final rule requiring reductions of GHG emissions by 2014. Canada has proposed to adopt the same standards. As these reductions involve fuel-efficiency improvements to engines and tractors, CAC emissions from engines will see a reduction in proportion to the fuel reduction. The average reductions sought from tractor suppliers include the savings required by engine sub-suppliers, and the combined reductions vary by class of truck and cab style. The combined engine and tractor-body reductions required by 2014 range from 7% to 20%, and a further 3% reduction is required by 2017.

As with the other modes, the post-renewal scenario assumes 100% of the fleet is comprised of post-renewal (in this case post-2017) trucks. Since the regulatory reductions are related to a defined base vehicle, the actual service-specific performance will not necessarily result in the same savings. The post-renewal scenario for trucks assumes operators maintain the improvements required by the EPA for tractor manufacturers. The impacts of the GHG regulations are specific to the types of trucks and loads involved in this assessment.

5. Study Findings

All study results are presented in both metric and in United States customary units. For example, tonnage figures are presented in metric tonnes (2,204 pounds) and in net tons (2,000 pounds); liquid measures are presented in liters as well as in U.S. gallons.

Energy Efficiency

Current Conditions

A comparative analysis of the fuel used and engine technologies deployed in 2010 by each of the modes showed that marine vessels were able to carry one tonne of cargo significantly farther on one liter of fuel than both rail and trucks. The analysis related to the energy efficiency for each grouping of vessels shows the following results relative to rail and truck modes:

- The Seaway-size Fleet can move its cargo 24% farther (or is 24% more fuel-efficient) than rail and 531% farther (or is 531% more efficient) than truck.
- The U.S. Fleet can move its cargo 11% farther (or is 11% more fuel-efficient) than rail and 592% farther (or is 592% more efficient) than trucks.
- The Combined Great Lakes-Seaway Fleet can move its cargo 14% farther (or is 14% more fuel-efficient) than rail and 594% farther (or is 594% more efficient) than trucks (see Figure ES2).

Future Conditions

In addition to 2010 performances, energy and emissions performances are also derived for a post-renewal scenario — after each mode's upcoming regulatory changes are met and each mode's fleet (or the engines of the U.S. Fleet) is renewed. The results showed that the marine mode could significantly widen its fuel-economy advantage over rail and trucks.

Once all modal fleets are renewed:

1. The Seaway-size Fleet will move its cargo 74% farther (or will be 74% more fuel-efficient) than rail and 704% farther (or will be 704% more efficient) than truck;
2. The U.S. Fleet will move its cargo 53% farther (or will be 53% more fuel-efficient) than rail and 754% farther (or will be 754% more efficient) than trucks; and
3. The Combined Great Lakes-Seaway Fleet can move its cargo 59% farther (or is 59% more fuel-efficient) than rail and 773% farther (or is 773% more efficient) than trucks (see Figure ES3).

Table ES1. Fuel efficiency to move Great Lakes-Seaway cargo

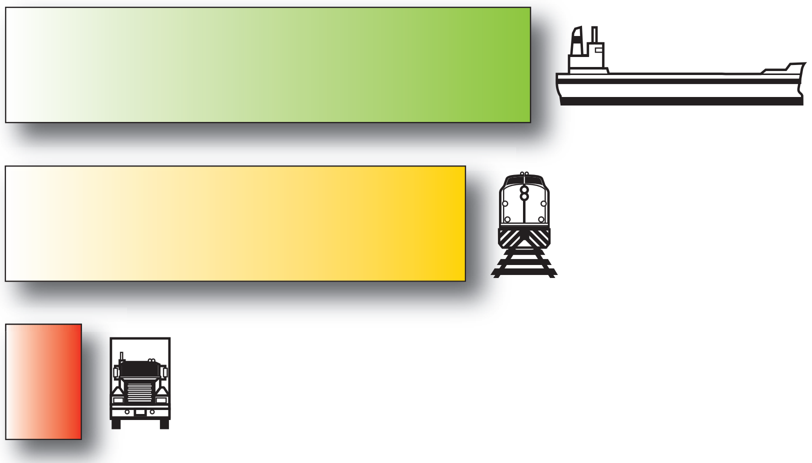
Distance in kilometers to move one tonne of cargo with 1 liter of fuel	**Base year 2010**			**Post renewal of all modes**		
	Marine	***Rail***	***Truck***	***Marine***	***Rail***	***Truck***
Seaway-size Fleet	265	213	42	394	226	49
U.S. Fleet	235	212	34	342	224	40
Combined Great Lakes-Seaway Fleet	243	213	35	358	225	41

Distance in miles to move one ton of cargo with 1 U.S. gallon of fuel	**Base year 2010**			**Post renewal of all modes**		
	Marine	***Rail***	***Truck***	***Marine***	***Rail***	***Truck***
Seaway-size Fleet	688	553	109	1,022	586	127
U.S. Fleet	610	550	88	887	581	104
Combined Great Lakes-Seaway Fleet	631	553	91	929	584	106

Source: RTG analysis of confidential marine carrier data.

Figure ES2. Energy Efficiency Comparison – Combined Great Lakes-Seaway System Fleet (2010)

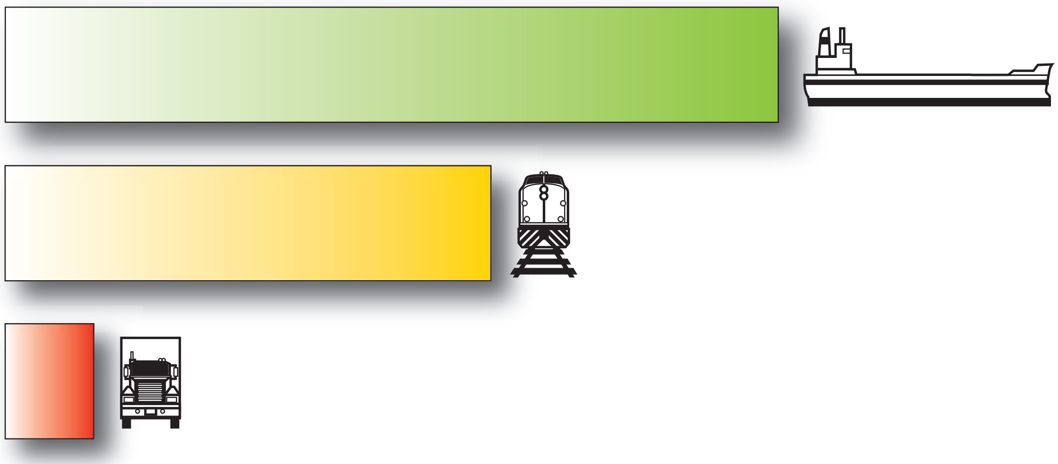
Tonne-Km per liter	Ton-miles per U.S. gallon
243	631
213	553
35	91



Source: RTG analysis based on each mode carrying Great Lakes-Seaway traffic an equal distance.

Figure ES3. Energy Efficiency Comparison – Combined Great Lakes-Seaway System Fleet (Post Renewal of All Modes)

Tonne-Km per liter	Ton-miles per U.S. gallon
358	929
225	584
41	106



Source: RTG analysis based on each mode carrying Great Lakes-Seaway traffic an equal distance.

These results reflect the fact that the magnitude of technological change will be much greater for the marine mode than for the two ground modes. Domestic vessels in the Great Lakes-Seaway Fleet are over 30 years old, whereas the rail mode's mainline locomotive fleet and truck mode's long-haul tractor fleet are newer than 20 years, with much of the fleets newer than 10 years. As noted earlier, the repeal of the Canadian import duty and the introduction of the EPA assistance program for new power plants on existing U.S. vessels are stimulating fleet and power plant renewal that is expected to significantly improve the Great Lakes-Seaway Fleet's overall efficiency.

Greenhouse Gas (GHG) Emissions

Current Conditions

Once energy efficiency was determined, a comparison of GHG emissions was made based on total equivalent carbon dioxide (CO_2-e) emitted by each mode in carrying the same cargo an equal distance. The results show that marine produces fewer greenhouse gas emissions per tonne/kilometer (or thousand-cargo-ton/miles) than both the rail and truck modes.

In terms of incremental GHG emissions:

1. Compared to the Seaway-size Fleet carrying one tonne of cargo one kilometer, rail would produce 22% higher GHG emissions, and the truck mode 450% higher GHG emissions than marine.
2. Compared to the U.S. Fleet carrying one ton of cargo one mile, rail would emit 15% more GHG, and the truck mode 534% more GHG than marine.
3. Compared to the Combined Great Lakes-Seaway Fleet carrying one tonne of cargo one kilometer, rail would emit 19% more GHG, and the truck mode 533% more GHG than marine.

Table ES2 provides more detailed data and includes a column that shows the relative intensity when indexed to the marine fleet. The indexed columns indicate what each mode produces in emissions relative to marine. For example, for each tonne of GHG emissions from the Seaway-size Fleet in carrying a tonne of Seaway cargo one kilometer in 2010, the rail mode would produce 1.22 tonnes and trucks would produce 5.5 tonnes of GHG emissions.

Future Conditions

The truck is the only mode to have regulatory standards for GHG emissions requiring the use of fuel-saving technologies by highway tractor manufacturers over the 2014-2019 timeframe.

Table ES2. GHG Emissions Intensity Comparisons

GHG Emissions Intensity for the Seaway-size Fleet						
	2010			***Post Renewal***		
	g/CTK	***lb/kCTM***	***Index***	***g/CTK***	***lb/kCTM***	***Index***
Marine	11.5	37.0	1.00	7.7	24.9	1.00
Rail	14.1	45.1	1.22	13.3	42.7	1.72
Truck	63.4	203.5	5.50	55.1	177.0	7.12
GHG Emissions Intensity for the U.S. Fleet						
	2010			***Post Renewal***		
	g/CTK	***lb/kCTM***	***Index***	***g/CTK***	***lb/kCTM***	***Index***
Marine	12.4	39.6	1.00	8.5	27.3	1.00
Rail	14.2	45.7	1.15	13.4	43.0	1.57
Truck	78.3	251.2	6.34	67.9	217.9	7.98
GHG Emissions Intensity for the Combined Great Lakes-Seaway Fleet						
	2010			***Post Renewal***		
	g/CTK	***lb/kCTM***	***Index***	***g/CTK***	***lb/kCTM***	***Index***
Marine	11.9	38.3	1.00	8.1	26.1	1.00
Rail	14.2	45.5	1.19	13.3	42.9	1.64
Truck	75.5	242.4	6.33	65.5	210.3	8.07

g/CTK = grams emitted per cargo-tonne-kilometer.
lb/kCTM = pounds emitted per thousand cargo-ton-miles.

Source: RTG analysis.

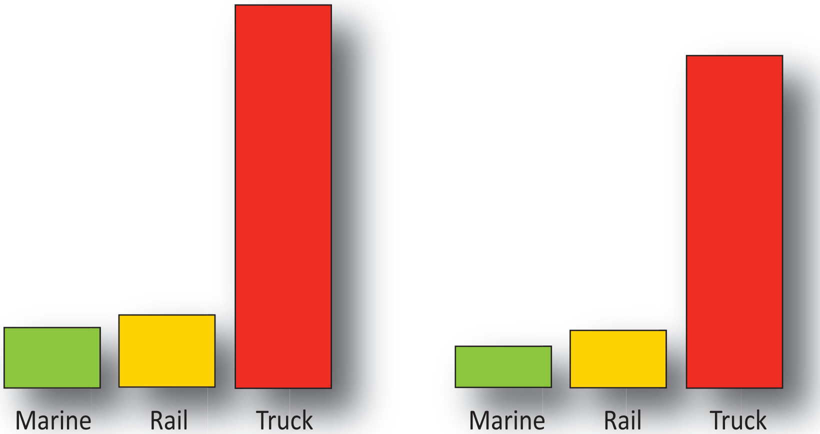
Table ES2 illustrates post-renewal comparisons that show it is expected that the marine mode will considerably improve its GHG performance relative to rail and trucks. Again, this is a reflection of fleet renewal and engine-replacement programs currently underway in the Canadian and U.S. Fleets.

Post renewal of all three modes:

1. Compared to the Seaway-size Fleet carrying one tonne of cargo a distance of one kilometer, rail would produce 72% higher GHG emissions, and the truck mode 612% higher GHG emissions;
2. Compared to the U.S. Fleet carrying one ton of cargo a distance of one mile, rail would emit 57% more GHG, and the truck mode 698% more GHG; and
3. Compared to the Combined Great Lakes-Seaway Fleet moving one tonne of cargo a distance of one kilometer, rail would emit 64% more GHG, and the truck mode 708% more GHG than marine.

Figure ES4 illustrates the GHG emissions intensity for the Combined Great Lakes-Seaway Fleet compared to the rail and truck modes.

Figure ES4. GHG Emissions Comparisons (2010 vs Post Renewal) Combined Great Lakes-Seaway Fleet



	2010			**Post Renewal**		
	Marine	Rail	Truck	Marine	Rail	Truck
Grams per cargo-tonne-kilometer	11.9	14.2	75.5	8.1	13.3	65.6
Pounds per 1,000 cargo-ton-miles	38.3	45.5	242.4	26.1	42.9	210.3
Index	1.0	1.2	6.3	1.0	1.6	8.1

Source: RTG analysis.

Criteria Air Contaminants (CAC) Emissions

Criteria air contaminants (CACs) are a set of air pollutants that cause smog, acid rain and other health hazards. In the transportation industry, these emissions are related to the combustion of fuel to provide engine and auxiliary power.

The marine sector has been a later target for emissions regulations than the other modes. Criteria air contaminant (CAC) regulations were initially focused on the truck mode, then the rail mode and are now being introduced for the marine mode.

The truck mode was the focus of early regulatory standards and no further changes to the 2010 CAC regulations have been identified. The long-haul truck fleet is renewed more frequently than the other modes so regulatory changes work into the system performance quite quickly.

The rail mode was the second focus of CAC regulatory standards and partial advances were in place by 2010. Additional reductions of hydrocarbons (HC), nitrogen oxides (NO_X), particulate matter (PM) and sulfur dioxide (SO_2) are required by 2015.

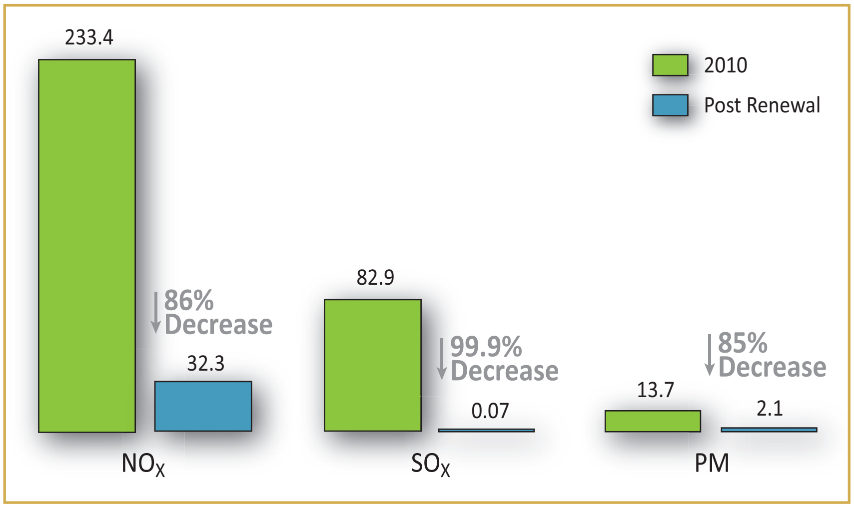
The marine mode has been the last mode to see CAC emissions regulations and all will take place over the 2012-2025 timeframe. The regulations will require significant reductions of NO_X and SO_2, and the reductions of SO_2 will produce reductions in PM. The marine fleet is also the oldest of the three modes. As a consequence, marine will see a much more dramatic improvement than the two ground modes in the future.

The study notes that in 2010, the marine mode overall was the lowest emitter for NO_X, but higher for sulfur oxides (SO_X) and PM compared to other modes. In the future, however, the fleets operating on the Great Lakes-Seaway System will realize significant reductions in CAC emissions. After meeting new regulatory conditions and achieving improvements with the use of new technology that would be economically available over the time frame 2012 to 2025, the Combined Great Lakes-Seaway Fleet would achieve significant decreases in emissions as follows:

- NO_X emission reductions of 86%
- SO_X emission reductions of 99.9%
- PM emission reductions of 85%

The emissions comparisons of NO_X, SO_X and PM for each mode are summarized in Table ES3 for the Seaway-size Fleet, Table ES4 for the U.S. Fleet and Table ES5 for the Combined Great Lakes-Seaway Fleet under current and future conditions.

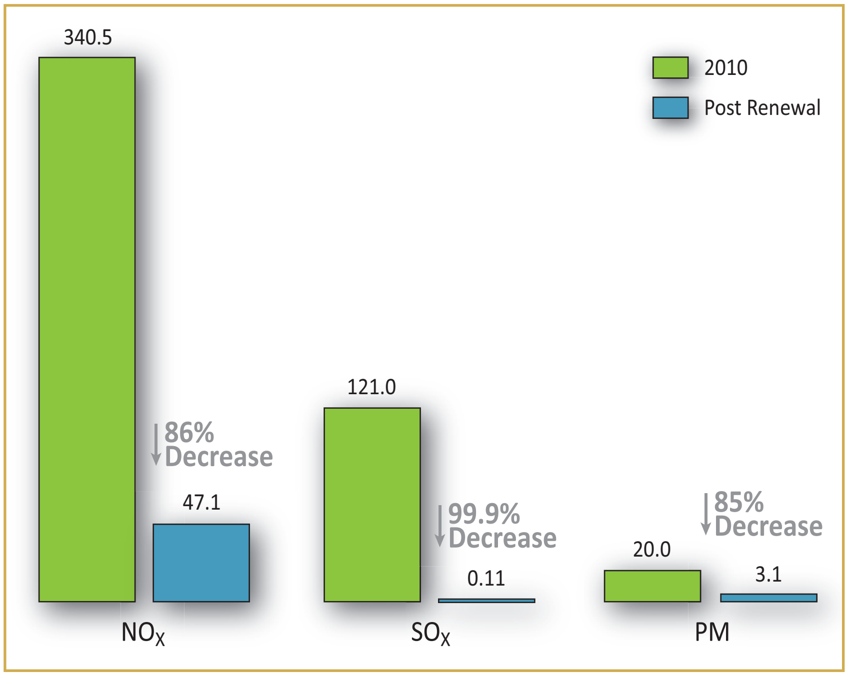
Figure ES5. CAC Comparison for Combined Great Lakes-Seaway Fleets (2010 vs Post Renewal)



g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.

Source: RTG analysis.

Figure ES6. CAC Comparison for Combined Great Lakes-Seaway Fleets (2010 vs Post Renewal)



g/kCTM = grams emitted per thousand-cargo-ton-miles.

Source: RTG analysis.

Table ES3. Comparison of the Primary CAC Emissions for the Seaway-size Fleet

Year	Mode	NO_X		SO_X		PM	
		(g/kCTK)	(g/kCTM)	(g/kCTK)	(g/kCTM)	(g/kCTK)	(g/kCTM)
2010	Seaway-size Fleet	250.3	365.2	105.3	153.6	17.0	24.8
	Rail	237.1	346.2	0.8	1.2	6.1	9.0
	Truck	315.2	459.9	0.6	0.9	11.4	16.6
Post Renewal	Seaway-size Fleet	30.9	45.1	0.07	0.10	2.0	2.9
	Rail	33.4	48.8	0.108	0.158	0.5	0.7
	Truck	27.1	39.5	0.5	0.8	2.4	3.6

g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.
g/kCTM = grams emitted per thousand-cargo-ton-miles.

Source: RTG analysis of confidential marine carrier data.

Table ES4. Comparison of the Primary CAC Emissions for the U.S. Fleet

Year	Mode	NO_X		SO_X		PM	
		(g/kCTK)	(g/kCTM)	(g/kCTK)	(g/kCTM)	(g/kCTK)	(g/kCTM)
2010	U.S. Fleet	215.2	313.9	58.9	85.9	10.1	14.7
	Rail	251.8	367.4	1.9	2.8	7.6	11.1
	Truck	391.6	571.4	0.7	1.1	13.7	20.0
Post Renewal	U.S. Fleet	33.8	49.3	0.08	0.11	2.2	3.2
	Rail	36.4	53.1	0.10	0.15	0.6	0.8
	Truck	38.5	56.2	0.6	0.9	2.7	4.0

g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.
g/kCTM = grams emitted per thousand-cargo-ton-miles.

Source: RTG analysis of confidential marine carrier data.

Table ES5. Comparison of the Primary CAC Emissions for the Combined Great Lakes-Seaway Fleet

Year	Mode	NO_X		SO_X		PM	
		(g/kCTK)	(g/kCTM)	(g/kCTK)	(g/kCTM)	(g/kCTK)	(g/kCTM)
2010	Marine	233.4	340.5	82.9	121.0	13.7	20.0
	Rail	245.9	359.0	1.5	2.2	7.0	10.3
	Truck	392.0	572.0	0.7	1.0	13.3	19.4
Post Renewal	Marine	32.3	47.1	0.07	0.11	2.1	3.1
	Rail	35.2	51.4	0.10	0.15	0.53	0.77
	Truck	54.5	79.5	0.61	0.90	2.7	3.9

g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.
g/kCTM = grams emitted per thousand-cargo-ton-miles.

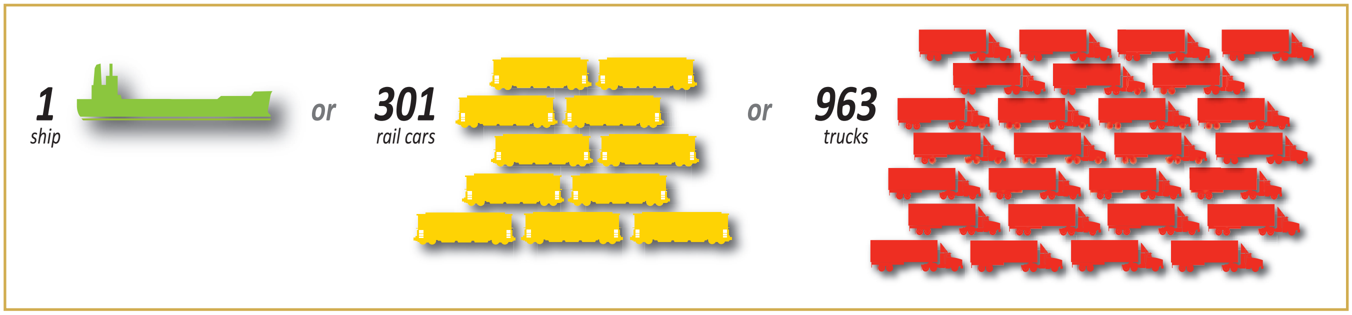
Source: RTG analysis of confidential marine carrier data.

The study authors note that marine's CAC emissions when on open water are comprised of emissions from propulsion engines and auxiliary engines, while emissions when docked at port are only from auxiliary engines. Criteria Air Contaminant (CAC) emissions consequences are dependent on the source location relative to areas of air-quality concern. Marine's CAC emissions on open water (as well as at many ports in remote areas) will have significantly different consequences than emissions at ports located in urban areas. Similarly, CAC emissions from the ground modes while traveling through remote areas will have significantly different consequences than their emissions when traveling through urban areas. The consequences of each mode's CAC emissions relative to each other, and the relative consequences of transportation's emissions relative to fixed-plant emissions are beyond the scope of this assignment. The authors believe that such a comparative evaluation would be in favor of the marine mode and recommend that such a comparative analysis be undertaken.

Modal Capacity

In the case of Seaway-size vessels carrying roughly 30,000 tonnes of cargo, it would take 963 trucks or 301 rail cars to carry the same load, as shown in Figure ES7.

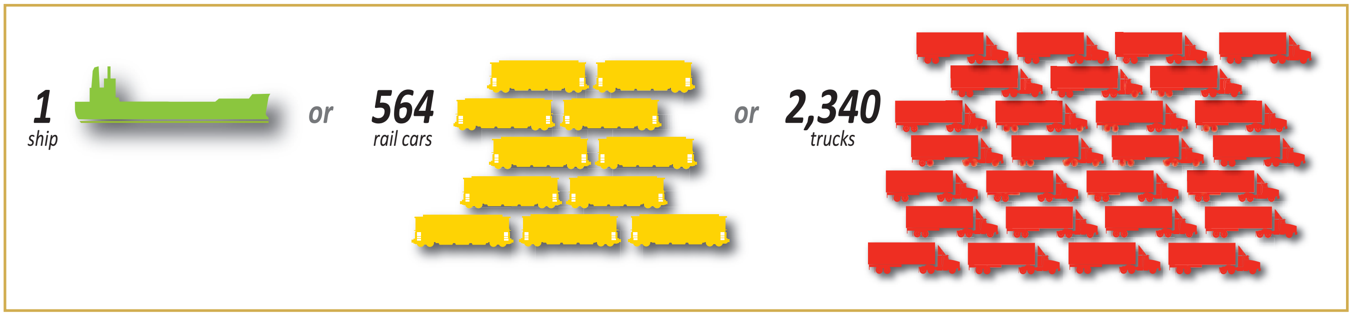
Figure ES7. To move 30,000 tonnes of cargo with a Seaway-size vessel



Source: RTG analysis.

The largest Great Lakes vessels, typically 1,000 feet in length, can carry 62,000 tons of cargo — equivalent to 2,340 trucks or 564 rail cars, as illustrated in Figure ES8.

Figure ES8. To move 62,000 tons of cargo with a Great Lakes 1,000-foot vessel



Source: RTG analysis.

The study calculates the potential traffic that would be created on highways or railways if the cargo transported by Great Lakes-Seaway vessels was shifted to trucks or rail and the resulting congestion and maintenance impacts.

- If the total cargo transported by the Combined Great Lakes-Seaway Fleet in 2010 was instead transported by truck, 7.1 million additional truck trips in the region would be required.
- An extra 1.9 million truck trips across the border would be required to move the cross-border cargo carried by the Combined Great Lakes-Seaway Fleet. To put this into perspective, the additional volume of trucks (equivalent to 8.8 million passenger car-equivalent traffic units) would be more than the total amount of annual traffic across the Ambassador Bridge in Detroit-Windsor — the busiest Canada-U.S. border crossing in terms of trade.
- One 1000-foot vessel carrying 62,000 tons (56,260 tonnes) passing under the Ambassador Bridge between Windsor and Detroit is equivalent to 2,340 trucks at a nominal 26.5 ton (24.1 tonne) load passing over the bridge. That is enough to fill a traffic lane for 50 kilometers (30 miles) back from the border inspection booths. While the number of trucks required to replace a single 1,000-foot vessel would not arrive at a border crossing at the same time, the comparison is still illustrative.
- The traffic moved by the combined Great Lakes-Seaway Fleet in 2010 would require about 3.0 million additional railcar trips throughout the region. This is equivalent to an additional 115 trains per day that would be distributed across the rail network. The increase for specific rail segments would represent as much as double the existing traffic on some rail lines in Canada and at least a 50% increase in traffic on some of the busiest lines in the U.S.

Traffic Congestion

The study notes that marine transport activities in the Great Lakes-Seaway region have a negligible impact on congestion delays for the traveling public. However, a shift of Great Lakes-Seaway traffic to the highway or rail modes would lead to increased levels of congestion and delays for the traveling public. The study attempts to quantify the costs of the delay impacts but notes that the impacts would be highly sensitive to the specific cargo movements that shifted, and to the values and time periods assumed for those delays.

Both of the ground modes have an impact on road traffic delays — trucks via direct interaction with other traffic and trains via delays incurred at road-rail at-grade crossings. Traffic congestion is mainly an urban issue. Nonetheless, a hypothetical shift of Great Lakes-Seaway traffic to the highway mode would decrease the available capacity of rural freeways by 5% to 15% (with the range covering level to rolling terrain). The capacity impacts would be higher for rural arterial highways with occasional passing lanes; however, capacity utilization is also lower on these highways.

The estimated cost of incremental urban congestion associated with shifting Great Lakes-Seaway traffic to trucks was in the range of $346 million to $380 million per year. The present value of this incremental cost would be $5.6 billion to $6.1 billion over a 24-year time period, assuming a 2.5% annual rate of growth in traffic.

The estimated cost of incremental delays at highway-railway grade crossings associated with shifting Great Lakes-Seaway traffic to rail was $46 million per year. The present value of this incremental cost would be approximately $750 million over a 24-year time period, assuming a 2.5% annual rate of growth in traffic.

Infrastructure Impacts

The study looks at the impacts on highway maintenance costs if the Great Lakes-Seaway cargo was shifted to trucks.

The trucking mode uses publicly maintained highway infrastructure with maintenance costs that are sensitive to traffic levels. Maintenance costs are a mix of recurring annual and longer-interval renewal investments. Pavement damage, which is the main traffic-sensitive component of the maintenance costs, is quite sensitive to axle loads. The Great Lakes-Seaway traffic is mostly bulk cargo, and involves truck configurations and axle loads that are much larger/heavier than the existing mix of intercity truck traffic. The incremental maintenance costs are derived on the basis of both the incremental traffic involved and the incremental axle loads utilized in hauling the traffic.

If Great Lakes-Seaway marine shipping cargo shifted to trucks permanently, it would lead to $4.6 billion in additional highway maintenance costs (calculated on a present-value basis over a 60-year period using a 6% discount rate).

The study did not undertake a full social cost analysis to determine the extent to which incremental fuel taxes generated by new truck traffic should be allocated to mitigate the maintenance costs.

Noise Impacts

Noise footprints for the three modes were developed on the basis of noise emitted during line-haul activity for each of the three modes.

The noise impacts of trains are a combination of the noise from air horns blown on approach to public highway-railway at-grade crossings and the noise from movement of trains that occurs everywhere. In the case of trucks, it is primarily the noise associated with the freeway and arterial highway systems that is relevant in determining noise impacts. Noise from trucks and trains related to loading and unloading activities at terminals and yards was not considered.

The noise footprint of the Great Lakes-Seaway Fleet is associated with the sounding of horns when vessels meet and when mooring lines are dropped in preparation for departure from locks and ports. As in the case of rail and trucks, noise emitted by vessels while at ports related to loading/unloading activity was not included.

On the basis of the analysis undertaken, the results show that:

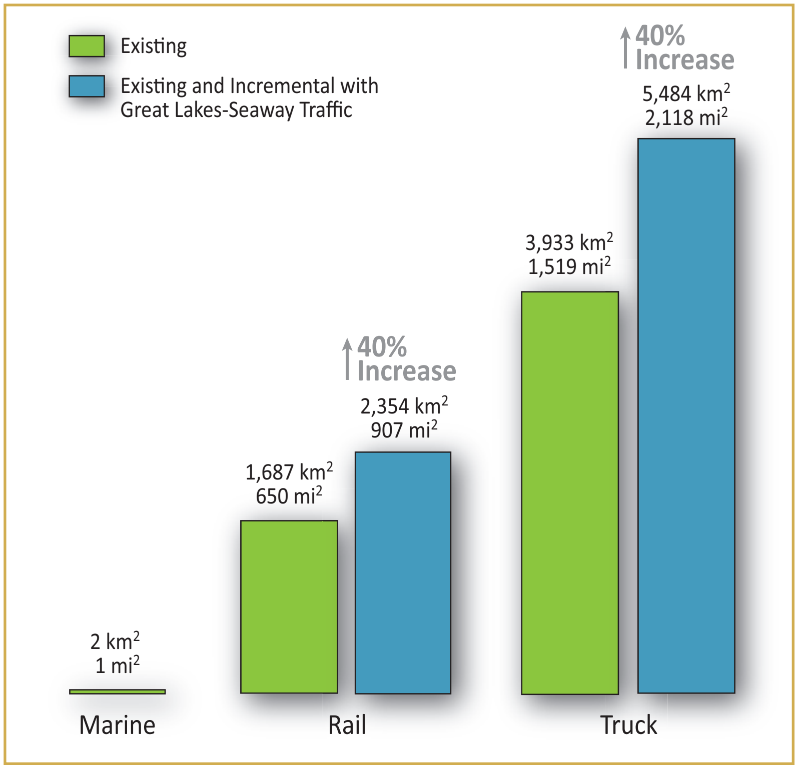
- The noise footprint of the Combined Great Lakes-Seaway fleet is negligible in comparison with that of the other modes; and
- The noise footprint for the rail and truck modes would increase by 40% if either mode were to transport the Great Lakes-Seaway cargo.

The noise footprints of the three modes illustrated in Figure ES9 show both the existing footprint and the marginal incremental footprint associated with a traffic shift from marine.

Figure ES9. Modal Noise Footprint Comparisons

Severe Ldn Footprint (sq. km.) /
Severe Ldn Footprint (sq. mi.)

Source: RTG analysis.



6. Peer Review of Study

To ensure that the methodology used by Research and Traffic Group to measure and compare the impacts for marine, rail and trucking modes of transportation was sound and met generally accepted precepts of environmental analysis, a final draft version of this analysis was submitted to three Canadian and U.S. experts in transport logistics, economics and environmental sciences, for independent peer review. Research and Traffic Group responded in writing to all peer reviewer comments to the satisfaction of all three reviewers. Based on these comments, several minor adjustments were made to the analysis prior to final release. Letters from each of the three peer reviewers confirming their overall satisfaction with the analysis are included in the next section of this report.

Closing Comments from the Study Authors

This report, *The Environmental and Social Impacts of Marine Transport in the Great Lakes–St. Lawrence Seaway Region*, highlights that Great Lakes ships are more fuel-efficient and emit fewer greenhouse gases per tonne-kilometer than land-based alternatives. The analysis also shows that a shift of cargo carried by marine vessels on the Great Lakes-St. Lawrence Seaway navigation system to road and/or rail modes of transport would lead to increased levels of traffic congestion, higher infrastructure costs to maintain highways and significantly greater levels of noise.

New ship designs and engine technology being introduced to the Great Lakes fleet over the next few years will only serve to increase these benefits. In particular, the Great Lakes-Seaway fleet overall is expected to achieve significant reductions in emissions with a 32% decrease in GHG emissions, an 86% reduction in NO_X emissions, a 99% reduction in SO_X emissions and an 85% reduction in PM emissions.

With this report, the Great Lakes-Seaway shipping industry now has the latest information on its environmental and social performance compared to other modes. This bi-national data will allow the industry to measure its progress as a whole as it continues to reduce its environmental footprint in the coming years.

Gordon English, Partner
David Hackston, Partner
Research and Traffic Group

1

Introduction

1.1 Background

In 2009, the Research and Traffic Group assessed the potential mode shift associated with extension of Emissions Control Area (ECA) regulations into the Great Lakes [Research and Traffic Group, 2009]. The study identified potential traffic shifts from marine to both rail and truck in different markets. The marine community wants to be in a better position to inform policy makers of the potential environmental consequences of introducing policies that could produce mode shifts. Accordingly, this study was commissioned and produced in collaboration with the Chamber of Marine Commerce, the Canadian Shipowners Association, the St. Lawrence Seaway Management Corporation and the Saint Lawrence Seaway Development Corporation to assess the environmental and social impacts of marine transport within the Great Lakes-Seaway navigation system.

1.2 Objectives

The objectives of the assignment were to compare the environmental footprints and external social impacts of marine, rail and truck under scenarios where marine carriers operating on the Great Lakes-Seaway System gain or lose existing traffic relative to road and/or rail.

1.3 Methodology Overview

The external impacts comparison of each transportation mode (i.e., rail, truck and vessel) includes the following:

- Fuel efficiency;
- Greenhouse Gas (GHG) emissions;
- Criteria Air Contaminant (CAC) emissions;
- Traffic congestion;
- Infrastructure impacts;
- Noise impacts.

The external impacts included in this study are not intended to be an exhaustive, but rather, represent key impacts common to each of the three surface transportation modes, enabling comparison. All modes have had historic impacts that are not included in a marginal impact assessment of future traffic shifts. For example, the marine mode`s past impacts related to invasive aquatic species were significant but are been addressed to prevent future occurrences. Similarly, the impacts of road and rail infrastructure on wildlife habitats were significant historic influences but are not significant marginal impacts for future traffic changes and are not included in this study. The ongoing loss of animal life on roads and railways, the infrequent instigation of forest fires from rail activity and the uncertain impact of marine activity on shore erosion are examples of external impacts that are related to changes in traffic but are not quantified in this study due to data limitations and/or scientific uncertainty.

GHG and CAC emissions impact comparisons were made for both the current range of technologies in use within each mode, and for currently available technologies anticipated to be partially or fully adopted into the propulsion fleets of the three modes over a defined time frame (i.e., 2012-2025). The latter comparison is based on the long-term modal performance potential associated with 100% adoption of the new technologies by all three modes.

For the impacts evaluated in this study, the traffic levels and technologies used in 2010 are selected as the basis of comparison. Since air emissions are quite sensitive to the technology and regulatory framework, a second comparison is made of each mode's potential based on the 2015/2016 regulatory framework and technologies expected to be economically viable for each mode.

The 2010 marine traffic on the Great Lakes-Seaway System is used as the basis of comparison. The impact of marine vessel activity on the system in 2010 is calculated for each of the external impact areas. The same categories of impact are then calculated and compared for the rail and highway modes — under the hypothetical scenario that the same tonne-kilometers (ton-miles) of cargo had been carried by these modes. This comparison ignores land-side activity at ports, as well as differences in modal distance between specific origin-destination pairs, which can favor either one mode or another depending on the movement selected. To address this latter limitation, a few sensitivity tests are undertaken.

The specific methodology used for each of the impact areas is presented in more detail in the relevant impact chapter.

1.4 Chapter Outline

This report contains 11 chapters, with the remaining chapters presented in the following order:

Chapter 2 provides an overview of the Great Lakes-Seaway region and develops the 2010 Great Lakes-Seaway traffic activity, which forms the basis for comparison of the three modes.

Chapter 3 provides the methodology used in the comparison of modal air emissions impacts and provides summary results.

Chapter 4 presents the results of the air emissions comparison for the Canadian and International Seaway fleets (Seaway-size Fleet). Comparisons are made using the 2010 traffic levels of the Seaway-size Fleet for two timeframes — one using the fleet characteristics of each mode in 2010 in Canada, and another hypothetical comparison using circa-2016 technology and regulatory conditions representative of each mode's long-term potential in Canada.

Chapter 5 presents the results of the air emissions comparison for the U.S. Great Lakes fleet (U.S. Fleet). Comparisons are made using the 2010 traffic levels of the U.S. Fleet for two timeframes — one using the fleet characteristics of each mode in 2010 in the U.S., and another hypothetical comparison using circa-2016 technology and regulatory conditions representative of each mode's long-term potential in the U.S.

Chapter 6 provides the sensitivity of the air emissions findings to some key parameters.

Chapter 7 makes a modal capacity comparison.

Chapter 8 compares the congestion impacts of the three modes on the traveling public.

Chapter 9 provides the findings of the marginal impact comparison for maintenance of public infrastructure.

Chapter 10 provides a comparison of noise impacts.

Chapter 11 provides our conclusions.

Details of the air emissions modeling and related modal characteristics are presented in Appendix B.

2

The Study Area

2.1 Great Lakes-Seaway System

The purpose of the subsections of this chapter is to define the fleet cargo movements within the Great Lakes-Seaway System, which are used as the basis of activity for comparison across modes. The modal activity influences each of the impact areas that are compared in later chapters.

The Great Lakes-St. Lawrence navigation system stretches from the Gulf of St. Lawrence to the Lakehead (Duluth/Thunder Bay), a distance of 3,700 kilometers (see Figure 1). The system includes the five Great Lakes and their connecting channels, as well as the St. Lawrence River to the Gulf of St. Lawrence.

The system has a series of locks (illustrated in Figure 2) to overcome the elevation changes. The major differences in elevation are:

- The seven Seaway locks between Montreal and Lake Ontario (MLO) lift/lower ships 68.8 meters (226 feet);
- The eight Seaway locks of the Welland Canal (Welland) between Lake Ontario and Lake Erie bypass Niagara Falls and lift/lower ships 99.4 meters (326 feet); and
- The Soo locks between Lake Superior and Lake Michigan/Lake Huron lift/lower ships 9.2 meters (30 feet).

The Great Lakes-Seaway System is bi-national, with the Canada-U.S. border bisecting four of the five Great Lakes and the St. Lawrence River from Cornwall to Lake Ontario. The only portions that are strictly Canadian are the Gulf of St. Lawrence and the St. Lawrence River from the Gulf to Cornwall. Lake Michigan is completely surrounded by American soil. Three of the locks segments are operated by the U.S. and the remainder by Canada. The Soo locks are operated by the U.S. Army Corp of Engineers (USACE), while the Seaway locks (including the MLO and Welland segments) are operated by the St. Lawrence Seaway Management Corporation (SLSMC) if in Canada, and by the Saint Lawrence Seaway Development Corporation (SLSDC) if in the U.S.

This study focuses on Canadian and U.S marine operations on the Great Lakes-Seaway System. These operations primarily occur within that part of the system that is enabled by the Seaway and Soo locks systems. Import and export traffic movements transit the Seaway locks and are subject to ground mode competition via transfers at ports on the lower St. Lawrence River (i.e., east of Montreal) or at Atlantic Coast ports. On the other hand, imports/exports carried by international vessels to/from lower St. Lawrence River ports are not subject to surface mode competition. Thus, while all movements of Canadian, U.S. and internationally flagged vessels within the Great Lakes-Seaway System are included in the study, movements on the lower St. Lawrence River are only included if the vessel transits the MLO section of the Seaway.

Due to the basis of reporting in the underlying data, emissions intensity and ballast ratios considered that portion of international trips that were in domestic waters (west of the Cabot Strait and the Strait of Belle Isle). However, for the impact comparison with the other modes, the tonne-kilometers of marine activity were limited to the Great Lakes-Seaway region west of Les Escoumins, Quebec (between Quebec City and Baie Comeau). International trips are a small part (less than 5%) of the overall dataset. The difference introduced by this characterization of international vessels is a small impact on a small subset and is not believed to have a significant impact on the results.

Figure 1. Great Lakes-Seaway System Ports and Locks

Source: The St. Lawrence Seaway Management Corporation, the Saint Lawrence Seaway Development Corporation

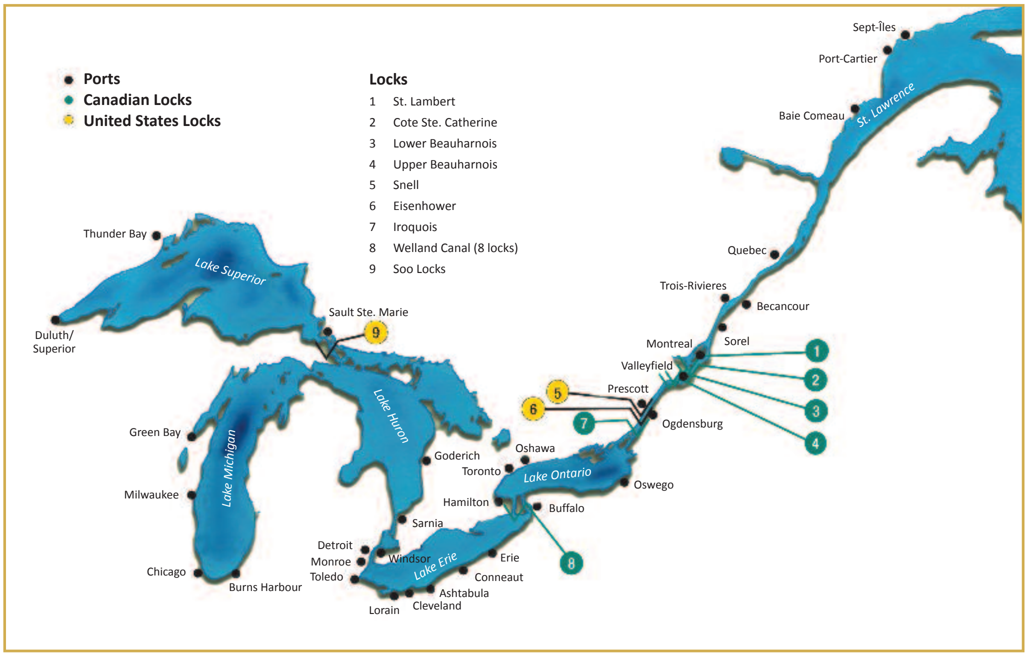
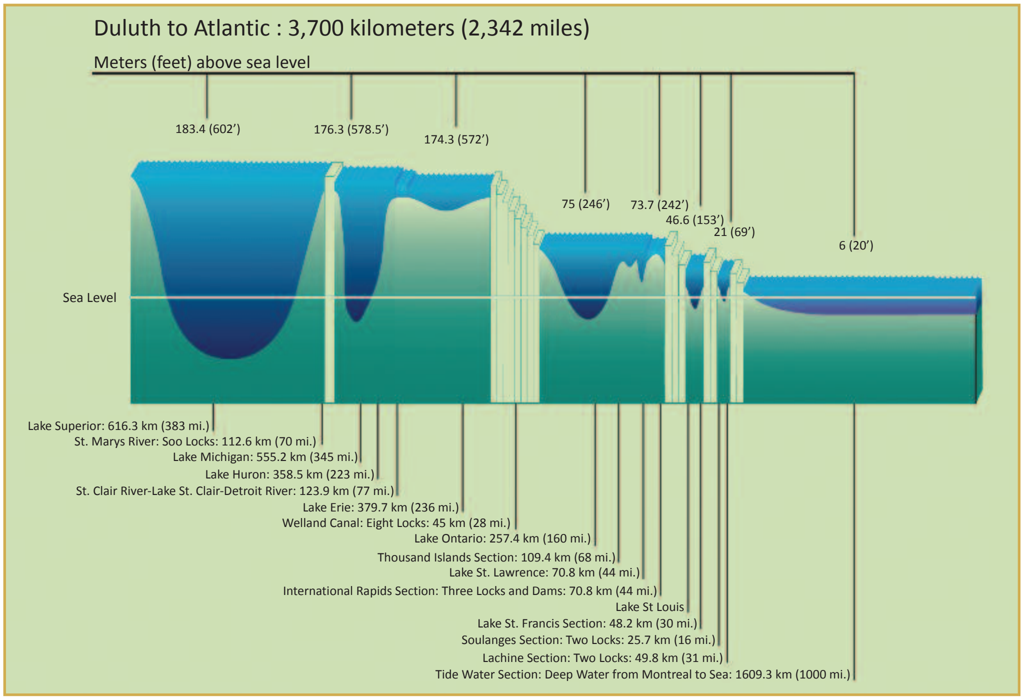


Figure 2. Elevation Changes of the Great Lakes St. Lawrence Seaway

Source: The St. Lawrence Seaway Management Corporation, the Saint Lawrence Seaway Development Corporation.

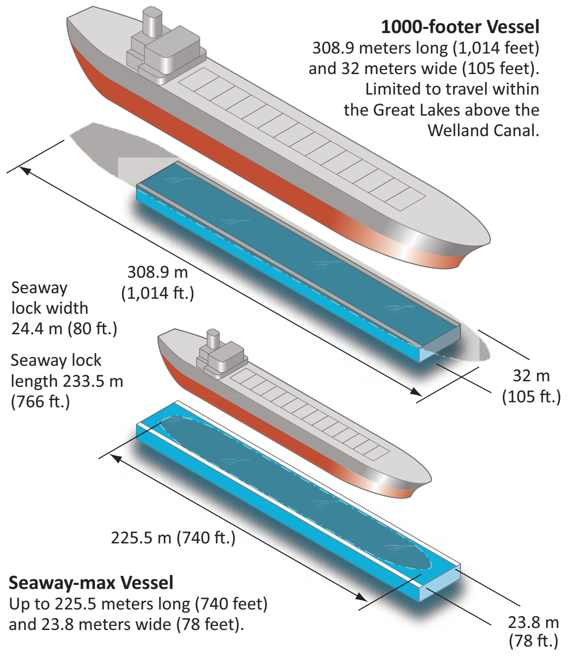


2.1.1 *Fleet Segmentation*

The marine operations in the Great Lakes-Seaway System include Canadian, U.S. and internationally flagged vessels. The dimensions of the Soo locks at Sault St. Marie are larger than those in the MLO segment of the Seaway and the Welland Canal segment of the Seaway between Lake Erie and Lake Ontario. The dimensional constraints of the Seaway locks are compared with the dimensional constraints of the Poe lock (the largest of the Soo locks at Sault Ste. Marie) in Figure 3. The 1000-footer vessel illustrated in the figure can only operate though the Poe lock, while the Seaway-max vessel reflects the constraints of the Seaway System's locks/channels/canals. In this report, we refer to vessels sized to the Seaway limits as Seaway-max vessels and vessels sized to the limits of the Poe lock as Poe-max vessels.

A large portion of the U.S. fleet that operates on the Great Lakes (called the U.S. Fleet in this report) is sized to fit the Soo locks but is either too long or too wide to transit the Welland Canal and MLO locks. The Canadian fleet is sized to fit the MLO and Welland locks and carries much of the traffic that moves into or out of the upper four lakes (i.e., above the Welland Canal). International fleets are restricted by U.S. and Canadian cabotage laws to carrying import/export traffic and therefore do not carry domestic traffic within the lakes. The import/export traffic that international vessels carry into or out of the Great Lakes must transit the Seaway locks and thus, international vessel dimensions are closer to those of Canadian vessels than to U.S. vessel dimensions.

Marine operational performance data are not publicly available. We were provided confidential data from U.S., Canadian and international carriers by agreement that the data would be aggregated and averaged in reporting, such that an individual carrier's attributes could not be discerned. To maintain confidentiality, the data are segmented into the U.S. Fleet (based on data from three carriers) and the Seaway-size Fleet (based on data from two Canadian carriers and two international carriers).



Soo Locks Dimensions:*

Poe Lock:

Length	366.0 m (1200 ft)
Width	33.5 m (110 ft)
Depth	9.8 m (32 ft)

MacArthur Lock:

Length	244.0 m (800 ft)
Width	24.4 m (80 ft)
Depth	9.4 m (31 ft)

* Either the Poe lock or the MacArthur lock can be used to transit between Lake Superior and Lake Huron.

Seaway System Dimensions:**

Length	233.5 m (766 ft)
Width	24.4 m (80 ft)
Depth	8.2 m (27 ft)

** Both the MLO and Welland Canal segments operate with these constraining dimensions.

Figure 3. Vessel Dimensions Constraints Imposed by the Locks of the Great Lakes-Seaway System

Source: Derived from *Great Lakes St. Lawrence Seaway Study*, Transport Canada, et. al., Fall, 2007.

2.1.2 Baseline 2010 Great Lakes-Seaway Traffic

The major commodity movements on the Great Lakes-Seaway System are iron ore, coal and stone within the lakes, iron ore into the lakes, and grain out of the lakes. Other important movements include petroleum products, chemicals, salt and fertilizer within the Great Lakes-Seaway System, and raw steel and project cargo imported to the lakes. Table 1 illustrates the distribution of cargo on a tonnage-loaded basis. On a tonne-kilometer basis , grain would be a higher proportion and aggregate a lower proportion. Grain is carried from Lake Superior (Thunder Bay and Duluth/Superior), as well as from Lake Erie and Lake Ontario to transfer elevators on the Lower St. Lawrence River. Iron ore is carried by the Seaway-size Fleet from Sept-Îles and Port Cartier to steel plants on Lake Ontario and Lake Erie — while the U.S. Fleet carries iron ore from Duluth/Superior to steel plants on the Upper Lake (west of the Welland Canal). Coal is carried to steel mills and power plants by both fleets, and aggregate is carried by both fleets. General cargo and liquid cargo are primarily carried by the Seaway-size Fleet.

Table 1. Great Lakes-Seaway Cargo Distribution for 2010 by Quantity Loaded

Cargo Type	Distribution
Iron Ore	38%
Coal	25%
Aggregate/Other Bulk	20%
Grain	12%
General Cargo	3%
Liquid Cargo	2%

Source: RTG estimate from USACE and SLSMC Traffic Data.

Most of the seven participating marine carriers provided detailed confidential data for the following:

- Tonne-kilometers of cargo moved by vessel;
- Total fuel consumed by vessel and by type of fuel; and
- Propulsion and auxiliary engine types by vessel.

Some carriers provided less detail — excluding fuel consumed and cargo moved but including the number of active days in 2010 by vessel, vessel engine types for each vessel, a breakout of typical activity (days-loading/unloading/in-transit) by vessel class, and estimated emissions; from this data, we estimated tonne-kilometers of cargo moved, fuel consumed and emissions generated. Total traffic for 2010 was available on a tonnage-carried basis from USACE and St. Lawrence Seaway Management Corporation (SLSMC) data. However, an energy-intensity comparison requires traffic data on a tonne-kilometer basis and these data are not publicly available. We estimated total tonne-kilometers of travel on the basis of regional origin-destination tonnage data that are published by the USACE and SLSMC, and estimated average interregional distance data based on the confidential carrier data. International traffic was limited to those vessels that entered the MLO section of the Seaway and trip distances were limited to domestic waters west of Les Escoumins, Quebec.[2] The resulting estimate of total 2010 traffic — broken out by country — is provided in Table 2.

The corresponding proportion of traffic carried by the seven cooperating carriers is shown in Table 3. As indicated, the cooperating U.S. and Canadian carriers represent over 80% of the corresponding activity. The International Fleet sample was the lowest, but as can been seen in Table 2, the traffic carried by internationally flagged vessels is less than 5% (i.e., 7/147) of total tonne-kilometers. Overall, the tonne-kilometer weighted average sample size was 79%.

The range of vessel types included in the sample is summarized in Table 4. The 12 Poe-max vessels represent 100% of the active fleet in 2010 — one of the 13 Poe-max vessels was out of service. Further details on the fleet attributes that are specific to energy efficiency and emissions intensity can be found in Appendix B.

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[2] While the performance data for international carriers was based on domestic waters west of the Strait of Belle Isle and the Cabot Strait, the modal comparison of tonne-km activity was based on SLSMC data for the MLO and considered the shorter trip distance west of Les Escoumins, Quebec in the lower St. Lawrence River.

Table 2. Derived Great Lakes-Seaway Cargo Distribution by Country for 2010

Country*	Tonnes	Tons	Proportion (%)
U.S.–U.S.	72,888,797	80,323,455	54.7
Cross-border	32,731,818	36,070,464	24.5
Canada–Canada	21,359,455	23,538,119	16.0
Import/Export via International Vessels	6,386,520	7,037,945	4.8
Total	133,366,590	146,969,982	100.0
	Kilometers	***Miles***	
Average Distance	1,090	677.5	
	Million tonne-kilometers	***Million ton-miles***	
Total Activity	145,276	99,572	

* Some of the domestic and cross-border movements might have export destinations via port transfer.

Source: Derived from USACE and SLSMC Traffic Data, and confidential carrier data for some trip distances.

Table 3. Carrier Provided Data (% of Total Derived Traffic by Vessel Flag)

Source	Sample Proportion of Total Tonne-km Carried for Each Flag
Canadian Carriers	80%
U.S. Carriers (full details*)	41%
U.S. Carriers (including partial details*)	83%
International Carriers	31%
Tankers (Canadian and International)	66%
Overall	79%

* Full details included fuel, trips and cargo-ton-miles. Carriers providing less detail (i.e. excluding fuel consumed and cargo moved) included the number of active days in 2010 by vessel, vessel engine types for each vessel, a breakout of typical activity (days-loading/unloading/in-transit) by vessel class; see text.

Source: RTG analysis.

Table 4. Carrier Provided Data (Number of Vessels by Class)

Vessel Class	Detailed Carrier Data[1]	Summary Carrier Data[1]	Total Number
Poe-max (1,000') SU[2]	6	6	12
Between Seaway-max and <Poe-max	9	1	10
<=Seaway length (740') SU and Bulk[3]	47	6	53
International General Cargo	10	0	10
Tanker (Domestic and International)	7	0	7
Total Vessels[4]	79	13	92

Notes:

1. Detailed data included fuel, trips and cargo-ton-miles. Carriers providing summary data excluded fuel consumed and cargo moved but included the number of active days in 2010 by vessel, vessel engine types for each vessel and a breakout of typical activity (days-loading/unloading/in-transit) by vessel class; see text.
2. Self-unloader
3. Eight of the 53 were U.S. flag, 45 were Canadian flag.
4. Two self-unloaders were dedicated tug/barge configurations.

Source: RTG analysis of confidential carrier data.

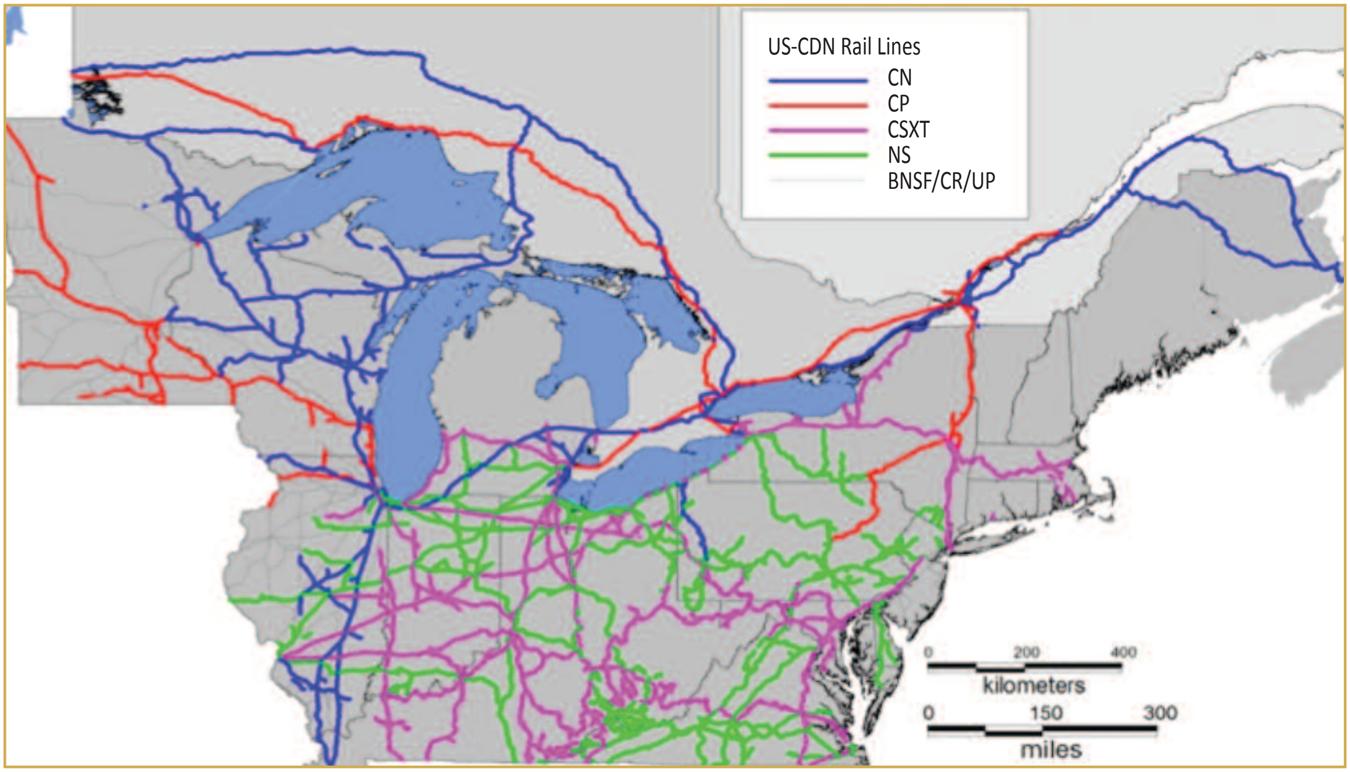
2.2 The Study Area Surface Modes' Networks

2.2.1 Rail Network

The rail network included in the study area involves CN and Canadian Pacific (CP) on both sides of the border, and CSX Transportation (CSXT) and Norfolk Southern Railway (NS) more principally within the U.S. but also with short border crossings into Canada. The rail network in the study area is shown in Figure 4. Due to data availability, rail mode characterization is based on the complete rail networks of these railways, not just those rail segments located in the Great Lakes-Seaway region.

As discussed in Appendix B, the data publicly reported to the U.S. Surface Transportation Board (STB) by CSXT and NS offer details that support segmentation of performance by car types and train types. Such details are not publicly reported by the Canadian railways. All North American railways use similar equipment and follow a uniform interchange agreement. The CSXT and NS cargo mix of bulk, general cargo and containerized cargo is also similar to the cargo mix of CN and CP. Thus, the cargo-specific performance derived with NS and CSXT data is adopted for the complete study rail network.

Figure 4. Study Rail Network



Source: RTG using U.S. DOT NTAD data.

2.2.2 *Highway Network*

The highway network included in the study area involves the Interstate highway system in the states bordering the Great Lakes, and the strategic highway network in Ontario and Quebec — as shown in Figure 5.

Unlike the rail mode, truck operations differ significantly between the U.S. and Canada. Truck axle load limits and body-style configurations are the main differences and the related truck performance analyses had to be segmented by country. Appendix B has the details.

Figure 5. Study Highway Network

Source: RTG using map vector files from DOT-NTAD for the U.S. and MTO and TC for Canada.

3

Modal Comparison for Air Emissions

The methodology used to compare air emissions intensities involves some elements that are common to all comparisons (e.g., the development of vehicle-kilometer activity) and other elements that are unique to the air emissions comparison (e.g., emissions intensity by fuel type).

The detailed characteristics of each mode are developed in Appendix B. The intent of this chapter is to provide an overview and highlight some of the differences and commonalities across the three modes assessed in this study. This overview will generate some questions that are only answered in the more detailed technical appendix, but some aspects are best compared though the multimodal discussion presented here.

Technical aspects of the methodologies used for impact areas other than air emissions are presented within the related impact comparison chapter.

3.1 Comparative Framework

Making an accurate comparison across modes requires models of modal energy consumption that reflect the specific characteristics applicable to the cargo being carried and the region where it is being carried. Simple comparisons of modal average performance such as liters/cargo-tonne-kilometers (L/CTK) and cargo-ton-miles/US-gallon (CTM/US-Gal) can be drawn from sector aggregate statistics. However, due to the significantly different operating characteristics and cargo types being carried by the different modes, these averages offer very little insight into how the modes compare when transporting the same cargo in the same region. To make a like-for-like comparison requires a level of detail that is not generally reported in modal statistics.

In this study, we have confidential data from marine carriers that allow a cargo-specific assessment of efficiency and emissions intensity. However, such detailed data are not available for the ground modes. In the absence of cargo/region-specific data, simulation models were used to estimate the performance of the rail and truck modes in carrying the baseline Great Lakes-Seaway cargo. This project has used rail and truck simulation models with mode-specific validation data to make the modal comparisons. The simulation models employed to derive cargo-specific modal efficiencies are believed to provide as accurate an indication as is possible with publicly available data. The rail mode estimates have a higher level of confidence than the truck mode estimates, since the Class 1 railways publicly report fuel and traffic data at an aggregate level. The truck mode's energy and emissions intensities are based on a model validated for a wide range of cargos and truck types, but the truck mode's operating characteristics are based on publicly reported sample surveys — rather than the regulatory filings required for the rail mode.

As the performance comparison is only valid for the mix of cargo and equipment being assessed, it is necessary to define these parameters. This modal comparison is based on the mix of cargo currently being carried on the Great Lakes-Seaway System. The equipment used in the comparisons is representative of what each mode uses in carrying the various cargoes. Different vessel types/sizes, rail equipment and truck axle loads/dimensions exist in Canada and those states that border the Great Lakes-Seaway System. These differences are all reflected in the analyses.

In summary, the 2010 air emissions comparison involves the following elements:

- Marine fuel types and energy intensity values were derived from a sample of confidential data from seven participating carriers, covering Canadian, U.S. and internationally flagged vessels operating in the Great Lakes-Seaway System in 2010. The marine characterization is documented in the Marine section of Appendix B.
- Rail energy intensity was derived via a simulation model, calibrated using public data from railroad filings to Transport Canada (TC)/Environment Canada (EC) and the U.S. Surface Transportation Board (STB). Energy intensity was derived by cargo type (and related equipment and empty return ratios) and then scaled up in proportion to the cargo carried by the relevant marine fleet being compared. Criteria Air Contaminant (CAC) and Greenhouse Gas (GHG) emissions intensities used the U.S. Environmental Protection Agency (EPA) and TC/EC data. The rail mode characterization is documented in the Rail section of Appendix B.
- Truck energy intensity was derived via a simulation model, using public data for truck characterization and both public and private data for validation. Energy intensity was derived by cargo type (and related equipment and empty return ratios) and then scaled up in proportion to the cargo carried by the relevant marine fleet being compared. CAC and GHG emissions intensities used EPA certification data for truck engines. The truck mode characterization is documented in the Truck section of Appendix B.
- Each mode is simulated for intensities and impacts in a scenario where it carries the marine traffic on the Great Lakes-Seaway System in 2010 an equal distance. Modal differences in route lengths are case-specific and range from a significantly shorter marine trip for cross-lake services to longer marine trips for some services such as Duluth to Chicago. Indexed results are provided such that a user can interpret the break-even distance, where a surface mode attains the same emissions as the marine mode and/or relative emissions for actual modal distances involved for a specific origin-destination movement.

3.2 Adjustments Made to Attain a Like-for-Like Comparison

3.2.1 Auxiliary Power Adjustment

Data were available for the fuel consumed by the onboard engines in each mode. Separate propulsion and auxiliary engines (and fuels) are used in the marine mode, while auxiliary power is drawn from the main propulsion engine in the rail and truck modes. Fuel is consumed in auxiliary services such as engine cooling, maintaining comfortable crew compartments and some modal-specific requirements (such as ballast water pumping for marine and electric traction motor cooling for rail). The final component of auxiliary energy consumption is the loading and unloading of the cargo being carried.

Hotel services and auxiliary loads are a higher component of onboard fuel consumption for marine and in most cases involve the use of different fuel. Thus, it is much easier to separately account for hotel power and propulsion power. This separation is important because the fuel used at port is only for hotel and auxiliaries; the main propulsion engines are shut down. The fuel used at port is a smaller portion of overall vessel fuel consumption and is also a cleaner fuel than the intermediate fuel oil (IFO) that many vessels use as fuel in propulsion engines.

For trucks and freight locomotives, auxiliary loads are met by the prime engine and in some cases, by smaller auxiliary power units that allow the main engine to be stopped during periods of extended idle. The fuel for auxiliary loads is not differentiated in the fuel statistics but can be estimated and modelled.

Comparison of fuel consumption associated with auxiliary loads is a more difficult task than for propulsion aspects. Hotel power is a constant requirement for marine, since crews live on board the vessel. Long-haul truck drivers often have sleeper cabs with heating and air conditioning, but meals and occasional overnight stays involve ground facilities (hotels or bunk stops). Railways also use hotels and bunkhouses at some crew stops, and on lower density lines, they use taxis to return crew to home stations. Hotel power is automatically included in the marine fuel consumption and to the extent that it is provided by truck engines, it exists in truck fuel use. The energy consumption for those parts of the crew accommodation that are not met with onboard power for truck and for rail should be included in a like-for-like comparison; however, the assumptions and estimates involved are much less reliable than those made for the propulsion aspects.

Similarly, self-unloading vessels consume fuel to move materials from ship to shore. For the ground modes, wayside conveyors are required to get the material from the unloading point and in some cases, wayside power is used for unloading (e.g., rotary dumping of rail cars by a wayside powered facility). The operation of wayside facilities and equipment would ideally be included in a like-for-like comparison.

It is a complex task to develop the energy intensity of those parts of truck and rail's hotel and unloading power requirements that are provided with wayside equipment. Since the fuel consumed in the provision of these services by the marine mode is separately reported in the data, it is much easier to exclude those aspects of marine fuel consumption in order to provide a like-for-like comparison. Therefore, we eliminated the energy consumed by onboard conveyors used to unload dry bulk cargo on self-unloading vessels, and we reduced the auxiliary fuel consumed at port to provide crew hotel services by 10%, as a means of attaining a like-for-like comparison. We did include the other 90% of hotel power used while at port and the 100% of hotel power used while the vessels are underway.

Thus, our basis of comparison is the fuel used by equipment in line-haul transportation, including idle and hotel fuel used at terminals/ports — after adjustments are made to attain a like-for-like comparison of that fuel component. A case-by-case analysis would have to review the full transportation cycle involved and decide whether cargo transfer/loading/unloading should be included for one or more modes. For example, a shipment of coal or grain that originates with rail and is transferred to marine should include marine's incremental handling energy at the transfer port involved, but the final delivery requires unloading by either direct rail or rail/marine and both are excluded in our number. The 10% reduction in hotel power at port was essentially an estimate of what would produce a like-for-like comparison and therefore, sensitivity cases of 5% and 20% were assessed.

3.2.2 Base Year Ballast Ratio Adjustment

Empty travel is an important element in every mode, but more so for marine vessels as ballast water must be added in order to load the vessels to a sufficient depth to submerge the propeller. Thus, the vessel is partially loaded on an empty-cargo trip. This is an unavoidable characteristic of the mode; however, it is important that the ballast ratio that is used in the performance comparison is a representative one.

The year 2010 was selected as a baseline dataset because it was the most recent data available and reflected the most current technology. However, on reviewing the aggregate data, the carriers believed that 2010 was not representative of the backhaul potential on the Great Lakes-Seaway System and using the ballast ratios for that year would unduly penalize the marine mode. Therefore, the ballast ratios were adjusted to better reflect the long-term average performance.

The marine carriers on the steering committee indicated that 2008 was the most recent representative year, and review of available data for the Soo locks[3] indicated that the year 2008 was within 2.5% of the average of the four years of available data. We therefore accepted the recommendation to adjust the ballast ratios to reflect the 2008 values. The SLSMC's Traffic Reports for the St. Lawrence Seaway had a ballast/laden ratio for domestic bulk carriers in 2008 that was 87.5% of the 2010 ratio, and the Soo locks had a ratio that was 80% of the 2010 ratio.

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[3] Directional data at the Soo locks were available from the Lake Carrier's Association website www.lcaships.com for the years 2003, 2005, 2006 and 2007.

Table 5. Empty (or Ballast) Return Ratios

Mode	Empty / Laden Distance Ratio	Empty / Total Distance Ratio
Marine-2010	63%	39%
Marine-2008	52%	34%
Rail	95%	49%
Truck	42%	29%

Note: Empty travel for marine is a ballast state, where the vessel is "loaded" with water. Two definitions of ballast ratios are shown as some consider the ratio to be non-cargo travel distance divided by laden travel distance (as shown in Column 2), while others consider it to be non-cargo travel distance divided by total travel distance (as shown in Column 3). Ballast ratios shown for the marine mode are for the Combined Great Lakes-Seaway Fleet.

Source: RTG analysis of confidential marine carrier data.

Thus, for the U.S. Fleet that is most influenced by the Soo locks, the 2010 ballast movements were reduced to 80% of the 2010 actuals and for the Canadian Fleet that is most influenced by the Seaway, the 2010 ballast movements were reduced to 87.5% of the 2010 actuals. The International Fleet's ballast ratio was not adjusted.[4]

With respect to the empty return ratios of the other modes, the truck ratio was based on the most recent survey data from 2006. While the truck survey did not ask if the empty return ratios in 2006 were indicative of normal backhaul potential, we believe the economy was such that the 2006 survey data would be a conservative estimate of the mode's backhaul potential. Rail data exhibit little variation in empty/load ratios for the equipment used to haul the predominantly bulk cargoes being compared. Thus, we believe the data for both ground modes were representative.

3.3 Estimates of Long-Term Modal Potential via a Post-Renewal Comparison

3.3.1 Methodology

The technologies used in the year 2010 baseline comparison can be expected to change over time for each of the modes. However, the magnitude of change will be much greater for the marine mode than for the two ground modes. Domestic vessels in the Canadian and U.S. fleets operating in the Great Lakes-Seaway System are over 30 years old — whereas the rail mode's mainline locomotive fleet and truck mode's long-haul tractor fleet are less than 20 years old. The delay in renewal of the marine fleet has been influenced by the 25% duty on new ships in Canada and the Jones' Act restrictions on foreign-built vessels for U.S. operators.

The repeal of the Canadian 25% import duty and the introduction of the EPA's assistance program for new power plants on existing U.S. vessels are stimulating fleet and power-plant renewal that will significantly improve the efficiency of both fleets. Current EPA and Canadian government regulatory initiatives will also lead to reductions in CAC emissions intensity for marine over the interval 2012 to 2025 and for rail by 2016. The truck mode, as the least emissions-efficient mode, was the target of early CAC regulatory initiatives and is not expected to see further reduction in CAC emissions intensity on a grams-emitted-per-liter of fuel basis. However, there are regulatory initiatives to reduce truck GHG intensity over the 2014 to 2017 timeframe. Energy efficiency improvements made to meet these regulations will have an equivalent reduction for the truck mode's engine-based CAC emissions.

Similarly, there are longer-term efficiency improvements in proposed regulations of the marine mode. International Maritime Organization (IMO) initiatives for ocean vessels built after 2013 will lead to further opportunities (and in some jurisdictions, requirements) for efficiency advances in ship design/operations. If Canada and the U.S. extend the IMO regulations to their domestic fleets, efficiency improvements of 30% over 2010 baseline technology will be required for newly purchased vessels.

In order to assess the long-term potential performance of each mode, we have included a "post-renewal" scenario for each mode — under the assumption that 100% of each mode's fleet is comprised of equipment that meets circa-2016 regulations. We note that this approach ignores the additional efficiency improvements that would be required under the IMO's GHG regulations post-2015.

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[4] The International Fleet was not adjusted partly because international vessels are not captive to the Great Lakes-Seaway System and are less likely to make a trip into the Seaway if a return load is not available, and partly because the reporting basis inherent to the international data marginally improves its ballast ratio relative to the domestic fleet — since any carriage of cargo in domestic waters is included for cargo transferred at Lower St. Lawrence River ports as long as the vessel made a trip into the Great Lakes-Seaway System.

3.3.2 Marine Mode’s Post-Renewal Framework

The basic post-renewal comparison is based on the following assumed conditions for the fleets operating on the Great Lakes-Seaway System:

- The Canadian Fleet is renewed (engine and vessel-design) at an estimated 36.5% average improvement from the present technology being used on newly ordered vessels (with 2013/2014 deliveries).
- The U.S. Fleet is repowered to attain the performance exhibited by the “Best-in-Fleet” vessel in the U.S. carriers’ data, but with a 90% effectiveness ratio to account for trade-specific differences (e.g., shorter distances, smaller vessels). This results in a 33.4% average improvement for the U.S. Fleet.
- The International Fleet sees an average 10% efficiency improvement and meets Emission Control Area (ECA)-2015 emissions requirements while in the Great Lakes-Seaway.
- All Fleets use 100% marine diesel oil (MDO) fuel — with auxiliary engines meeting EPA-C2 regulations and propulsion engines meeting EPA-C3 regulations for ECA-2015 (involving a phase-in of sulfur dioxide (SO_2) reductions by 2020 to 2025).

We note that the load capacity and related energy efficiency of the marine mode and the deeper draft U.S. Fleet in particular, are sensitive to water-level variations on the Upper Great Lakes. The baseline data reflect the conditions of 2010, which was reasonably representative of the previous decade; however, the 2001-2010 decade was lower than the long-term average. There is no consensus forecast of future water levels; however, the performance of the marine mode and the deeper draft U.S. fleet in particular could improve or worsen in the post-renewal scenario, depending on future changes in water levels.

It should be noted that both the U.S. and Canadian Fleets would see initial efficiency improvements much greater than the above fleet-wide averages — as the lowest efficiency vessels would be the first to be displaced by the newer vessels/engines.

Algoma Central Corporation and Canada Steamship Lines have both ordered new vessels since the lifting of the 25% import duty. Preliminary performance data presented by Algoma Central Corporation indicate the newly ordered vessels will attain about a 9% efficiency performance advantage, relative to the IMO’s Energy Efficient Design Index (EEDI) baseline [Algoma Central, 2011]. Thus, the incremental impact of the IMO’s 2025 EEDI requirement of a 30% improvement would be a further 21% reduction, if we included it in our post-renewal scenario. This incremental improvement was not included, as it was not viewed as being economical for the fleets operating in the Great Lakes-Seaway System. This same approach was applied to the rail mode, where technological advances exist but are not considered economical. The truck mode is somewhat different — in that energy-improving technologies have been included in new GHG regulations and are thus included in truck’s post-renewal fleet whether economical or not.

3.3.3 Rail Mode’s Post-Renewal Framework

Rail’s baseline emission performance and expected post-renewal performance are discussed in Sections B.3.4 and B.3.5 of Appendix B. As noted there, rail mode engines will be subject to more stringent CAC emissions regulations in 2015 and sulfur content of railway diesel fuel will also be reduced in 2016. We estimate that there is little scope for additional cost-effective engine efficiencies over the 2010 engine by 2015. Nonetheless, our post-renewal performance exceeds the 2010 performance, as all locomotives in the 2010 fleet are replaced with engines that meet the circa-2016 regulations. The 2010 fleet had a distribution of ages, including many older less efficient engines with higher emissions intensities. In the post-renewal scenario, the line-haul fleet is comprised of 100% new equipment meeting 2016 standards. The emissions intensity factors are drawn from the EPA’s estimated emissions factors for the 2040 locomotive fleet — where the fleet is considered to have been largely upgraded to 2015 technology after 25 years [EPA, 2009].

Investment opportunities to reduce fuel consumption exist for all modes and it is difficult to forecast how many will get adopted. For rail, it is assumed that the following operating-efficiency improvements will be economical in the "post-renewal" scenario:

- Locomotive fleet updated to 100% new engines, attaining 2016 emissions regulatory compliance and efficiency performance estimated by the EPA for the 2040 locomotive fleet;
- Coal-car average load increased to 115 tons;
- Grain and other bulk cargo average load increased to 100 tons;
- Train length increased by 10%;
- Layover idle decreased by 20%.

3.3.4 Truck Mode's Post-Renewal Framework

Truck's baseline emission performance and expected post-renewal performance are discussed in Section B.4.4 of Appendix B. All existing CAC regulations for trucks were in effect in 2010. While the EPA has not published notices of new CAC regulations for trucks, it has introduced a final rule requiring reductions of GHG emissions by 2014 and later [Federal Register, 2009; Federal Register, 2011]. As these reductions involve fuel-efficiency improvements to engines and tractors, CAC emissions from engines will see a reduction in proportion to the fuel reduction. The average reductions sought from tractor suppliers include the savings required by engine sub-suppliers, and the combined reductions vary by class of truck and cab style. The combined engine and tractor body reductions required by 2014 range from 7% to 20% and a further 3% is required by 2017. In April 2012, Canada proposed to adopt the same standards [Canada Gazette, 2012].

As with the other modes, the post-renewal scenario assumes 100% of the fleet is comprised of post-renewal (in this case post-2017) trucks. Since the regulatory reductions are related to a defined base vehicle, the actual service-specific performance will not necessarily result in the same savings. Our post-renewal scenario for trucks assumes that the improvements required by the EPA for tractor manufacturers are maintained by operators. The impacts of the GHG regulations are specific to the types of trucks and loads involved in this assessment.

3.4 Summary of Findings

The specific findings for the Seaway-size Fleet (Canadian and international vessels that are sized to transit the Seaway locks system) and for the U.S. Fleet (U.S. vessels operating on the Great Lakes) are presented separately in the two following chapters. In this chapter, we summarize the findings of the combined fleets operating on the Great Lakes-Seaway System. In each case the combined fleet numbers are based on the ratio of total emissions or fuel consumed by all vessels divided by total cargo carried by all vessels.

The energy efficiency comparisons for 2010 and post renewal of all modes are presented in Table 6, the GHG intensity comparisons are presented in Table 7, and the key CAC intensity comparisons are presented in Table 8.

Table 6. Fuel efficiency to move Great Lakes-Seaway cargo

Distance in kilometers to move one tonne of cargo with 1 liter of fuel	Base year 2010			Post renewal of all modes		
	Marine	**Rail**	**Truck**	**Marine**	**Rail**	**Truck**
Seaway-size Fleet	265	213	42	394	226	49
U.S. Fleet	235	212	34	342	224	40
Combined Great Lakes-Seaway Fleet	243	213	35	358	225	41

Distance in miles to move one ton of cargo with 1 U.S. gallon of fuel	Base year 2010			Post renewal of all modes		
	Marine	**Rail**	**Truck**	**Marine**	**Rail**	**Truck**
Seaway-size Fleet	688	553	109	1,022	586	127
U.S. Fleet	610	550	88	887	581	104
Combined Great Lakes-Seaway Fleet	631	553	91	929	584	106

Source: RTG analysis of confidential marine carrier data.

Table 7. GHG Emissions Intensity Comparisons

GHG Emissions Intensity for the Combined Great Lakes-Seaway Fleet						
	2010			**Post Renewal**		
	g/CTK	**lb/kCTM**	**Index**	**g/CTK**	**lb/kCTM**	**Index**
Marine	11.9	38.3	1.00	8.1	26.1	1.00
Rail	14.2	45.5	1.19	13.3	42.9	1.64
Truck	75.5	242.4	6.33	65.5	210.3	8.07

g/CTK = grams emitted per cargo-tonne-kilometer.
lb/kCTM = pounds emitted per thousand cargo-ton-miles.

Source: RTG analysis.

Table 8. Comparison of the Primary CAC Emissions for the Combined Great Lakes-Seaway Fleet

Year	Mode	NO_X		SO_X		PM	
		(g/kCTK)	**(g/kCTM)**	**(g/kCTK)**	**(g/kCTM)**	**(g/kCTK)**	**(g/kCTM)**
2010	Marine	233.4	340.5	82.9	121.0	13.7	20.0
	Rail	245.9	359.0	1.5	2.2	7.0	10.3
	Truck	392.0	572.0	0.7	1.0	13.3	19.4
Post Renewal	Marine	32.3	47.1	0.07	0.11	2.1	3.1
	Rail	35.2	51.4	0.10	0.15	0.53	0.77
	Truck	54.5	79.5	0.61	0.90	2.7	3.9

g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.
g/kCTM = grams emitted per thousand-cargo-ton-miles.

Source: RTG analysis of confidential marine carrier data.

4

Air Emissions Comparison — Canadian and International Vessels

4.1 Summary

This chapter compares the energy efficiency and air emissions of the Seaway-size Fleet to that of rail and trucks if they were to carry the same cargo, the same distance. The analysis shows that the Seaway-size Fleet is more fuel-efficient and a lower emitter of Greenhouse Gases than both land-based alternatives. In terms of Criteria Air Contaminant (CAC) emissions — sulfur oxides (SO_X), nitrogen oxides (NO_X) and particulate matter (PM) — the Seaway-size Fleet compared less favorably in 2010. In the future, however, marine CAC emissions will dramatically decrease. The marine mode has been the last mode to see CAC emissions regulations and new standards will be implemented over the time frame 2012-2025.

In a post-renewal scenario, where all three modes meet the regulatory conditions and the technology and fuel-use improvements that would be economically available over the time frame 2012-2025, the Seaway-size Fleet becomes the lowest emitter of SO_X and NO_X, and second to rail for PM emissions.

4.2 Energy Efficiency

As noted in Section 2.1.1, Canadian and international vessels operating in the Great Lakes-Seaway System are combined in our analysis, in order to maintain confidentiality of the data provided. As the two groups of vessels are sized to fit the Seaway locks, we refer to the combined group of vessels as the Seaway-size Fleet. However, the comparisons are based on all activities of the Seaway-size fleet (i.e., on the Great Lakes and on the St. Lawrence River, not just in the Seaway region). The fleet-average values of some of the key performance attributes are presented in Table 9.

Table 9. Seaway-size Fleet's Key Energy Performance Attributes

Parameter Description	Fleet Average Value	
Ballast Ratio (Note 1)		
Ballast-km / laden-km	40.1%	
Ballast-km / total-travel-km	28.6%	
Fuel Efficiency (Note 2)	***CTK/liter***	***CTM/US-gal.***
Laden Trip only (propulsion and auxiliary)	413	1,072
Full Voyage, including port and ballast legs	256	664
Full Voyage, adjusted auxiliary power at port (Note 3)	265	688

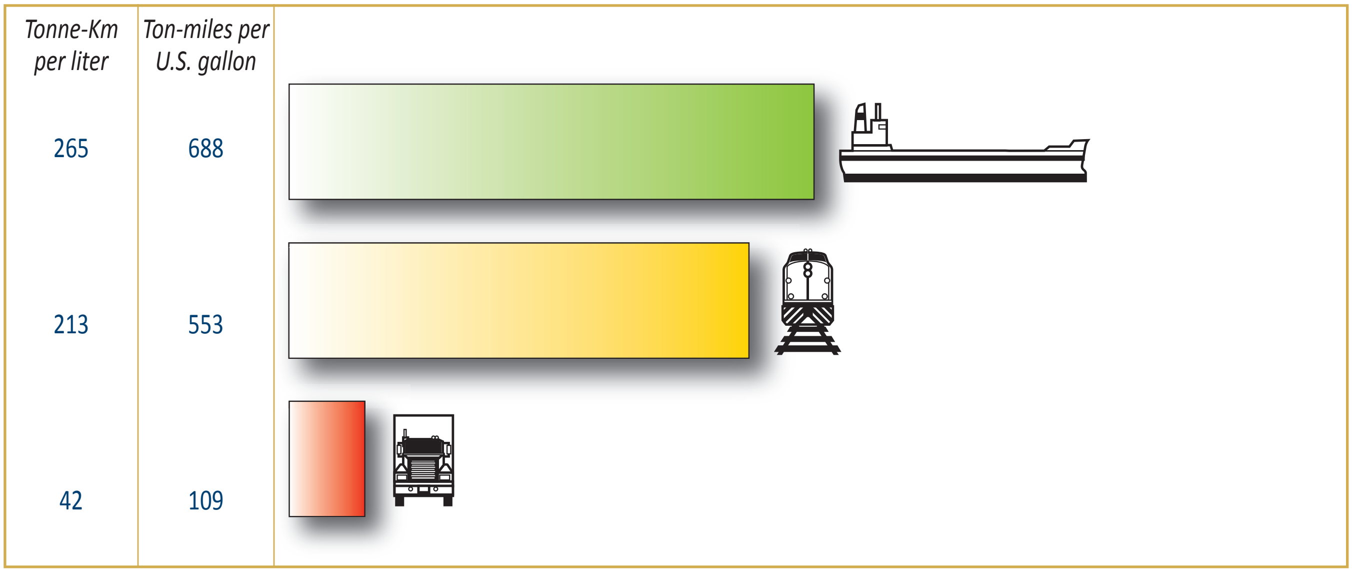
Notes:

1. Two definitions of ballast ratios are shown as some consider the ratio to be non-cargo travel distance divided by laden travel distance, while others consider it to be non-cargo travel distance divided by total travel distance. For the Seaway-size Fleet, grain is a major eastbound cargo movement, while iron ore offers a partial-trip cargo movement in the opposite direction.
2. CTK = cargo tonne-kilometer; CTM = cargo ton-mile;
3. Adjusted auxiliary power excludes self-unloading power and reduces hotel power by 10% while at port.

Source: RTG analysis of confidential carrier data.

The energy efficiencies of the three modes in the year 2010 are compared in Figure 6. The performance comparison is based on ratio of work done (weight of cargo moved a unit distance) divided by total fuel consumed (laden and empty/ballast trips). The analysis indicates that the Seaway-size Fleet can move cargo 24% farther (or is 24% more fuel-efficient) than rail and 531% farther (or is 531% more efficient) than truck.

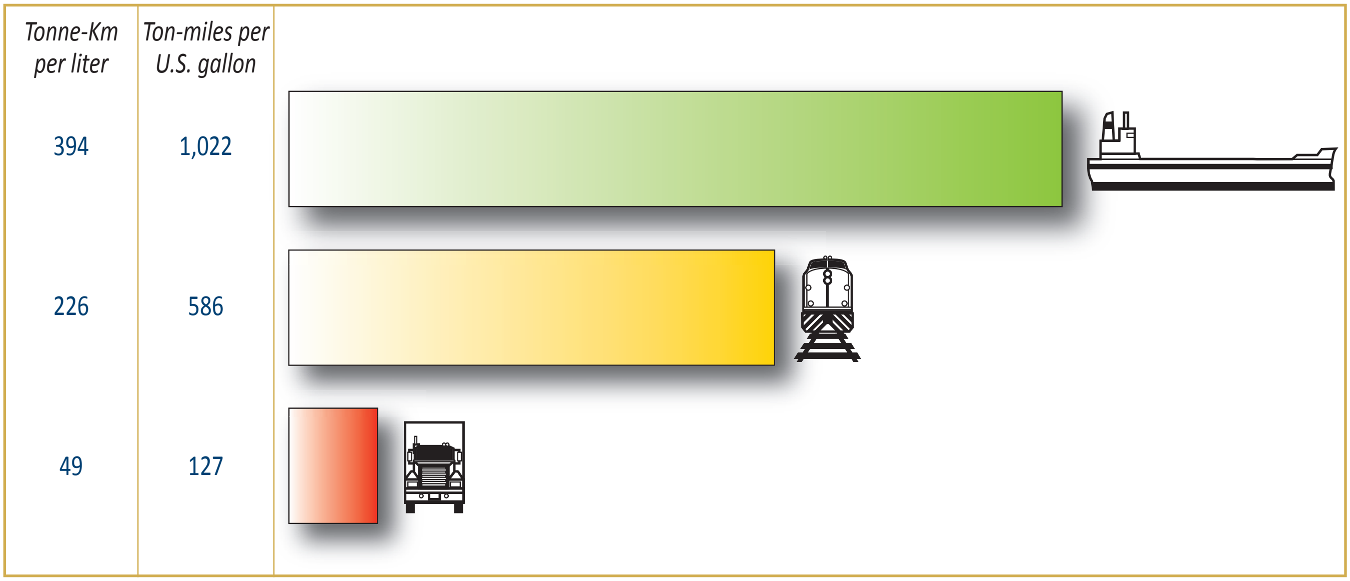
Figure 6. Energy Efficiency Comparison – Seaway-size Fleet (2010)



Source: RTG analysis based on each mode carrying Great Lakes-Seaway traffic an equal distance.

The fuel-efficiency comparison of the three modes under the post-renewal scenario for each mode is illustrated in Figure 7. The post-renewal comparison reflects the fact that the renewal of the marine fleet has been delayed relative to the ground modes, due to regulatory constraints. Canada's removal of the 25% import duty on foreign-built vessels is stimulating modernization of the Canadian fleet. All modes make improvements but the Canadian fleet, being older, has greater potential for

Figure 7. Energy Efficiency Comparison – Seaway-size Fleet (Post Renewal of All Modes)



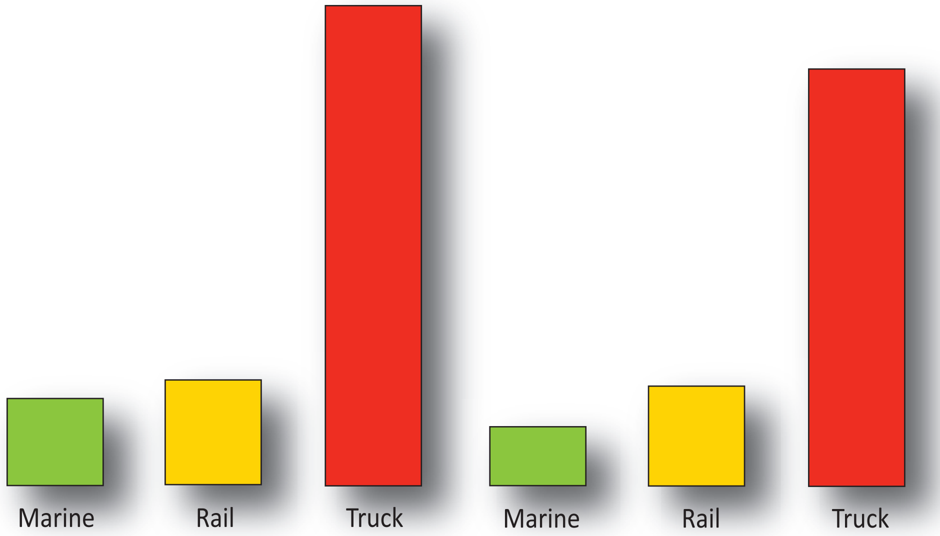
Source: RTG analysis based on each mode carrying Great Lakes-Seaway traffic an equal distance.

improvement. Post renewal of all modes, the Seaway-size Fleet will be able to move cargo 74% farther (or is 74% more fuel-efficient) than rail and 704% farther (or is 704% more efficient) than truck.

4.3 Greenhouse Gas (GHG) Emissions Intensity

The Greenhouse Gas (GHG) emissions intensities of the Seaway-size Fleet and the two ground modes are shown separately for the 2010 base year and for each mode's post-renewal scenario in Figure 8a.

Figure 8a. GHG Emissions Comparisons — Seaway-size Fleet (2010 and Post Renewal)



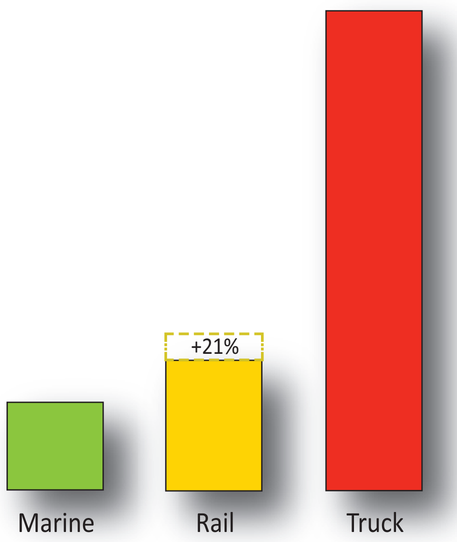
	2010			Post Renewal		
	Marine	Rail	Truck	Marine	Rail	Truck
Grams per cargo-tonne-kilometer	11.5	14.1	63.4	7.7	13.3	55.1
Pounds per 1,000 cargo-ton-miles	37.0	45.1	203.5	24.9	42.7	177.0
Index	1.00	1.22	5.50	1.0	1.72	7.12

Source: RTG analysis.

The relative intensities, when indexed to the Seaway-size Fleet's intensity, are shown at the bottom of Figure 8a. Thus, for each tonne of GHG emissions from the Seaway-sized Fleet in carrying a tonne of cargo one kilometer in 2010, the rail mode would produce 1.2 tonnes and trucks would produce 5.5 tonnes. In terms of incremental GHG emissions, the rail mode would produce 22% higher GHG emissions, and the truck mode 450% higher GHG emissions, than the Seaway-sized Fleet in carrying a tonne of cargo one kilometer.

As GHG emissions are directly linked to fuel consumption, the GHG post-renewal comparison reflects the fact that the renewal of the marine fleet has been delayed relative to the ground modes due to regulatory constraints and thus, has more potential for reductions. Post renewal of all three modes, for each metric tonne of GHG emissions from the Seaway-size Fleet in carrying a tonne of cargo one kilometer, the rail mode would produce 1.7 metric tonnes and trucks would produce 7.1 metric tonnes. In terms of incremental GHG emissions, the rail mode would produce 72% higher GHG emissions, and the truck mode 612% higher GHG emissions, than the Seaway-size Fleet in carrying a tonne of cargo one kilometer.

Figure 8b. GHG Emissions Comparisons — Seaway-size Fleet Compared to Rail Carrying Own Mix of Cargo (2010)



	Marine	Rail	Truck
	2010		
Grams per cargo-tonne-kilometer	11.5	17.1	63.4
Pounds per 1,000 cargo-ton-miles	37.0	54.6	203.5
Index	1.0	1.5	5.5

Source: RTG analysis.

Figure 8b shows the same data as shown for 2010 on Figure 8a but includes a dashed bar on the rail GHG intensity to illustrate our like-for-like comparison of each mode carrying the 2010 Great Lakes-Seaway traffic an equal distance. The solid bar is based on rail carrying the Great Lakes-Seaway traffic and is the basis of comparison used in our study. The dashed bar shows what rail's incremental intensity is, if a simple ratio of rail's total fuel to rail's total cargo tonne-kilometers (ton-miles) is used. The bulk commodity nature of the Great Lakes-Seaway traffic is more efficiently carried than is the average composition of traffic that is actually carried by the rail mode. The increment (of about 21% for Canada) illustrated by the dashed bar would be applicable to every GHG and CAC emission comparison made, if one wished to know Canadian rail's performance in carrying its own mix of cargo.

Our like-for-like basis of comparison also affects the truck mode, which is much more efficient carrying heavy commodities than the normal average truck traffic. Similar to the Seaway-size Fleet comparison, a dashed line is not shown for the "average" truck's efficiency carrying a representative mix of truck traffic because the truck mode's average value is not known with any accuracy in either the U.S. or Canada. Nonetheless, truck commodities tend to be much lighter-weight than the Great Lakes-Seaway traffic mix and the dominant body style is a high cube trailer, rather than the hoppers and flatbed trailers used to haul Great Lakes-Seaway-type cargo. Both factors would lead to much higher fuel and emissions intensities for the average truck than the like-for-like truck fleet simulated and compared herein.

4.4 Criteria Air Contaminant (CAC) Emissions Performance

Emissions regulations for the marine sector have been introduced later than for the two ground modes. Criteria Air Contaminant (CAC) regulations were initially focused on the truck mode, then the rail mode, and were introduced for the marine mode in 2012. Thus, marine's 2010 performance with respect to CAC emissions is not as favorable as the GHG emissions comparison.

In terms of reductions in the future, the Seaway-size Fleet will realize significant reductions in CAC emissions — directly from new emissions regulations and indirectly due to the efficiency improvements realized with fleet renewal. The key CAC emissions categories (NO_X, SO_X and PM) have different regulations for the two fuel/engine types used on most of the vessels in the Seaway-size Fleet. The regulatory emissions requirements are more demanding for the auxiliary engines that continue to be used while at port than for the propulsion engines that are not used when vessels are docked at port.

Regulations for the Seaway-size Fleet's propulsion engines call for NO_X emissions reductions of 80%, while regulations for auxiliary engines will result in NO_X reductions of 87%. The overall impact for the Seaway-size Fleet post renewal is an 87.6% reduction in NO_X emissions.

Sulfur oxides (SO_X) regulations are imposed on the fuel being used, rather than the engines. The main propulsion engines will be required to use fuel with a maximum sulfur content of 0.1%, while the auxiliary engines that are used at port will be required to use fuel with a sulfur content of 0.0015%. The two separate requirements translate into reductions in the order of 94% of the 2010-level emissions from each engine type. Marine diesel oil (MDO) is currently used in auxiliary engines, while many vessels use an intermediate fuel oil (IFO) for propulsion — IFO is a blend of heavy residual oil and diesel oil. Canadian carriers will be phasing in the use of MDO until the blend is 100% MDO. While the regulation allows a fuel of 0.1% sulfur content, the suppliers of MDO are not expected to create a separate type of MDO for propulsion engines — the sulfur content of MDO supplied in 2010 was already below the 0.1% requirement for propulsion fuels post-regulation. Thus, we assume that once 100% MDO is attained, the sulfur content of that fuel will be 0.0015%, regardless of the application. The combined effect of energy-efficiency improvements and ultra-low sulfur fuel in the post-renewal scenario is a 99.9% reduction in SO_X emissions.

Particulate matter (PM) emissions are not being directly regulated for marine propulsion engines; however, due to the high correlation of PM emissions to sulfur content, the sulfur-content regulations will lead to reduced PM emissions. The auxiliary engines that are used at port will be required to meet an emissions level of 0.04 g/kWh, representing an 82% reduction from the 2010 emissions levels. The combined effect of efficiency improvements and sulfur regulations applied in the post-renewal scenario is an 88.1% reduction in PM emissions.

The CAC emissions intensity comparisons for 2010 and post renewal are summarized in Table 10. For the post-renewal scenario for all modes, marine is the lowest emitter of NO_X and SO_X and second to rail in PM.

Table 10. Seaway-size Fleet — Summary Comparison of GHG and Key CAC Emissions for all Modes in 2010 and Post Renewal

Scenario	Mode[1]	CO_2-e		NO_X		SO_X		PM	
		(g/CTK)	*(lb/kCTM)*	*(g/kCTK)*	*(g/kCTM)*	*(g/kCTK)*	*(g/kCTM)*	*(g/kCTK)*	*(g/kCTM)*
2010	Seaway-size Fleet[2]	11.5	37.0	250.3	365.2	105.3	153.6	17.0	24.8
	Rail	14.1	45.1	237.1	346.2	0.8	1.2	6.1	9.0
	Truck	63.4	203.5	315.2	459.9	0.6	0.9	11.4	16.6
Post Renewal	Seaway-size Fleet[3]	7.7	24.9	30.9	45.1	0.07	0.10	2.0	2.9
	Rail	13.3	42.7	33.4	48.8	0.108	0.158	0.5	0.7
	Truck	55.1	177.0	27.1	39.5	0.5	0.8	2.4	3.6

Notes:

1. Based on each mode carrying the 2010 cargo carried by the Seaway-size Fleet an equal distance.
2. With 2008 ballast ratio and excluding self-unloading auxiliary power and 10% of hotel power at port.
3. Post renewal assumes 100% ultra-low sulfur MDO is used for marine propulsion and auxiliary engines.

Units:

- g/CTK = grams emitted per cargo-tonne-kilometer.
- lb/kCTM = pounds per thousand-cargo-ton-miles.
- g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.
- g/kCTM = grams emitted per thousand-cargo-ton-miles.

Source: RTG analysis.

5

Air Emissions Comparison for the U.S. Fleet

5.1 Summary

This chapter compares the energy efficiency and air emissions of the U.S. Fleet to that of rail and trucks if they were to carry the same cargo, the same distance. The analysis shows that the U.S. Fleet is more fuel-efficient and a lower emitter of Greenhouse Gases (GHGs) than both land-based alternatives. In terms of Criteria Air Contaminant (CAC) emissions, the U.S. Fleet was the lowest emitter of nitrogen oxides (NO_X) but not the lowest emitter of sulfur oxides (SO_X) and particulate matter (PM) in 2010. In the future, however, marine CAC emissions will dramatically decrease. The marine mode has been the last mode to see CAC emissions regulations, and new standards will be implemented over the time frame 2012-2025.

In a post-renewal scenario where all three modes meet the regulatory conditions and the technology and fuel-use improvements that would be economically available over the time frame 2012-2025, the U.S. Fleet becomes the lowest emitter of SO_X and NO_X, and second to rail for PM emissions.

5.2 Energy Efficiency

The comparisons made in this chapter are based on the cargo carried by the U.S. Fleet and the marine characterization is that of the U.S. Fleet. Canadian vessels that stay within the Great Lakes and all Canadian and international vessels making trips into the Great Lakes are included in the analysis in Chapter 4. The fleet-average values of some of the key performance attributes of the U.S. Fleet are presented in Table 11.

Table 11. U.S. Fleet's Key Energy Performance Attributes

Parameter Description	Fleet Average Value	
Ballast Ratio (Note 1)		
Ballast-km / laden-km	66.2%	
Ballast-km / total-travel-km	39.8%	
Fuel Efficiency (Note 2)	***CTK/liter***	***CTM/US-gal.***
Laden Trip only (propulsion and auxiliary)	420	1,090
Full Voyage, including port and ballast legs	221	573
Full Voyage, adjusted auxiliary power at port (Note 3)	235	610

Notes:

1. Two definitions of ballast ratios are shown as some consider the ratio to be non-cargo travel distance divided by laden travel distance, while others consider it to be non-cargo travel distance divided by total travel distance. For the U.S. Fleet, iron ore is the main cargo movement and coal and aggregate offer partial-trip cargo movements in the opposite direction.
2. CTK = cargo tonne-kilometer; CTM = cargo ton-mile.
3. Adjusted auxiliary power excludes self-unloading power and reduces hotel power by 10% while at port.

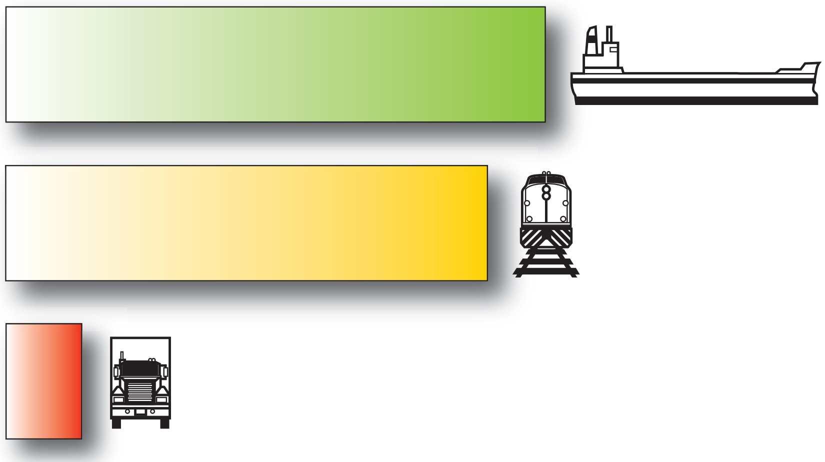
Source: RTG analysis of confidential carrier data.

The energy efficiencies of the three modes in the year 2010 are compared in Figure 9. The performance comparison is based on ratio of work done (weight of cargo moved a unit distance) divided by total fuel consumed (laden and empty/ballast trips and adjusted fuel while at port). The analysis indicates that the U.S. Fleet can move cargo 11% farther (or is 11% more fuel-efficient) than rail and 592% farther (or 592% more fuel-efficient) than truck.

The fuel-efficiency comparison of the three modes under the post-renewal scenario for each mode is illustrated in Figure 10. The post-renewal assumptions for each mode were described in Section 3.3. As discussed in Subsection 3.3.1, the post-renewal comparisons reflect the fact that the marine fleet modernization has been delayed relative to the ground modes due to regulatory constraints — specifically the Jones' Act restrictions on foreign-built vessels for U.S. operators. The extension of the Emissions Control Area (ECA) to the Great Lakes and the U.S. EPA's associated introduction of an assistance program for new

Figure 9. Energy Efficiency Comparison – U.S Fleet (2010)

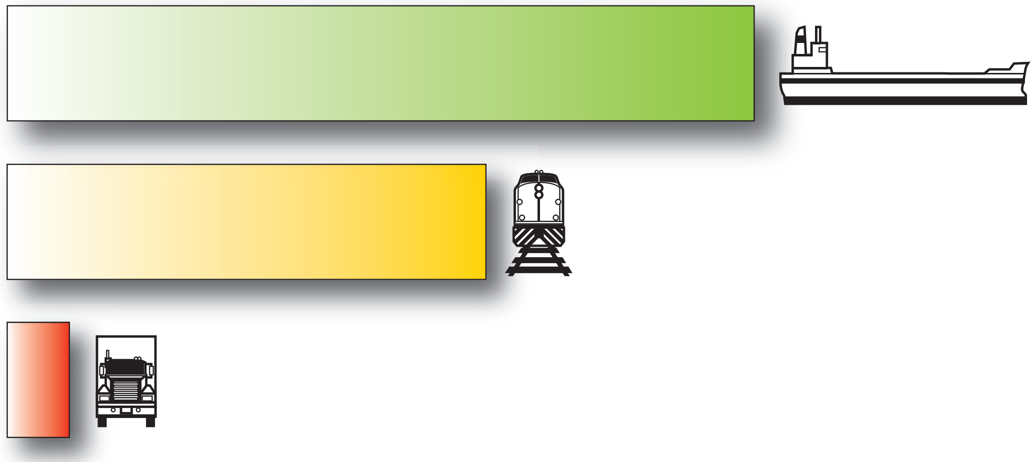
Tonne-Km per liter	*Ton-miles per U.S. gallon*
235	610
212	550
34	88



Source: RTG analysis based on each mode carrying Great Lakes-Seaway traffic an equal distance.

Figure 10. Energy Efficiency Comparison – U.S Fleet (Post Renewal of All Modes)

Tonne-Km per liter	*Ton-miles per U.S. gallon*
342	887
224	581
40	104



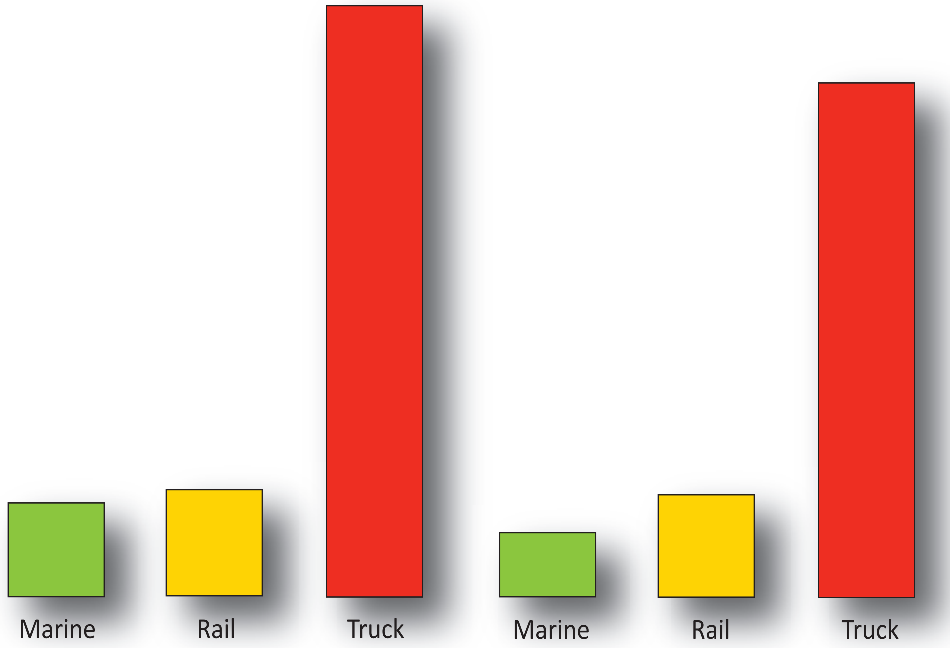
Source: RTG analysis based on each mode carrying Great Lakes-Seaway traffic an equal distance.

power plants on existing U.S. vessels will stimulate modernization of the fleet's engines. Thus, the U.S. Fleet has more potential for improvement than the ground modes. Post renewal of all modes, the U.S. Fleet will be able to move cargo 53% farther (or is 53% more fuel-efficient) than rail and 754% farther (or is 754% more fuel-efficient) than truck.

5.3 Greenhouse Gas (GHG) Intensity

The Greenhouse Gas (GHG) emissions intensities of the U.S. Fleet and the two ground modes are shown for the 2010 base year and for each mode's post-renewal scenario in Figure 11a. In addition to the marine mode being based on the U.S. Fleet, the rail and truck modes are based on U.S. traffic and U.S. modal characteristics, and are thus different than those reported for the Canada/International Seaway traffic comparison in Chapter 4.

Figure 11a. GHG Emissions Comparisons — U.S. Fleet (2010 and Post Renewal)



	2010			Post Renewal		
	Marine	Rail	Truck	Marine	Rail	Truck
Grams per cargo-tonne-kilometer	12.4	14.2	78.3	8.5	13.4	67.9
Pounds per 1,000 cargo-ton-miles	39.6	45.7	251.2	27.3	43.0	217.9
Index	1.00	1.15	6.34	1.0	1.58	7.98

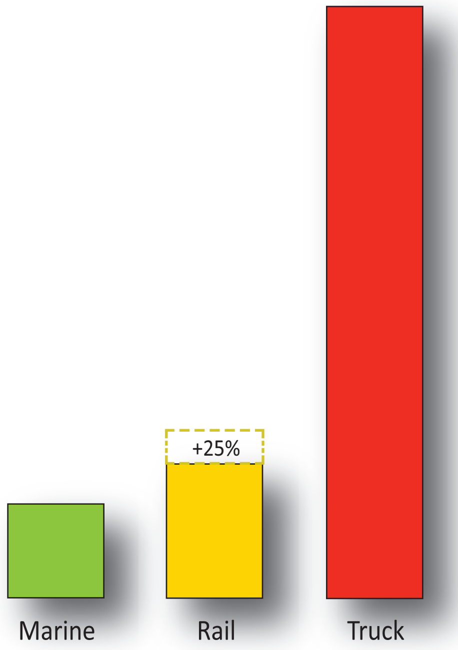
Source: RTG analysis.

The relative intensities, when indexed to the U.S.-Fleet intensity, are shown at the bottom of each chart. Thus, in 2010 (Figure 11a), for each ton of GHG emitted by the U.S. Fleet in carrying a ton of cargo one mile, the rail mode would emit 1.15 tons, and trucks would emit 6.34 tons. In terms of incremental emissions, the rail mode would emit 15% more GHG, and the truck mode 534% more GHG, than the U.S. Fleet in carrying a ton of cargo one mile.

Similarly, post renewal of all three modes (Figure 11a), for each ton of GHG emitted by the U.S. Fleet in carrying a ton of cargo one mile, the rail mode would emit 1.58 tons, and trucks would emit 7.98 tons. In terms of incremental GHG emissions, for the U.S. Fleet comparison, the rail mode would produce 58% higher GHG emissions, and the truck mode 698% higher GHG emissions, than the U.S. Fleet in carrying a ton of cargo one mile.

Figure 11b shows the same data as shown for 2010 on Figure 11a but includes a dashed bar for the rail GHG intensity to illustrate our like-for-like comparison of each mode carrying the 2010 Great Lakes traffic an equal distance. As was the case for the Seaway-size Fleet in the previous chapter, the solid bar is based on rail carrying the Great Lakes traffic and is the basis of comparison — while the dashed bar shows what the rail comparison would be, if based on a simple average of rail's fuel to traffic carried, as reported at the aggregate level. The bulk commodity nature of the Great Lakes traffic is carried more efficiently than the average composition of traffic that is actually carried by the rail mode. The increment (of about 25% for the U.S.) that is illustrated by the dashed bar would be applicable to every GHG and CAC emission comparison made, if one wished to know U.S. rail's performance in carrying its own mix of cargo.

Figure 11b. GHG Emissions Comparisons — U.S. Fleet Compared to Rail Carrying Own Mix of Cargo (2010)



	2010		
Grams per cargo-tonne-kilometer	12.4	17.8	78.3
Pounds per 1,000 cargo-ton-miles	39.6	57.1	251.2
Index	1.0	1.4	6.3

Source: RTG analysis.

Our like-for-like basis of comparison also affects the truck mode, which is much more efficient carrying heavy commodities than the normal average truck traffic. A dashed line is not shown for the "average" truck's GHG intensity carrying a representative mix of truck traffic because the truck mode's average value is not known with any accuracy in either the U.S. or Canada. Nonetheless, truck commodities tend to be much lighter-weight than the Great Lakes traffic mix and the dominant body style is a high cube trailer, rather than the hoppers and flatbed trailers used to haul Great Lakes-type cargo. Both factors would lead to much higher fuel and emissions intensities for the average truck than the like-for-like truck fleet simulated and compared herein.

5.4 Criteria Air Contaminant (CAC) Emissions Performance

Emissions regulations for the marine sector have been introduced later than the two ground modes. Criteria Air Contaminant (CAC) regulations were initially focused on the truck mode, then the rail mode and were introduced for the marine mode in 2012. Thus, marine's 2010 performance with respect to CAC emissions is not as favorable as the GHG emissions comparison. The U.S. Fleet has a different mix of propulsion engines and fuels than the Seaway-size Fleet and thus has different CAC intensities. A key factor is that it had a higher proportion of engines using marine diesel oil (MDO) for propulsion in 2010. This lead to lower CAC emissions in 2010 but also lowers the reduction potential in the post renewal of its engines.

As with the Seaway-size Fleet, the key CAC emissions categories — nitrogen oxides (NO_X), sulfur oxides (SO_X) and particulate matter (PM) — have different regulations for the two fuel/engine types used on most of the vessels. The regulatory emissions requirements are more demanding for the auxiliary engines that continue to be used while at port than for the propulsion engines that are not used when vessels are docked at port.

Environmental Protection Agency (EPA) regulations for the U.S. Fleet's diesel propulsion engines call for NO_X emissions reductions of 80%, while regulations for auxiliary engines will result in NO_X reductions of 87%. The overall impact for the U.S. Fleet post renewal is an 84.3% reduction in NO_X emissions.

Sulfur oxides (SO_X) regulations are imposed on the fuel being used rather the engines. The main propulsion engines will be required to use fuel with a maximum sulfur content of 0.1%, while the auxiliary engines that are used at port will be required to use fuel with a sulfur content of 0.0015%. The two separate requirements translate into reductions in the order of 94% of the 2010-level emissions from each engine type. The U.S. Fleet already uses a high proportion of MDO fuel in propulsion engines. It also uses some steam engines using residual fuel with relatively high sulfur content. The renewal scenario assumes all vessels will be upgraded to the 2010 best-in-class performance and engines will use MDO. While the regulation allows a fuel of 0.1% sulfur content, the suppliers of MDO are not expected to create a separate type of MDO for propulsion engines — the sulfur content of MDO supplied in 2010 was already below the 0.1% requirement for propulsion fuels post-regulation. Thus, we assume that once 100% MDO is attained, the sulfur content of that fuel will be 0.0015%, regardless of the application.
The combined effect of energy efficiency improvements and ultra-low sulfur fuel in the post-renewal scenario is a 99.9% reduction in SO_X emissions.

Table 12. U.S. Fleet — Summary Comparison of Air Emissions for all Modes in 2010 and Post Renewal

Scenario	Mode[1]	CO_2-e		NO_X		SO_X		PM	
		(g/CTK)	*(lb/kCTM)*	*(g/kCTK)*	*(g/kCTM)*	*(g/kCTK)*	*(g/kCTM)*	*(g/kCTK)*	*(g/kCTM)*
2010	U.S. Fleet[2]	12.4	39.6	215.2	313.9	58.9	85.9	10.1	14.7
	Rail	14.2	45.7	251.8	367.4	1.9	2.8	7.6	11.1
	Truck	78.3	251.2	391.6	571.4	0.7	1.1	13.7	20.0
Post Renewal	U.S. Fleet[3]	8.5	27.3	33.8	49.3	0.08	0.11	2.2	3.2
	Rail	13.4	43.0	36.4	53.1	0.10	0.15	0.6	0.8
	Truck	67.9	217.9	38.5	56.2	0.6	0.9	2.7	4.0

Notes:
1. Based on each mode carrying the 2010 cargo carried by the U.S. Fleet an equal distance.
2. With 2008 ballast ratio and excluding self-unloading auxiliary power and 10% of hotel power at port.
3. Post renewal assumes 100% ultra-low sulfur MDO for marine propulsion and auxiliary engines.

Units:
- g/CTK = grams emitted per cargo-tonne-kilometer.
- lb/kCTM = pounds per thousand-cargo-ton-miles.
- g/kCTK = grams emitted per thousand-cargo-tonne-kilometers.
- g/kCTM = grams emitted per thousand-cargo-ton-miles.

Source: RTG analysis.

Particulate matter (PM) emissions are not being directly regulated for marine propulsion engines; however, due to the high correlation of PM emissions to sulfur content, the sulfur-content regulations will lead to reduced PM emissions. The auxiliary engines that are used at port will be required to meet an emissions level of 0.04 g/kWh, representing an 82% reduction from the 2010 emissions levels. The combined effect, post renewal, is a 78.2% reduction in PM emissions.

The modal comparison of GHG and CAC emissions for 2010 and the post-renewal scenario are summarized in Table 12. For the post-renewal scenario for all modes, marine is the lowest emitter of NO_X and SO_X and second to rail in PM.

6

Air Emissions Conclusions and Sensitivity to Key Parameters

6.1 Energy and Air Emissions Conclusions

The marine mode is the most fuel-efficient of the three modes and marine's efficiency relative to the two ground modes will increase in the future. A post-renewal scenario was developed for each mode, in recognition of the changes in emissions regulations and opportunities for economical advancements of propulsion technology and/or operational procedures.

The truck mode was the focus of early regulatory standards and no further changes to the 2010 Criteria Air Contaminant (CAC) regulations have been identified. The truck is the only mode to have regulatory standards for Greenhouse Gas (GHG) emissions requiring the use of fuel-saving technologies by highway tractor manufacturers over the 2014-2019 timeframe. The long-haul truck fleet is renewed more frequently than the other modes, so regulatory changes work into the system performance quite quickly.

The rail mode was the second focus of CAC regulatory standards and partial advances were in place by 2010. Additional reductions of hydrocarbon (HC) emissions, nitrogen oxides (NO_X), particulate matter (PM) and sulfur dioxide (SO_2) are required by 2015. Rail has been renewing its long-haul fleet, while its yard-switching fleet remains quite old. We see continued operational and equipment advances for rail but have not assumed any significant improvement in economically viable locomotive efficiency beyond the 2010 technology.

The marine mode has been the last mode to see CAC emissions regulations and all will take effect over the 2012-2025 timeframe. The regulations will require significant reductions of NO_X and SO_2, and the reductions of SO_2 will produce reductions in PM. The marine fleet is, on average, the oldest of the three modes. The delay in renewal of the marine fleet has been influenced by the 25% duty on new ships in Canada and the *Jones' Act* restrictions on foreign-built vessels for U.S. operators. The repeal of the Canadian import duty and the introduction of the EPA assistance program for new power plants on existing U.S. vessels are stimulating fleet and power plant renewal that will significantly improve the efficiency of both fleets.

As a consequence of the above factors, marine will see a much more dramatic improvement in the future than the two ground modes. Post renewal of all modes, the Seaway-size Fleet will be 74% more fuel-efficient than rail and 704% more efficient than truck. Similarly, the U.S. Fleet will be 53% more fuel-efficient than rail and 754% more efficient than truck.

The marine mode is already the lowest GHG emitter of the three modes and marine's performance relative to the two ground modes will improve in the future. In terms of incremental GHG emissions post renewal of all modes: the rail mode would produce 72% higher GHG emissions, and the truck mode 612% higher GHG emissions, than the Seaway-size Fleet in carrying a tonne of cargo one kilometer. Similarly, the rail mode would produce 57% higher GHG emissions, and the truck mode 698% higher GHG emissions, than the U.S. Fleet in carrying a ton of cargo one mile.

The marine mode was not the lowest CAC emitter in 2010. Of the three CACs of primary interest (NO_X, SO_X and PM) — the U.S. Fleet was the lowest emitter of NOx, while the Seaway-size Fleet was second to rail; and both fleets were the highest emitters of SO_X and PM. Post renewal of all modes, marine will be the lowest emitter of NO_X and SO_X, and will be second to rail in PM emissions.

We note that marine's CAC emissions when on open water are comprised of emissions from propulsion engines and auxiliary engines, while emissions when docked at port are only from auxiliary engines. CAC emissions consequences are dependent on the source location relative to areas of air-quality concern. Marine's CAC emissions on open water (as well as at many ports in remote areas) will have significantly different consequences than emissions at ports located in urban areas. Similarly, CAC emissions from the ground modes while traveling through remote areas will have significantly different consequences than their emissions when traveling through urban areas. The consequences of each mode's CAC emissions relative to each other, and the relative consequences of transportation's emissions relative to fixed-plant emissions are beyond the scope of this assignment. We believe that such a comparative evaluation would be in favor of the marine mode and recommend that such a comparative analysis be undertaken.

6.2 Sensitivity to Modal Distance Variations

The analysis is conducted on the basis of equal travel distances for the three modes. A detailed analysis of impacts would require consideration of alternate route distances for rail or truck, in cases where a transfer to marine involves a different route than the rail or truck direct route. Nonetheless, the indexed values shown at the bottom of the charts in Chapter 4 and Chapter 5 can be scaled by the relative modal distances involved, to provide a ballpark estimate of relative modal performance for specific origin-destination (OD) movements.

We considered two cases to illustrate the process — one involving a shorter marine trip and one involving a longer marine trip. The shorter marine distance trip is from Goderich, Ontario to Thunder Bay, Ontario and the longer marine trip is from Thunder Bay to Montreal, Quebec (see Figure 1 for map locations). The modal distances, including a comparison indexed to the marine distance, are shown in Table 13. It should be noted that the modal distances for Thunder Bay, Ontario to Montreal are historic and appear to use the Ottawa Valley Railroad (OVR), which provided a shorter trip when it was operational. The OVR is no longer operating, and the rail distance via Toronto would be very close to the marine distance. Nonetheless, we include the trip as an illustrative one rather than a factual one for the OD involved.

Table 13. Modal Trip Length Sensitivity Cases

Trip Origin		**Goderich, ON**			**Thunder Bay, ON**		
Trip Destination		**Thunder Bay, ON[1]**			**Montreal, QC[2]**		
		Trip Length					
		km	***miles***	***Index***	***km***	***miles***	***Index***
Mode	Marine	816	506	1	2087	1217	1
	Rail	1617	1003	1.98	1702	1055	0.87
	Truck	1569	973	1.92	1691	1048	0.86

Notes:

1. The assumed road trip is via Canadian major highways (Hwy 401 to Toronto, Hwy 17 to Thunder Bay) as the shorter U.S. route is not permitted by U.S. law. The rail trip is via the Goderich and Exeter Railway to Toronto and via CP to Thunder Bay.
2. The distance data are factual for marine and truck, but assume the use of the now defunct OVR for rail. The rail distance is essentially the same as the marine distance without the OVR. Nonetheless, it is used as an illustrative hypothetical case.

Source: RTG analysis.

Results for incremental GHG emissions relative to the marine emission are presented in Table 14. As an example of the calculation, consider the incremental GHG emissions for a mode shift from marine to rail for Goderich to Thunder Bay (the upper-left data cell in the table showing 142%). The incremental GHG intensity for a rail trip of equal length is shown as 22% and is the rail-to-marine GHG performance ratio for the Seaway-size Fleet (1.22 from Figure 8 minus 1 = 22%). To get the relative performance for a specific distance of interest, the calculation process is:

a) Calculate the rail/marine emissions ratio:

(rail-distance/marine-distance) X (rail-intensity/marine-intensity)

= 1.98 (from Table 13) X 1.22 (direct from Figure 8 or use 1 plus the equal distance increment from Table 13 (1+0.22))

= 2.42

b) Calculate the incremental emissions due to the alternate mode:

Incremental emissions = (rail emission – marine emission)

Proportional increase in emissions = incremental emissions / marine emission

= rail emissions/marine emissions – 1.

= 2.42 – 1 = 1.42 (or 142% as shown in the Table 14).

For the case where marine has a shorter trip, the incremental GHG emissions would be 142% for a shift to rail and 958% for a shift to truck (compared with 22% for rail and 450% for truck at equal-distance trips in Canada). For the case where marine has a longer trip, the GHG emissions would be increased by 6% for a shift to rail and increased by 374% for a shift to truck (compared with increments of 22% for rail and 450% for truck at equal-distance trips). As noted above, the rail comparison is illustrative and based on a routing that is no longer available. The factual comparison of rail on the Thunder Bay to Montreal trip would now be the equal-distance route involving increments of 22% for 2010 and 72% post renewal.

Table 14. Modal Trip Length Sensitivity Results for GHG Emissions

Trip Origin		**Goderich, ON**	**Thunder Bay, ON**	**Equal Distance**
Trip Destination		**Thunder Bay, ON**	**Montreal, QC**	
Base-2010			***GHG Increment for a Mode Shift from Marine[1]***	
Mode shifted to	Rail	142%	6%[2]	22%
	Truck	958%	374%	450%
Post Renewal of all modes			***GHG Increment for a Mode Shift from Marine[1]***	
Mode shifted to	Rail	240%	49%[2]	72%
	Truck	1268%	513%	612%

Notes:

1. While scaled for mode-specific distance, each mode's performance is based on Great Lakes-Seaway average conditions as developed for the Seaway-size Fleet.
2. The Thunder Bay to Montreal comparison (at 6% increment in 2010) is illustrative only, since the rail routing uses a shortline railroad that is no longer operating; the rail distance is essentially the same as marine without the shortline, and the equal-distance comparison (at 22% increment in 2010) would now apply for rail.

Source: RTG analysis.

6.3 Sensitivity to the Hotel Power Assumption

The sensitivity of the results to the assumed 10% reduction of hotel power at port was tested by assessing the marine fuel intensity results with alternate assumptions of 5% and 20% reductions in hotel power at port. For the Seaway-size Fleet, cutting the base value in half to 5% led to a 0.6% increase in marine`s overall fuel consumption, and doubling the value to 20% led to a 1.3% decrease in fuel consumption. For the U.S. Fleet, cutting the base value in half to 5% led to a 0.7% increase in marine`s overall fuel consumption, and doubling the value to 20% led to a 1.5% decrease in fuel consumption. The U.S. Fleet is slightly more sensitive, possibly due to the higher proportion of less-efficient steamers in the U.S. Fleet.

Fuel consumption is the main driver for all emissions categories and thus, the impact for all emissions intensities would be very close to the fuel effects. Since doubling the assumed value has less than a 1.5% impact on total results, we conclude that the results are not highly sensitive to the assumed value.

7

Modal Capacity Comparison

7.1 Summary

This chapter compares the modal equipment and operating parameters that determine the level of activity required by road and rail to carry the same traffic as marine an equal distance.

The largest Great Lakes vessels, typically 1,000 feet in length, can carry 56,260 metric tons (62,000 net tons) of cargo — the equivalent of 2,340 trucks or 564 rail cars. In the case of Seaway-size ships carrying roughly 30,000 metric tons of cargo, it would take 963 trucks or 301 rail cars to carry the same load. If the total cargo transported by marine on the Great Lakes-Seaway System in 2010 was instead transported by truck, 7.1 million additional truck trips would be required. If the same cargo was moved by rail, it would require about 3.0 million additional railcar trips and 31,282 additional train trips.

The characterization of the three modes is presented in detail in Appendix B, which covers equipment characteristics, energy efficiency and emissions intensity characteristics of the three modes. The discussion of modal equipment and operating parameters presented in the following subsections summarizes (and in some cases repeats) the relevant material presented in Appendix B.

The comparisons of all impact intensities assessed in this report are based on the cargo-tonne-kilometers moved by each mode. However, all impacts are influenced by the total equipment activity generated by a cargo movement (i.e., gross weights and total vessel-kilometers, railcar-kilometers and truck-kilometers involved) rather than just the laden travel. Thus, it is necessary to derive total equipment activity that would be characteristic of each mode, if it moved the baseline Great-Lakes Seaway System cargo. Two factors are involved: 1) the relative load-carrying capacity of a unit piece of modal equipment and 2) the ratio of gross tonne-kilometers to net tonne-kilometers. Each factor is compared in turn in the following two subsections.

7.2 Load Carrying Capacity

7.2.1 Marine Mode

As previously illustrated in Figure 3, the capacities of the vessels in the fleets operating in the Great-Lakes Seaway System are constrained by the Seaway and Soo locks. Cargo confined to the upper lakes can be carried with Poe-max vessels with capacities of 56,260 tonnes (62,000 tons), and cargo entering the Seaway can be carried by existing Seaway-max vessels with capacities of 30,000 tonnes (33,070 tons) on the lakes and 27,000 tonnes (29,754 tons) — if restricted by the Seaway locks draft limit. Both classes of vessel far exceed the carrying capacity of individual railcars or trucks.

7.2.2 *Rail Mode*

Section B3 of Appendix B discusses the Canadian and U.S. train and railcar attributes applicable to the mix of Great Lakes-Seaway cargo. The mainline rail network in the Great Lakes-Seaway region limits railcar weight to 130 tonnes (286,000 lbs), which corresponds to a maximum cargo weight of about 104.4 tonnes (115 tons). The average cargo weight for Norfolk Southern Railway (NS) and CSX Transportation (CSXT) coal cars in 2010 was 99.8 tonnes (110 tons). Other cargo types have lower average axle loads.

7.2.3 *Truck Mode*

Truck load limits vary within the Great Lakes-Seaway region. Ontario and Quebec have higher axle load limits and use multiple trailer configurations that are not allowed in the U.S. states in the region. Section B4.3 of Appendix B discusses the Canadian and U.S. truck configurations applicable to the mix of Great Lakes-Seaway cargo. The truck capacities and configurations are summarized in Table 15.

Table 15. Summary Table of Truck Attributes by Cargo Type

Commodity	**Average Load - CAN**		**Average Load - U.S.**		**Average Number of Axles**		**Average Tare Weight CAN**		**Average Tare Weight U.S.**		**Empty distance ratios**	
											Empty/ laden	***Empty/ total***
	(mt)	***(t)***	***(mt)***	***(t)***	***CAN***	***U.S.***	***(mt)***	***(t)***	***(mt)***	***(t)***	***(%)***	***(%)***
Wheat and other cereal grains	30.0	32.9	24.1	26.5	6.21	5.50	17.9	19.7	14.9	16.4	35	26
Ores and concentrates	38.2	42.0	24.1	26.5	7.03	5.50	18.3	20.1	14.1	15.5	35	26
Fuel oil, gasoline and aviation fuel	34.6	38.1	23.4	25.7	7.88	5.80	17.2	18.9	14.5	16.0	59	37
Cement and non-metallic mineral products	33.7	37.1	24.1	26.5	7.36	5.50	16.5	18.1	14.1	15.5	35	26
Base metals and articles of base metal	25.6	28.1	20.0	21.9	6.47	5.40	16.7	18.4	12.8	14.1	22	18
Machinery	12.6	13.8	10.9	12.0	5.72	5.10	16.6	18.3	13.2	14.5	25	20

Note: The U.S. characteristics are also used for cross-border trips.
Units: mt is metric tonnes; t is tons.

Source: RTG analysis of the Transport Canada/Canadian Council of Motor Transport Administrators' National Roadside Survey, 2006.

7.2.4 *Summary Modal Comparisons*

7.2.4.1 Modal Unit Load Comparison by Country

The capacities of the truck and rail modes' equipment are compared in Table 16 and Figures 12 and 13, as indexed to the two dominant vessels operating in the Great Lakes-Seaway System: Poe-max and Seaway-max. Truck loads when carrying bulk commodities are shown for each country, based on the Great Lakes-Seaway average truck-load for ores and concentrates in Table 15. This category is the maximum truck cargo weight in Table 15 and therefore, produces a conservative ratio of trucks/vessel. For Seaway-max vessels, which would compete with trucks having higher axle loads for Canadian domestic movements and lower U.S. axle loads for cross-border movements, the number of trucks is based on 50% of the trips being within Canada and 50% involving cross-border trips. This ratio was derived from the traffic distribution data shown in Table 2, where 16% of all trips were

Canada to Canada, 4.8% of all trips were international and 24.5% of all trips were cross-border. Our assumption is that 33% of the international vessels' trips are within Canada, while 67% involve a border crossing, and the Seaway-size Fleet carries about 60% of the cross-border trips (i.e. 16+1.6 ≈ 3.2 + 0.6 X 24.5).

Table 16. Modal Load Capacity Comparison Indexed to One Marine Vessel

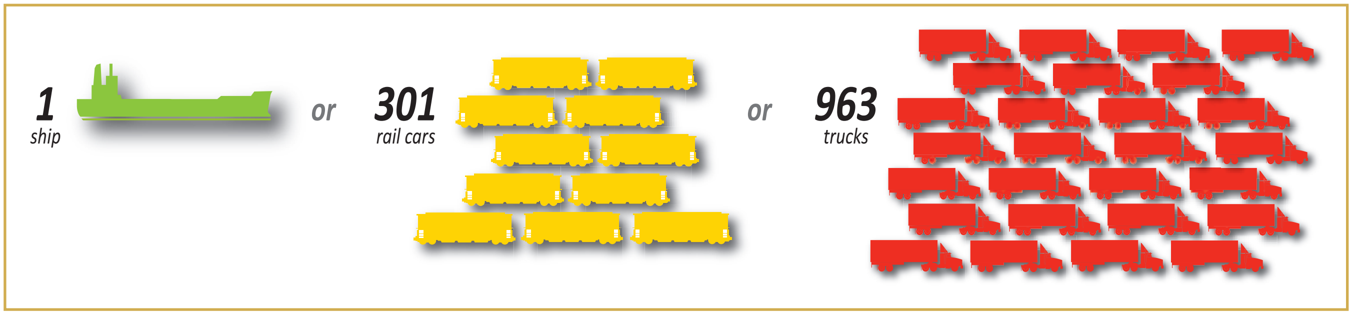
Mode	U.S. Per Poe-max Vessel	Canada Per Seaway-max Vessel (on Lakes)	Canada Per Seaway-max vessel (transiting the Seaway)
Marine Vessels	***1***	***1***	***1***
Railcars	564	301	270
Trucks	2,340	963	867

Notes:

1. Poe-max vessel capacity is 56,260 tonnes (62,000 tons); Seaway-max capacity is 30,000 tonnes (33,070 tons), and limited by draft to 27,000 tonnes (29,754 tons) when transiting the Seaway.
2. Truck capacity is based on "ore and concentrates" in Table 15 — Poe-max comparison uses U.S./cross-border truck capacity (24.1 tonnes, 26.5 tons) and Seaway-max comparison uses 50% Canada-only and 50% cross-border capacities (avg 31.15 tonnes, 34.33 tons).
3. Rail is based on 99.8 tonne (110 ton) load capacity.

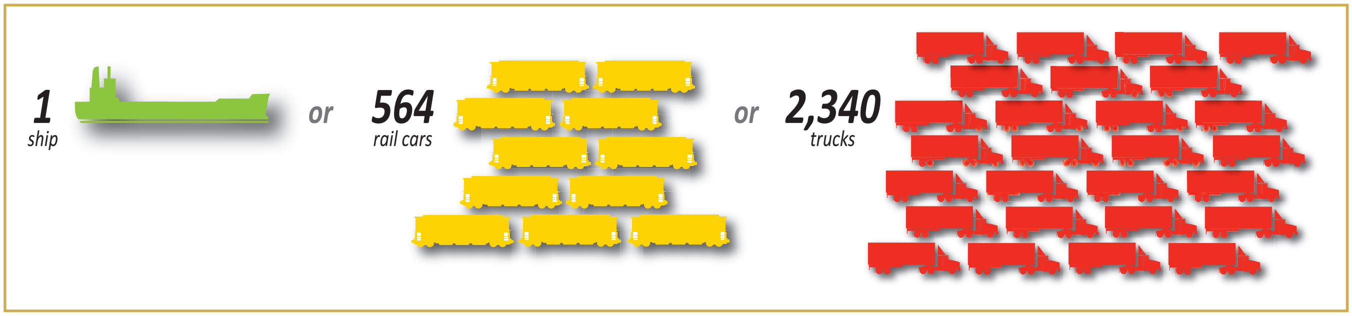
Source: RTG analysis of Statistics Canada, Surface Transportation Board and Carrier data (see Appendix B.).

Figure 12. To move 30,000 tonnes of cargo with a Seaway-size vessel



Source: RTG analysis.

Figure 13. To move 62,000 tons of cargo with a Great Lakes 1,000-foot vessel



Source: RTG analysis.

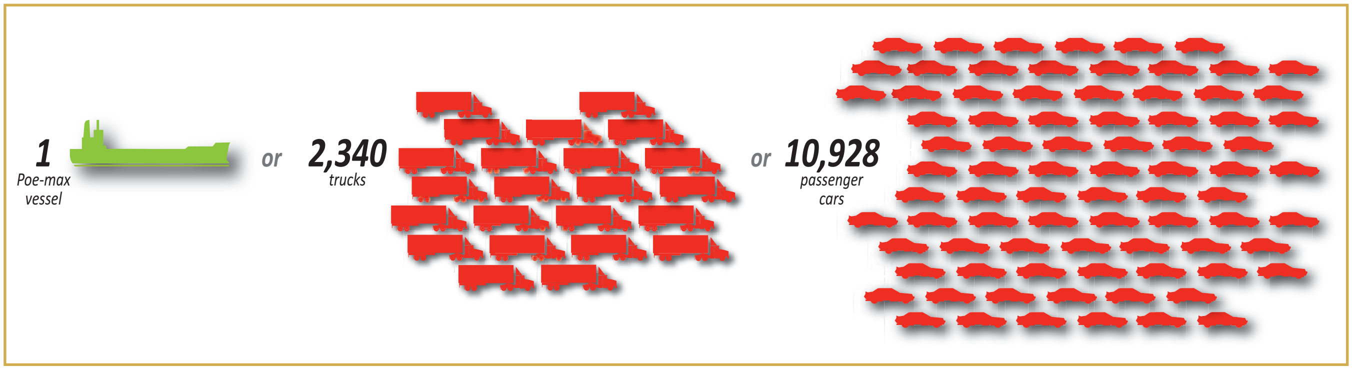
7.2.4.2 Highway Border Crossing Comparison

The unit load comparisons made in Figures 12 and 13 were for a weighted average truck, using data for Canada and the U.S. Trucks that cross the border are restricted to the more constrained U.S. axle loads. As a consequence, the number of trucks generated by cross-border movement of cargo is a higher number. Furthermore, since the main capacity constraint at border crossings is the queuing delay at inspection booths, the implications are directly related to the length of the vehicles. While the number of trucks required to replace a single Poe-max vessel would not arrive at a border crossing at the same time, the comparison is still illustrative.

One Poe-max vessel carrying 56,260 tonnes (62,000 tons) and passing under the Ambassador Bridge between Windsor and Detroit is the equivalent of 2,340 trucks at a nominal 24.1 tonne (26.5 ton) load passing over the bridge — enough to fill traffic lane for 50 kilometers (30 miles) back from the border inspection booths.

In a queuing situation with stopped vehicles, one truck-length is equivalent to 4.67 passenger-vehicle lengths. While the trucks have dedicated lanes and inspection booths, the length of the truck lanes could accommodate 4.67 passenger vehicles per truck and, due to the nature of queuing delays, the queue would occasionally back up past the dedicated lanes into mixed traffic lanes. The capacity utilization equivalent units of one Poe-max vessel at a highway border-crossing inspection station are illustrated in Figure 14. Similarly, a Seaway-max vessel would be equivalent to 963 trucks — enough to fill a traffic lane for 24 kilometers (15 miles) and equivalent to 4,497 passenger cars.

Figure 14. Border Crossing Inspection Queues Traffic Equivalents



Source: RTG analysis.

The cross-border cargo carried by the fleets operating on the Great Lakes-Seaway System would require an extra 1.9 million truck trips across the border, equivalent to 8.8 million passenger car equivalent (PCE) traffic units at the inspection-booth approach lanes. As a reference of the impact this traffic would have, the traffic volume on the Ambassador Bridge in 2010 was reported to be 7.2 million crossings. We note that the number of crossings in PCE units would be higher than 7.2 million, and the mix of truck and automobiles was not reported to enable a calculation of PCS traffic. In addition, all mode-shifted trucks would not cross at one location. Nonetheless, the border-crossing impacts would be significant.

7.3 Vehicle-kilometers Comparison

7.3.1 Empty Return Ratios

The modal activity needed to carry the Great Lakes-Seaway cargo is based on averages attained for the cargo mix and the country in which the trip takes place. To derive total vehicle-kilometers of activity requires information on the distance of travel in an empty or ballasted state required to get from an unloading location to a loading location. Empty travel is an important element in every mode but more so for marine vessels, as ballast water must be added for safety and operational reasons. This usually involves loading the vessel to at least submerge the propeller — and sometimes more. The vessel is partially loaded with non-revenue cargo on an "empty" trip. Thus, the term "ballast ratio" for the marine mode has a similar meaning to empty return ratios for the other modes.

The data provided by the marine carriers is the baseline for comparison and inherently includes the influence of both the laden and ballasted states. However, since the ballast ratios of the baseline data are adjusted in the air emissions comparison, the fuel intensity in the ballast state needs to be simulated. The activity of the other two modes in moving the baseline Great Lakes-Seaway cargo also needs to be simulated and thus, empty travel is an important element. Table 17 compares the empty and ballasted travel ratios for the three modes. See Appendix B for details.

Table 17. Empty (or Ballast) Return Ratios

Mode	Empty / Laden Distance Ratio	Empty / Total Distance Ratio*
Marine-2010	63%	39%
Marine-2008	52%	34%
Rail	95%	49%
Truck	42%	29%

* Note that empty travel for marine is a ballast state, where the vessel is "loaded" with water.

Source: RTG analysis of confidential marine carrier data.

7.3.2 Truck Mode Activity Associated with the Great Lakes-Seaway Cargo

The total number of truck loads and truck trips associated with the Great Lakes-Seaway cargo mix is summarized in Table 18. Canada and the U.S. have different axle load limits and truck configurations. Cross-border trips involving Canada, as well as international trips made via Canada, are subject to the U.S. load limits and are therefore grouped with the U.S. data.

The total number of cross-border trips included in the "U.S. or cross-border" column of Table 18 is 1,894,825 (about 32% of the combined total). The proportion of truck trips totally within Canada and using Canadian axle loads and trailer configurations is 16%.

Table 18. Truck Loaded Trips and Vehicle Trips Generated by the Great Lakes-Seaway Cargo (2010)

	Loaded Trips		Total Trips	
Commodity Group	***U.S. or Cross-border***	***CAN***	***U.S. or Cross-border***	***CAN***
Wheat and Other Cereal Grains	265,572	320,549	358,882	433,174
Metallic Ores and Concentrates	1,713,495	245,289	2,315,533	331,398
Fuel Oil, Gasoline and Aviation Fuel	23,845	64,506	37,850	102,391
Non-Metallic Mineral Products	2,260,372	156,686	3,054,557	211,738
Base Metals/Articles of Base Metal	119,775	35,474	146,004	43,243
Machinery	54,805	18,008	68,514	22,512
Total	4,437,864[1]	840,512	5,981,339	1,144,456

Note:

1. The total number of cross-border trips included in the "U.S. or cross-border" is 1,894,825.

Source: RTG analysis of cargo-specific axle loads and empty return ratios as developed in the truck section of Appendix B.

The impacts of highway travel are sensitive to the type of road involved. Referring back to the Study Highway Network (Figure 5), one can see that all of the Great Lakes U.S. states are served by the Interstate freeway system, while in Canada the 400-series freeways in Ontario and 2-digit freeways in Quebec are limited to the corridor between Windsor and Quebec City. Canadian cargo movements east of Quebec City or involving Lake Superior or Lake Huron would use arterial highways. The breakout of truck vehicle-kilometers travelled (VKT) or vehicle-miles-travelled (VMT) by type of road and by country was estimated on the basis of:

- cross-border trips involving a 50/50 split of VKT on each side of the border;
- 85% of U.S. travel on freeways;
- 40% of Canadian travel on freeways; and
- the remaining VKT on arterial highways.

The resulting distribution of VKT (VMT) is presented in Table 19. As an example of the calculation, the U.S. freeway VKT is derived as follows:

> {5,981,339 (total U.S. or cross-border trips from Table 18) - .5 * 1,894,825 (50% of the total cross-border trips included in the total trip number)} * 1,095 km/trip * .85 (proportion of U.S. travel on freeways) = 4,685 VKT.

Table 19. Truck Travel Distribution by Road Type

Road Type	U.S.		Canada		Total		Proportion (%)
	Millions VKT	*Millions VMT*	*Millions VKT*	*Millions VMT*	*Millions VKT*	*Millions VMT*	
Freeway	4,685	2,912	916	569	5,602	3,481	72%
Arterial	827	514	1,374	854	2,201	1,368	28%
Total	5,512	3,426	2,291	1,424	7,803	4,849	100%

Source: RTG analysis.

Assuming the traffic is distributed across 4 different segments and operates 364 days per year, the incremental truck traffic is:

- 3,513 average annual daily truck traffic (AADTT) for freeways; and
- 1,381 AADTT for arterials.

As an example of the calculation, the Freeway AADTT is derived as follows:

> [{5,981,339 (total U.S. or cross-border trips from Table) - .5 * 1,894,825 (50% of the total cross-border trips included in the total trip number)} * .85 (proportion of U.S. travel on Freeways) + {1,144,456 (total trips within CAN from Table) + .5 * 1,894,825 (50% of the total cross-border trips added to CAN)} * .4 (proportion of CAN travel on Freeways)] / 4 (highway segments) / 364 (days per year) = 3,513.

7.3.3 Rail Mode Activity Associated with the Great Lakes-Seaway Traffic

The following information is summarized from Appendix B. The data available for CN and Canadian Pacific (CP) in Canada do not differentiate train types — the average length for all trains was 99.6 cars. The average train length for Norfolk Southern Railway (NS) and CSX Transportation (CSXT) unit trains in 2010 was 91.7 cars. While the average train length for other “through trains” was 58.8 cars, the number includes intermodal 5-pack car sets that are counted as one car — even though they have 5 platforms. Without an accurate count for non-intermodal trains, we used the length of unit trains for all U.S. trains being assessed. The railcar capacities and train configurations are summarized in Table 20.

Table 20. Rail Carloads and Trips Generated by the Great Lakes-Seaway Cargo

Commodity	Average Carload		Empty Return Ratio*	Railcar Loads	Railcar Trips	Train Trips
	(Tonnes)	*(Tons)*				
Coal Unit Train	100.4	110.6	100%	332,143	664,286	7,121
Grain/Bulk	86.7	95.5	94%	1,074,246	2,084,038	21,775
Liquid Bulk	63.6	70.1	97%	43,841	86,367	874
General Cargo	49.0	54.0	79%	84,078	150,500	1,511
Total/Weighted-average	88.4	97.5	95%	1,534,309	2,985,191	31,282

* Empty-kilometers divided by Laden-kilometers.

Source: RTG analysis of Railway Association of Canada and U.S. Surface Transportation Board filing.

In terms of rail line loadings, we make similar assumptions to the highway mode – i.e. the GL-S traffic is carried on the equivalent of four separate line segment. For the average trip length of 1,095 kilometers (680 miles), an average service speed of 34 km/h (21 mph) and operating 364 days per year, the incremental traffic load would be 115 trains per day on the network and 29 trains per day on each of the four line segments.

8

Modal Congestion Comparison

8.1 Summary

This chapter illustrates that a shift of Great Lakes-Seaway traffic to the highway or rail modes would lead to congestion delays for the traveling public. The study attempts to quantify the costs of the delay impacts but notes that the impacts would be highly sensitive to the specific cargo movements that shifted and to the value of time assumed for those delays.

Both of the ground modes have an impact on road traffic delays — trucks via direct interaction with other traffic and trains via delays incurred at road-rail at-grade crossings. Traffic congestion is mainly an urban issue. Nonetheless, a hypothetical shift of Great-Lake Seaway traffic to the highway mode would decrease the available capacity of rural freeways by 5% to 15% (with the range covering level to rolling terrain). The capacity impacts would be higher for rural arterial highways with occasional passing lanes; however, capacity utilization is also lower on these highways.

In urban freeway settings, incremental delay to other traffic is imposed by each additional vehicle. If the hypothetical shift of Great Lakes-Seaway traffic to the highway mode involved 20% urban freeways, the incremental cost of delays to other vehicles would be in the range of $346 million to $380 million per year. If the traffic moved by the fleets operating on the Great Lakes-Seaway System in 2010 shifted to rail, the cost of road user delays at grade crossings due to incremental train trips would be $46 million per year.

The Great Lakes-Seaway System is operating well below capacity. The traffic carried by the Soo locks and the Seaway over the past decade is well below the peak traffic carried in 1979-80. While the U.S. Army Corps of Engineers (USACE) has recommended expansion of the Soo locks, the recommendation addresses the critical nature of the Poe locks to commerce and the inherent risks, rather than the throughput capacity utilization of the locks. Thus, the focus of this chapter is on the congestion of the rail and truck modes.

In our base case, the estimated cost of incremental urban congestion associated with shifting Great Lakes-Seaway traffic to trucks was in the range of $346 million to $380 million per year. The present value of this incremental cost would be $5.6 billion to $6.1 billion over a 24-year time period, assuming a 2.5% annual rate of growth in traffic.

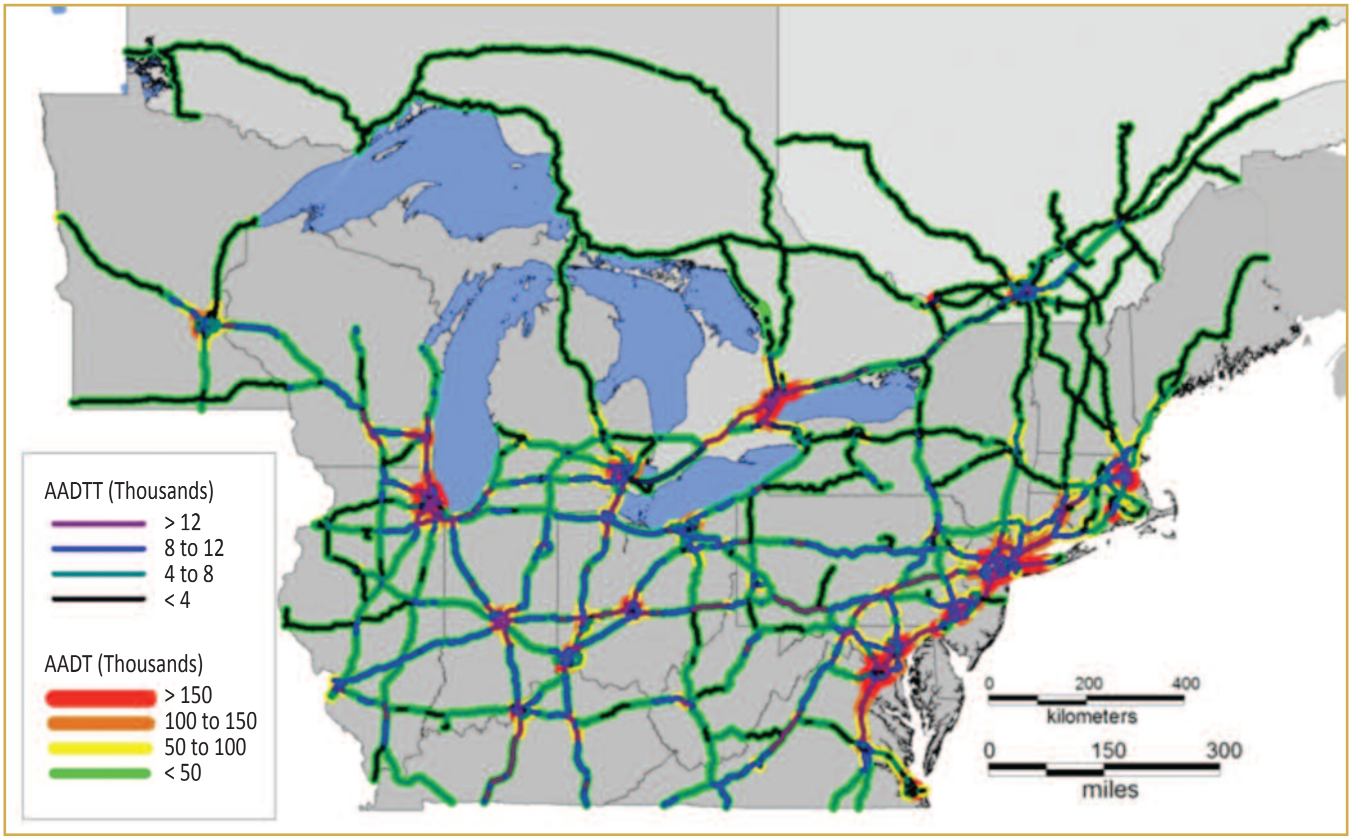
The estimated cost of incremental delays at highway-railway grade crossings associated with shifting Great Lakes-Seaway traffic to rail was $46 million per year. The present value of this incremental cost would be $750 million over a 24-year time period, assuming a 2.5% annual rate of growth in traffic.

8.2 Highway Congestion Impacts

Canadian highway traffic data for 2006 were obtained from the Ministry of Transportation of Ontario (MTO) and the Ministère des Transports du Québec (MTQ), while the corresponding map files were provided by MTO for Ontario and Transport Canada (TC) for Quebec. The U.S. highway data for 2007 were downloaded from U.S. Department of Transportation (DOT) websites. The data are a mix of linked information available from the DOT's Freight Analysis Framework (FAF-3) database and the DOT's National Transportation Atlas Database (NTAD).

Traffic levels on the highway network are illustrated in Figure 15. Both average annual daily traffic (AADT) and average annual daily truck traffic (AADTT) are layered on the map. In the U.S., the AADTT is above 8,000 for much of the rural east-west Interstate between Cleveland and Minneapolis, and between Cleveland and New York City. AADTT exceeds 12,000 in urban areas along this route. Over 30% of this high-density corridor in the U.S. is depicted as "urban freeway."

Figure 15. Highway Network Traffic Levels

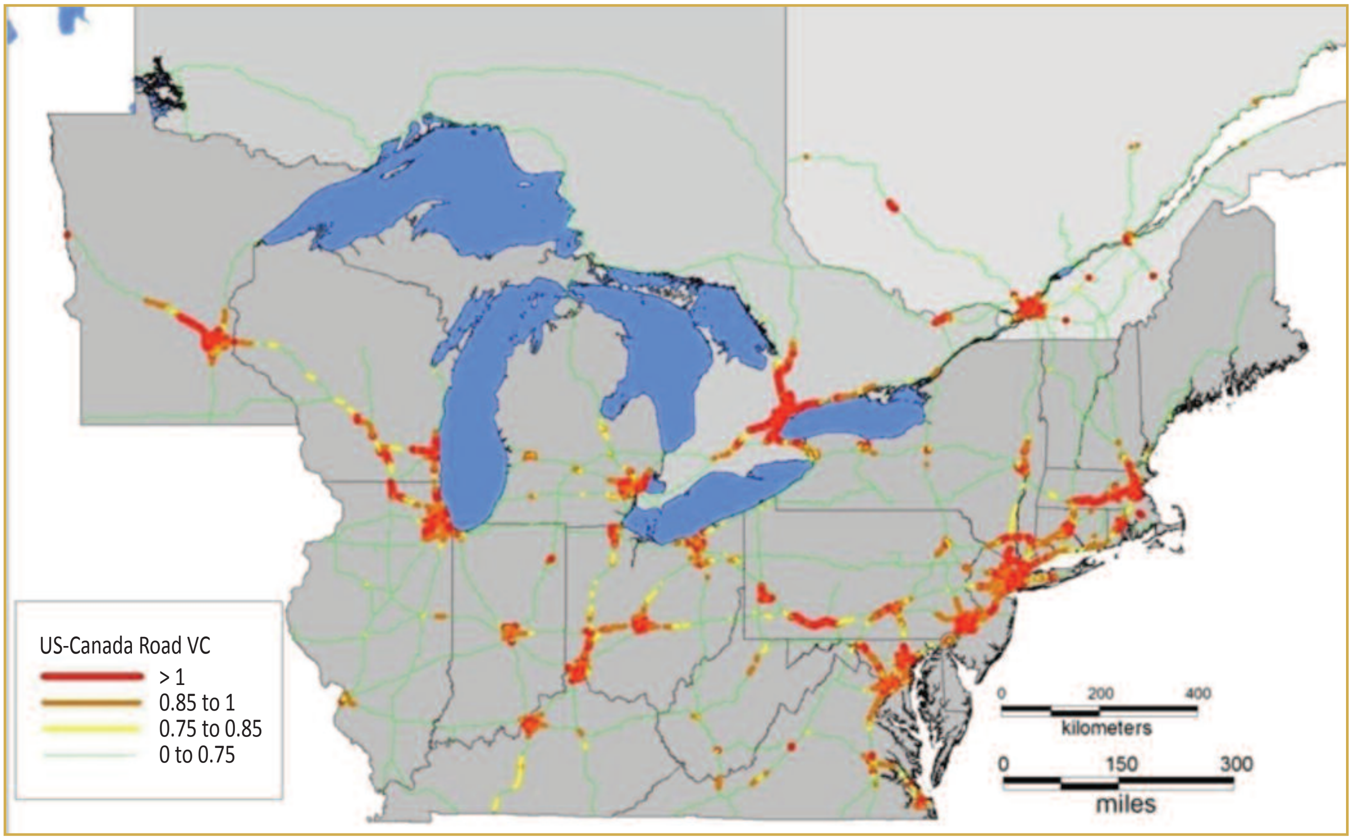


Sources: U.S.-FAF3, MTO, MTQ for data; U.S. NTAD, MTO, TC for map data.

In Canada, the AADTT exceeds 12,000 for much of the east-west region near Toronto. However, much of the network north of Lake Huron and Lake Superior involves lower-density rural arterial highways. The type of highway involved in carrying Great Lakes-Seaway cargo would be much more variable in Canada. Grain from Thunder Bay to the Lower St. Lawrence River ports would use mostly rural arterials, some rural freeways in Quebec and a few urban freeways. Salt and most other domestic Canadian cargo as well as all cross-border and international transfer cargo, would use the southern freeway system of both Ontario and Quebec, involving a proportion of urban segments similar to the 30% cited for the U.S. corridor.

Capacity utilization on the highway network during peak periods is illustrated in Figure 16. The volume capacity ratio depicts the ratio of traffic volume to road capacity during peak periods. The capacity of freeway segments is developed on both sides of the border, following procedures outlined in the *Highway Capacity Manual* (HCM2000) [Transportation Research Board, 2005].

Figure 16. Highway Capacity Utilization



Sources: Derived from U.S.-FAF3, MTO and MTQ data, using MTO, NTAD and TC map vector files.

The impact of incremental highway congestion is the incremental delay to other vehicles on the highway and over time, the advancement of investment in additional capacity. Since the traffic shift comparison being assessed is an illustrative hypothetical situation rather than a practical option, our analysis focuses on the costs of delay, which are immediate. The congestion criteria that trigger highway capacity investment and traffic growth rates are much more difficult to assess than the congestion impacts of adding a block of traffic. A rigorous analysis of a specific location would evaluate the present value (PV) of future delays considering traffic growth, and make an investment in additional capacity when the PV exceeds the capital costs of attaining additional capacity.

Many jurisdictions are hesitant to continue making investments in highway capacity and are considering other measures (e.g., peak pricing and mode shift). Our study is looking at the impact of a shift of Great Lakes-Seaway cargo to other modes and the reverse shift of highway traffic to the marine mode is not relevant to the cargo mix or analytic framework. Rather than devise an assumed advancement schedule for highway capacity investments, we have considered the long-term impact of delays as a conservative PV impact.

We use the same 60-year time period and 6% interest rate that are adopted for the highway maintenance impact assessment (see Chapter 9) but have not included a hypothetical future capital investment in the annual costs. Nor have we included a baseline growth rate for traffic; the marginal impact of the Great Lakes-Seaway traffic is simply assumed to continue for 60 years. This is a very conservative assumption, since traffic growth has a greater impact on the PV calculation than the years included — for example, a 2.5% traffic growth rate would attain the same PV in about 24 years and the longer daily congestion periods that result from traffic growth would exacerbate the impacts of the added truck traffic over those impacts that exist in the base-year calculation. Also, changing the duration of the calculation from 60 years to 30 years and keeping zero traffic growth would only reduce the PV by 15%.

The passenger car equivalent (PCE) traffic unit posed by a combination trailer truck on a rural freeway is much lower than it is for a stopped vehicle in a queuing situation (as was discussed in subsection 7.2.4.2). The relevant capacity utilization metric in low-gradient freeway conditions is still tied to vehicle headway but the gap between vehicles at highway speeds means that the headway between a truck and an automobile is not as significant a difference as the headway between two automobiles. Rather than a PCE of 4.67 that was used in the queuing calculations, the recommended PCE for moving traffic is lower. For rural freeways, the *Highway Capacity Manual* [Transportation Research Board, 2005] recommended values range from 1.5 for level terrain to 2.5 for rolling terrain. The capacity reduction from additional trucks on rural freeway segments is calculated by the formula (U.S. DOT *HPMS Field Manual*, 2010):

Relative Capacity = 1/(1+Pt(PCE-1))

Where:

Pt = proportion of trucks
PCE = passenger car equivalent

The Great Lakes-Seaway traffic on the rural freeway system was estimated in subsection 7.2.2 to be 3,513 AADTT, which is about 11% of the existing traffic. The capacity reduction from this incremental truck traffic would be from 5% to 15% (for the PCE range of 1.5 to 2.5 for level to rolling conditions). Where higher gradient conditions are encountered such that trucks cannot maintain speeds, the impacts are higher. The consequences are even greater on rural arterial highways with occasional passing lanes; however, capacity utilization is also lower on these highways.

Urban freeways during congested traffic periods pose similar exacerbating conditions to that of gradients. The slowing and in some cases, stop-and-go conditions of urban traffic congestion mean that slow accelerating vehicles such as trucks pose an exacerbated impact on traffic flow. The analysis conducted by Applied Research Associates as part of Transport Canada's (TC's) full cost initiative considered that one 5-axle truck is equivalent to 3.0 passenger vehicles and a 6-axle truck is equivalent to 3.3 [source: Applied Research Associates for Transport Canada, 2007]. This range is directly relevant to the U.S. and cross-border traffic; however, we note that many multiple trailer configurations would be involved in the Canadian traffic. We have adopted the range of 3.0 to 3.3 PCE but note that it will provide conservative estimates of the Canadian urban highway impacts.

As indicated previously in Table 18, the traffic moved by the fleets operating in the Great Lakes-Seaway System in 2010 would require 7.1 million additional truck trips. These trucks would pose the equivalent of 22 to 24 million additional passenger vehicle trips added to each urban freeway encountered.

Delay to other traffic is imposed by each additional vehicle. The methodology and data used in Research and Traffic Group's study for the Southern Ontario Gateway Council [Research and Traffic Group, 2008] was adopted. A value of $47 per hour was used for trucks (the estimated avoidable costs of truck operation). The values used for Toronto in TC's updated study of urban congestion [iTrans Consulting, 2009] were used for passenger vehicle occupants. The updated study involved two cost scenarios: one involving an update of an earlier study and the other involving a new methodology that differentiated commuters from business travel. Our assumed distribution of urban passenger travelers affected by long-haul trucks and the related costs of delay (in 2006$) for the two cost scenarios are:

- 60% business @ $33.45 + 40% leisure use @ $10.30 = $24.19 for Scenario 1; and
- 40% business @ $23.61 + 20% leisure @ $10.22 + 40% commuter @ 11.35 = $16.03 for Scenario 2.

We estimate an average occupancy of 1.2 for passenger vehicles, and estimate 85% of the traffic to be passenger vehicles and 15% to be truck. The resulting average hourly cost for the combined traffic was $31.72/vehicle/hr for Scenario 1 and $23.40/vehicle/hr for Scenario 2.

The capacity and congestion impacts of a mode shift are highly case-specific. However, assuming 20% of each Great Lakes-Seaway trip would occur on congested urban segments of freeways, the incremental cost of delays to other vehicles would be in the range of $346 million to $380 million per year with Scenario 1 costs. The present value (PV) (60 years, 6%) would be $5.6 billion to $6.1 billion under Scenario 1 costs.

Considering sensitivities, the annual costs under iTrans Consulting (2009) Scenario 2 would be $255 million to $281 million and associated PV would be $4.1 billion to $4.5 billion. Using the alternate PV calculation based on 20 years and 2% annual traffic growth, the PV would be about 16% lower — $4.7 billion to $5.2 billion under Scenario 1 and $3.5 billion to $3.8 billion under Scenario 2. Using a 30-year interval rather than a 60 year-interval and still ignoring traffic growth would reduce the PV by about 15%. Using a 2.5% traffic growth rate and a 24-year duration would produce the same results as the base case.

We note that the congestion costs would vary considerably depending on the real origin-destination of the movement involved. For the largest traffic categories, ore and coal, the impacts would be much higher in the U.S. and possibly slightly lower in Canada. For grain shipments from Thunder Bay to the Lower St. Lawrence River, the urban congestion impact would be substantially lower. The main impact for that traffic would be the capacity reduction and advanced investment schedule for the rural arterial highways involved for much of the route. As noted, these impacts have not been estimated.

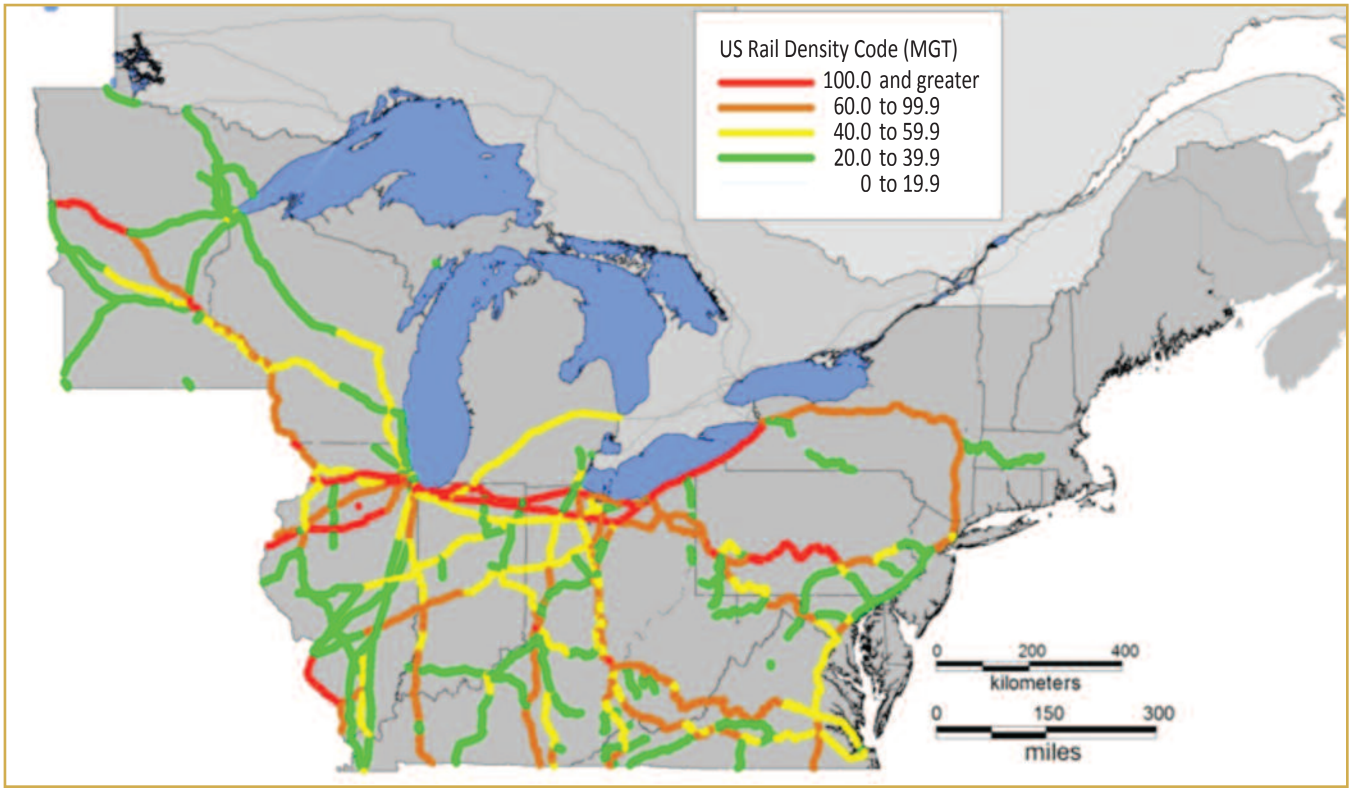
8.3 Railway Congestion Impacts

The congestion impacts of adding traffic to the rail network are assessed at two levels: 1) the short-term capacity in rolling stock and the track network to accept the traffic and 2) the long-term delays to the public at highway-railway grade crossings as a result of the extra trains.

As indicated previously in Table 20, the traffic moved by the fleets operating on the Great Lakes-Seaway System in 2010 would require about 3.0 million additional railcar trips and 31,282 additional train trips. We estimate that, on average, 115 trains per day would be added to the rail network. If these trips involved four different railways, an average of 28.7 incremental trains per day would be added to each.

The present traffic levels on the U.S. rail network are included in the National Transportation Atlas Database (NTAD) in terms of millions of gross tons (MGT) and are illustrated in Figure 17. Canadian rail traffic density data are considered confidential and could not be shown on the map.

Figure 17. Traffic Density on the U.S. Rail Network



Source: U.S. DOT – NTAD.

The line capacity utilization of U.S. railways was assessed by Cambridge Systematics [Cambridge Systematics, 2007]. The predictions for 2035 are illustrated in Figure 18 — indicating that much of the rail network west of Cleveland will be at or over capacity. The capacity utilization of the Canadian railway network is only known in more general terms as illustrated in Figure 19.

The incremental iron ore and coal traffic related to Great Lakes-Seaway cargo is about 84 million net tonnes, which translates into about 134 million gross tonnes (140 million gross tons). If spread across two parallel lines, it would pose close to a 100% increment to the existing lines west of Chicago and up to 70% for lines east of Chicago. The system could not accept traffic increments of this magnitude without capacity investment.

Railways do not have the capacity in equipment or track to accept sudden shifts of traffic of the magnitude involved; however, a gradual shift of traffic could be accommodated with investments in track, signaling and equipment. As the investments required would be largely made by private industry,[5] and covered by traffic revenue if the shift were commercially viable, the consequences are not included in this impact assessment.

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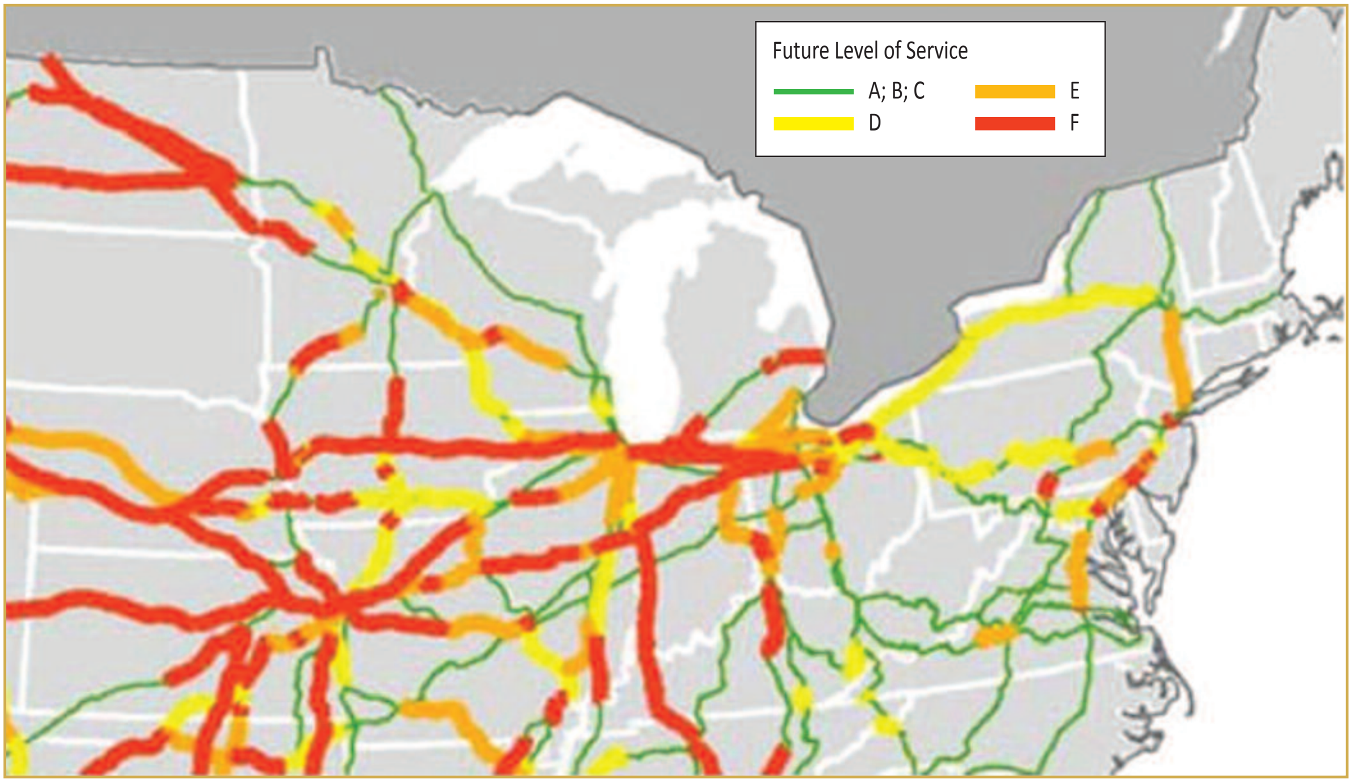
[5] The existence of public-private partnerships for some rail (and port) expansion projects is recognized but tracking the public proportion is beyond the scope of this assignment.

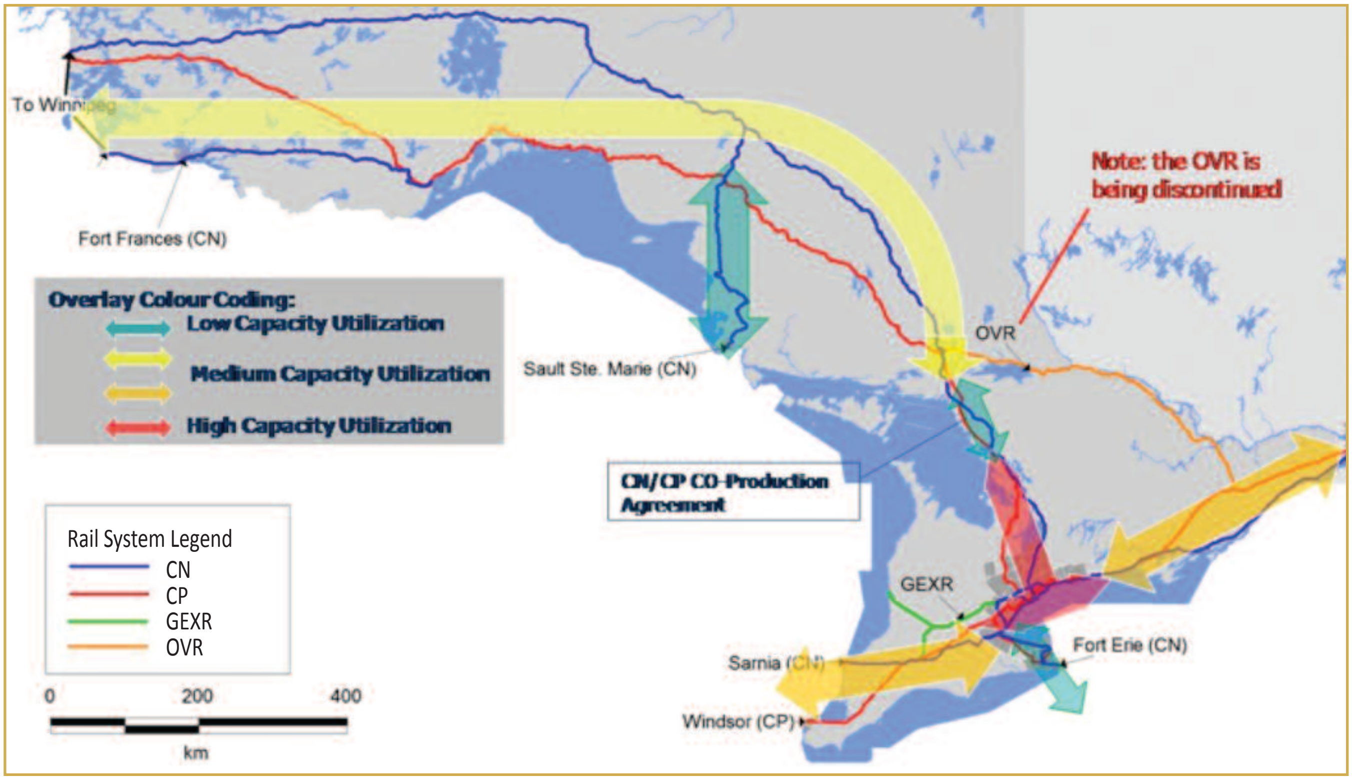
Figure 18. U.S. Railway Network Capacity Utilization Projections for 2035



Legend – note: E is at capacity, F is over capacity.

Source: Cambridge Systematics, for AAR, 2007.

Figure 19. General State of the Canadian Railway Network Capacity Utilization in 2006



Source: RTG, *Continental Gateway Research Workshop*, MTO, Toronto, June 24, 2011.

As with the highway congestion impacts, the present value (PV) of delay costs is calculated in order to have a common cost-presentation format. The advancement of grade separation investments is not included in the PV of costs nor is traffic growth considered. The PV derived is a conservative estimate of the impact.

Traffic shifts would lead to delays to the public at highway-rail grade crossings. A sample of grade crossings on principal rail lines in Ohio, Michigan and Illinois indicated on average:

- There is a public rail-highway at-grade crossing every 1.05 miles.
- The average daily traffic on the highway is 2,260 vehicles, of which 8.5% are trucks.

Using the values of time previously cited for urban highways (cost scenario 1) but adjusting the proportion of business travel at railway grade crossings down to 12% from 60% and increasing occupancy from 1.2 to 1.8, the PV (60 years, 6%) of the cost of delays due to incremental train trips would be $747 million ($46 million per year). The same PV sensitivities assessed for the highway congestion apply — a duration of 30 years reduces the PV by 15% and including traffic growth of 2.5% for a 24-year period produces the same PV.

8.4 Congestion Impacts Conclusions

We conclude that marine has a negligible impact on congestion delays for the traveling public. We also conclude that a shift of Great Lakes-Seaway traffic to the highway or rail modes would lead to increased congestion delays for the traveling public. We have attempted to quantify the costs of the delay impacts but note that the impacts would be highly sensitive to the specific cargo movements that shifted and to the value of time assumed for those delayed.

In our base case, the estimated cost of incremental urban congestion associated with shifting Great Lakes-Seaway traffic to trucks was in the range of $346 million to $380 million per year. The PV of this incremental cost would be $5.6 billion to $6.1 billion over a 24-year time period, assuming a 2.5% annual rate of growth in traffic.

The estimated cost of incremental delays at highway-railway grade crossings associated with shifting Great Lakes-Seaway traffic to rail was $46 million per year. The present value of this incremental cost would be $750 million over a 24-year time period, assuming a 2.5% annual rate of growth in traffic.

9

Highway Infrastructure Maintenance Impacts

9.1 Summary

This chapter shows that a shift of Great Lakes-Seaway traffic from marine to truck would lead to a significant increase in highway maintenance costs (estimated to be $4.6 billion over a 60-year timeframe). The chapter deals only with highway maintenance costs due to the fact that the highway system is a publicly maintained infrastructure and only highways have maintenance costs that are sensitive to traffic levels. The chapter also notes that some proportion of incremental fuel-tax revenues derived from the new truck activity would mitigate the incremental maintenance and other social costs. A full social cost and revenue analysis of the modes was beyond the scope of this assignment.

9.2 Highway Maintenance

Of the three modes being compared, the marine and highway modes have publicly maintained infrastructure and only the highway mode has maintenance costs that are sensitive to changes in traffic levels.[6] Thus, this chapter deals only with traffic-sensitive highway maintenance costs if the Great Lakes-Seaway cargo was shifted to trucks. As the cargo that could be considered in a mode shift from truck to marine could be quite different than the Great Lakes-Seaway cargo, the analysis undertaken here is not necessarily applicable to cargo shifts from highway to marine.

Highway impacts are the only areas where we have monetized the physical impacts. This is because the causal cost relationships are more direct. The other areas of noise and air emissions have less direct causal linkages and require adoption of a value for the social impacts — and these values range widely among different societies. Similarly, our analysis does not consider revenue sources, as it would be difficult to determine which revenue sources are aligned with which marginal costs and whether any single revenue source should be directed at any specific social cost. We note that a presentation on marginal costs of trucks made by Transport Canada (TC) did consider the marginal revenue from fuel taxes and did assume that these revenues are aligned with marginal maintenance costs, drawing the conclusion that:

> "Since estimated marginal revenues (Excise Taxes) are greater than estimated marginal road wear costs, it is recommended to NOT consider road wear as a social cost." (Jacques, B., 2011)

We agree that where governments derive revenues from modal activity, those revenue impacts should be considered in a total net cost comparison. Marginal fuel-tax revenues from trucks would be considered, as would any marginal revenues associated with the other modes. Such an exercise is beyond the scope of this assignment. We are also not convinced that fuel-tax revenues are associated with highway maintenance costs any more than they are with other social costs.[7] Thus, we simply present the estimated incremental costs of road maintenance that would be expected to arise, if Great Lakes-Seaway cargo was moved by truck — with the above-stated qualifications for any future use of the findings in a full social-cost comparison.

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[6] We note that a complete shutdown of the Great Lakes-Seaway System would result in maintenance cost savings but changes in traffic levels at the margin have little influence on maintenance costs.

[7] One could argue that fuel taxes are much more aligned with GHG and CAC impacts than with highway maintenance impacts. The fact that fuel taxes are assessed on automobiles (which have a negligible marginal impact on highway maintenance costs) and that many provinces assess fuel taxes on railways (which have no impact on highway maintenance costs) is an indication that governments make no intentional link between highway maintenance costs and fuel-tax revenues.

Table 21. Marginal Cost of Combination Trucks Derived by Transport Canada

Truck Configuration	TC Derived Marginal Costs (cents/vkm)	
	On Freeways	***On Arterials***
5-axle	0.59	2.69
6-axle	0.70	3.18
7-axle	0.80	3.35

Source: Data from Transport Canada (Jacques, B., 2011).

We draw from the work conducted by Transport Canada's (TC's) Full Cost Investigation that derived the costs of highway maintenance and allocated these costs among traffic types [Applied Research Associates (ARA), 2007] and the follow up work of TC in using the ARA results to calculate the marginal costs of additional truck traffic [Jacques, B., 2011]. Load-sensitive costs (pavement repair) were the dominant marginal cost, but bridge maintenance and "other infrastructure" variable costs were also included. While the details of the analysis are not provided in the TC presentation, the analysis appears to assume equal axle loads for all existing and marginal truck configurations. The marginal costs per truck-kilometer (in 2005 dollars) as presented in the TC presentation are shown in Table 21.

Pavement damage, which is the main traffic-sensitive component of the maintenance costs, is quite sensitive to axle loads and somewhat sensitive to axle configurations (single, dual or triple). For our mode-shift scenario, the analysis needs to consider the higher axle loads, and for Canada, the more frequent use of extra axles and trailers, in hauling the Great Lakes-Seaway bulk cargo. Thus, the marginal costs associated with uniform axle load need to be adjusted. We estimate from ARA's report [Applied Research Associates, 2007] that 80% of the marginal costs are load-sensitive pavement repair/renewal costs, which are sensitive to axle load. Highway engineers use equivalent single axle loads (ESAL) to assess the relative damage caused by different loads. The American Association of State Highway and Transportation Officials (AASHTO) recommends a "power of 4" damage relationship with axle load (i.e., an axle load 20% heavier than a reference axle load has $(1.2)^4 \approx 2$ times the damage consequences of the reference axle load).

There are a range of opinions on the influence of axle configurations. Researchers with the Ministry of Transportation of Ontario (MTO) believe that the AASHTO equivalent loads for multiple axle configurations "may underestimate the damaging effects of dual and triple axles in comparison with single axles" [Hajek, J.J. and Agarwa, A.C., undated]. AASHTO load equivalents of 1.38 and 1.68 are used for double and triple axle configurations respectively. The AASHTO load equivalency leads to higher axle loads on dual and triple axle configurations (21,600 kilograms for a double axle and 34,300 kilograms for a triple axle, versus 10,000 kilograms for a single axle). By comparison, the Ontario load limits for dual and triple axle configurations are sensitive to axle-spacing and lead to reduced axle loads rather than increased axle loads. The axle loads on dual and triple axle configurations as compared in Table 2 of Hajek's paper are 19,100 kilograms for a double axle at 1.8 meter spacing and 28,600 kilograms for triple axles at 4.8 meter spacing, versus 10,000 kilograms for a single axle.

For double and triple axle configurations, we use the MTO equivalency factors in Canada and the AASHTO equivalency factors in the U.S. We also do sensitivity cases by uniformly applying the ASSHTO equivalency factors and the MTO equivalency factors. For the 80% of TC's marginal costs that are considered to be load-sensitive, we apply the above factors to the axle loads and configurations for each category of cargo carried on the Great Lakes-Seaway System — to develop scale factors that differentiate the ESAL damage from that associated with the existing average axle load/configuration used in development of TC's marginal costs above. The other 20% of marginal costs are applied on a vehicle-kilometer basis using TC's marginal costs.

The average axle loads/configurations and cargo-specific axle loads and configurations are summarized in Table 22. The average gross vehicle weights shown at the bottom of the Table are for the existing mix of traffic. The value for Canada is that of intercity trucks in Ontario and Quebec, when loaded as derived from the 2006 National Roadside Survey. The value for the U.S. is the average of those trucks weighing more than 15 tonnes (33,100 lb) in the U.S. Federal Highway Administration's Vehicle Travel Information System's 2008 sample of 5-axle combination trucks [Oak Ridge National Laboratory (ORNL), 2011, Fig. 5.5]. We assume trucks weighing 15 tonnes or less in their Figure 5.5 to be empty and on that basis, the average tare (i.e., unladen) weight of trucks in the U.S. is estimated to be 13.65 tonnes (30,080 lb).

Table 22. Average Truck Axle Loads and Number of Axles

Commodity Group	**Number of Axles**		**Loaded Trip Axle Load (tonnes)**		**Tare Weight (tonnes)**	
	U.S. or Cross-border	*CAN-to-CAN*	*U.S. or Cross-border*	*CAN-to-CAN*	*U.S. or Cross-border*	*CAN-to-CAN*
Great Lakes-Seaway Cargoes:						
Wheat and Other Cereal Grains	5.50	6.21	7.10	7.71	14.9	17.9
Metallic Ores and Concentrates	5.50	7.03	6.95	8.04	14.1	18.3
Fuel Oil, Gasoline and Aviation Fuel	5.80	7.88	6.53	6.57	14.5	17.2
Non-Metallic Mineral Products	5.50	7.36	6.95	6.82	14.1	16.5
Base Metals/Articles of Base Metal	5.40	6.47	6.06	6.53	12.8	16.7
Machinery	5.10	5.72	4.73	5.10	13.2	16.6
Normal System-wide Cargo Mix	5.05	5.80	5.20	5.67	13.65	N.A.

Source: RTG analysis.

Maintenance costs are a mix of recurring annual and longer-interval renewal investments. We calculate the present value (PV) of the annualized marginal cost stream using a 60-year timeframe and 6% discount rate — the same values used by ARA [Applied Research Associates, 2008] in the underlying cost analysis that was in turn inherent to the TC marginal cost analysis. The resulting annualized and equivalent PV costs are summarized in Table 23. As indicated, the PV of incremental costs in 2010 dollars is $4.6 billion.

Table 23. Estimated Marginal Highway Maintenance Costs for Great Lakes-Seaway Traffic

Item	**U.S.**	**CAN-to-CAN**	**Cross-border in CAN**	**Total/Average**
Damage Factor	3.70	4.39	1.49	3.52
Freeway VKT	4,685,327,128	916,238,359		5,601,565,487
Arterial VKT	826,822,434	1,374,357,539		2,201,179,973
Incremental cost (2006-C$)	157,582,950	104,256,497		261,839,448
CPI (2006-2010)	1.082	1.068		1.076
Incremental cost 2010-$(millions)				281,773,945
PV (6%, 60 years)				$4.6 billion

Source: RTG analysis.

As noted, the influence of using AASHTO or MTO load equivalency factors for triple-axle configurations was assessed. If MTO values are used in the U.S., the U.S. costs are escalated by 5.2%. If AASHTO values are used in Canada, the Canadian costs are mitigated by 3.6%.

9.3 Maintenance Impact Conclusion

We conclude that a shift of Great Lakes-Seaway traffic from marine to truck would lead to a significant increase in highway maintenance costs (estimated to be $4.6 billion). However, we also note that some proportion of incremental fuel-tax revenues derived from the new truck activity would mitigate the incremental maintenance and other social costs. A full social cost and revenue analysis of the modes was beyond the scope of this assignment.

10

Noise Comparison

10.1 Summary

Noise footprints for the three modes were developed on the basis of noise emitted during line-haul activity (transportation from one destination to another). This analysis in this chapter shows that the noise footprint of the fleets operating in the Great Lakes-Seaway System is negligible in comparison with that of the other modes.

The analysis also shows that the noise footprint for the rail and truck modes would increase by 40% if either mode were to transport the Great Lakes cargo volume currently handled by the marine mode.

10.2 Methodology

Noise from transportation activity is a major social concern in urban areas and an analytic framework to quantify noise impacts has been developed by the U.S. DOT (U.S. Department of Transportation (DOT), 1998 and U.S. DOT, 2006). The same framework has been applied here, with one exception for truck noise attenuation with distance, which is discussed later in this section. Some of the definitions relevant to noise analysis are summarized below.

- Sound Pressure Level (SPL) is usually measured with respect to a reference level (Pref) of 20 micropascals. People's perception of loudness is not linear and an SPL measurement (Pmeas) is usually related on a log (base-10) scale in decibels (dB) where:

  SPL (dB) = 20 LOG(Pmeas / Pref) or = 10 LOG(Pmeas^2 / Pref^2).

- Sound Exposure Level (SEL) describes the cumulative noise exposure from a single noise event for its entire duration. In calculating SEL, the noise exposure is normalized to a time duration of one second, so that different noise events can be compared in terms of their sound energy.
- Leq is the equivalent SEL of all noise over a defined duration (one hour or one day) that is a log combination of the noise event and the background noise when the noise event is not present.
- Noise disturbance is a time-of-day weighted measure (Ldn) with overnight noise given a higher weighting. Noise events occurring between 10 p.m. and 7 a.m. are accentuated by 10 dB in a day-night sound exposure formula, using 15 hours of Leq_{day} and 9 hours of (Leq_{night}+10).
- A noise impact is defined as an Ldn that exceeds the background noise level (considered to be 55 dB) — while a severe impact is defined as an Ldn exceeding 61 dB.

Noise level attenuates with the log of increasing distance from the source. For point sources like horns, the attenuation rate is approximately -6 dB per doubling of distance and for line sources like road traffic, the attenuation rate is approximately -3 dB per doubling of distance. As the footprint being calculated in our study involves rural freeways and lower-density arterials, where truck traffic is more intermittent, we replaced the 3 dB attenuation factor with an attenuation rate of 4.5 dB to be more representative of traffic conditions across the study network.

The severe impact zone or footprint is the area inside the distance from the noise source to a boundary corresponding to an Ldn of 61 dB. This footprint is adjusted for the no-build buffer zone adjacent to the transportation right-of-way.

Thus, rail and truck movements lead to noise exposure to nearby residents beyond a +/- 33 meter (110 foot) no-build buffer zone. The noise emanates from the engine and from energy dissipation (primarily between wheels and the running surface and sometimes aerodynamic turbulence). Engines on vessels are housed deeper within the structure, which mitigates the sound level — and the energy dissipated at the running surface induces waves that have little noise impact. Thus, noise disturbance from movement is only relevant to truck and rail.

Additional noise events are generated due to regulatory safety requirements to sound an auditory warning under certain circumstances. A train must sound an air horn on approaching most public rail-highway at-grade crossings. Marine vessels must sound an air horn when vessels meet, and when mooring lines are dropped in preparation for departure from ports and locks. Trucks automatically sound a back-up alarm in many jurisdictions with severe noise impacts in loading/unloading areas. However, since port and railway terminal noise is not included in our comparison, we have also not included this aspect of truck noise.

The severe noise footprint associated with the above noise sources was calculated for each mode. As Ldn is based on the number of noise events at a location, the marginal impact of adding new traffic is different than the existing traffic. Thus, both the Ldn of existing traffic and the marginal impact generated by a shift of Great Lakes-Seaway cargo from marine to trucks are calculated.

We note that in areas where severe noise impacts exist, mitigating measures are sometimes taken. For example, noise barriers or earth berms are sometimes placed along highways and railways in urban residential areas, to mitigate the noise impacts. Night-time (or in some case all-day) whistle bans are also introduced for trains at some urban crossings. These measures vary widely on a site-specific basis and their consideration is not included in our assessment. We are simply comparing the noise footprints of each mode and the marginal increment associated with carrying the Great Lakes-Seaway traffic an equal distance.

10.3 Truck's Noise Footprint

Gillen applied the U.S. DOT highway noise model as part of Transport Canada's (TC's) Full Cost Investigation (Gillen, 2007). He cites the following equation to adjust the noise level with traffic speed and the proportion of heavy vehicles in the traffic:

$$L_{eq}\text{(hourly at 50 ft.)} = SEL_{ref} + 10\ LOG(V) + 25\ LOG(S/50) - 10\ LOG(S/50) - 35.6$$

where:

SEL_{ref} = the reference noise sound exposure level

V = hourly truck traffic volume

S = speed in mph

The traffic levels involved on the Great Lakes-Seaway highway network vary widely — average annual daily truck traffic (AADTT) can be a few hundred in parts of Northern Ontario and over 20,000 on the freeways passing through major urban centers. Northern Ontario also has lower population densities exposed to the noise. Thus, it is primarily the freeway system that is relevant to noise impacts.

Noise disturbance levels were calculated for a rural freeway case with 5,000 AADTT, an urban freeway with 15,000, and a rural arterial highway with an average of 500 trucks per day. In all cases, a time-of-day split of 80%-day/20%-night was applied. The extreme noise footprints were calculated for the existing reference traffic case and the marginal impacts due to shifting Great Lakes-Seaway cargo to trucks. The truck traffic associated with the Great Lakes-Seaway cargo mix would pose a significant increment. The total truck activity associated with carrying the Great Lakes-Seaway cargo was estimated in Section 7.3.2 to be 7.8 billion truck kilometers (7.1 million trips traveling an average of 1095 kilometers). For evaluation purposes, the 7.1 million truck trips generated by the Great Lakes-Seaway traffic were assumed to be spread across 4 different road segments and 28% of the traffic was allocated to rural arterial highways. The traffic split between freeway and arterial highway was 72% and 28% respectively. On average, 20% of the traffic was on urban freeways and 52% on rural freeways.

As discussed, we replaced the normal 3 dB attenuation factor for traffic with an attenuation rate of 4.5 dB to be more representative of intermittent truck traffic conditions in many segments of the study network.

The calculated footprints for the reference traffic and the incremental impacts of the Great Lakes-Seaway traffic are summarized in Table 24. The rural arterial is seen to have a relatively small existing footprint but would experience a larger marginal impact due to incremental Great Lakes-Seaway traffic. The urban freeway has the highest footprint and lowest marginal impact. The impact areas are calculated on the basis of a +/-33 meter buffer zone. Thus, for example, the severe noise footprint per kilometer of urban freeway length was comprised of two 1-kilometer wide strips — extending from 33 meters to 1,014 meters from each side of the road. For example, the urban freeway's base footprint in square meters is: 2 X (1014-33) = 1,963. Adding 3,513 trucks per day to the existing freeway traffic increases the severe noise boundary to +/-1,168 meters and the marginal impact is a 16% increase in severe noise exposure (2 X (2270-33) / (2 X (1,963-33)) - 1).

Table 24. Truck Noise Impact for Base and Incremental Great Lakes-Seaway Traffic

Road Segment	Severe Distance (m)		Per-Unit Footprint (m^2 per m of Roadway)		% increase
	Base	*with Great Lakes-Seaway*	*Base*	*with Great Lakes-Seaway*	
Urban Freeway	1,014	1,168	1,963	2,270	16%
Rural Freeway	486	694	907	1,323	46%
Rural Arterial	96	233	126	401	217%

Source: RTG analysis.

On the basis of the 20/52/28 traffic split for Urban-Freeway/Rural-Freeway/Rural-Arterial discussed above, the overall base footprint and marginal increment due to Great Lakes-Seaway traffic is shown in Table 25.

Table 25. Truck Noise Footprint for Base and Incremental Great Lakes-Seaway Traffic

Road Segment	Traffic Split	Base Footprint		Incremental Marginal Footprint	
		(km^2)	*(mi^2)*	*(km^2)*	*(mi^2)*
Urban Freeway	20%	8,597	3,321	1,343	519
Rural Freeway	52%	3,972	1,534	1,822	704
Rural Arterial	28%	554	214	1,202	464
Weighted Average		3,933	1,519	1,551	599

km^2 = square kilometers.
mi^2 = square miles.

Source: RTG analysis.

10.4 Rail's Noise Footprint

The noise impacts of a train are a combination of the impact from air horns blown on approach to public highway-railway at-grade crossings and the noise from movement of trains that occurs everywhere. The model used is a spreadsheet model developed by TranSys Research Ltd. to assess the relative community impacts of locomotive horns and wayside horns for the City of Saguenay [TranSys Research Ltd., 2008]. The model uses locomotive horn characteristics and a horn activation sequence beginning at a distance of 400 meters (a quarter mile) from the crossing that are representative of freight trains in both the U.S. and Canada. The model is similar to one used by the U.S. Federal Railroad Administration (FRA) to assess the noise impacts of train horns.[8] In these models, the SEL of a passing train that does not blow a horn is 10 dB lower than that of a train that does blow its horn (based on measurements made by the FRA). The severe noise footprint from a passing train anywhere and from the horn blowing sequence required at a crossing are calculated in a similar way to that described above for the truck mode's noise footprint— the differences being that:

- the source noise levels are different (the train horn's SPL is 107 dB at 30 meters (100 feet.);
- the horn sounding pattern involves four activations with a cumulative 10-to-20 seconds duration (11 seconds is used in the model);
- the time-of-day occurrence for freight trains is considered to be uniform rather than the 80%-day/20%-night that was estimated for trucks; and
- the attenuation with distance doubling is 6 dB for the rail point source rather than the 4.5 dB used for the highway noise line-source.

As with the truck impact case, rail traffic in Northern Ontario would impact fewer people than the remainder of the rail network. The U.S. mainlines and the Canadian mainline corridor, running east from Windsor and Sarnia, are the lines where a noise impact is most relevant. The frequency of occurrence of grade crossings on these lines was estimated to be one every 1.69 kilometers (1.05 miles), based on the sample of CSX Transportation (CSXT) and Norfolk Southern Railway (NS) mainlines as discussed in Section 8.3. The average baseline freight traffic is considered to be 28 trains per day and the incremental Great Lakes-Seaway traffic is estimated to be 29 trains per day. On this basis, the base and incremental severe noise footprints are as follows:

- The "Severe-Impact" area due to a train horn extends from the +/-33 meter buffer zone to +/- 295 meter noise-boundary measured laterally from the tracks, and occurring for a length of 900 meters along the tracks at each public grade crossing (at an occurrence interval of 1.69 kilometers).
- The "Severe-Impact" boundary associated with the train's movement is +/- 147 meters from the tracks and is continuous along the tracks.
- Adding 29 trains per day to the existing traffic of 28 trains per day increases the severe noise boundary to +/- 390 meters for the horn and +/- 202 meters due to movement. The marginal impact is a 36% increase in severe noise exposure due to horns (390-33)/(295-33) and a 48% increase due to movement (202-33)/(147-33).

The total rail activity associated with carrying the Great Lakes-Seaway cargo by rail was estimated in Section 7.3.3 to be 29 trains per day, traveling an average of 1,095 kilometers on 4 different railway-line segments. The total footprint from the existing 28 trains per day would be 1,687 square kilometers and the marginal increase from an additional 29 trains per day would be 667 square kilometers (see Table 26).

Table 26. Rail Noise Footprint for Base and Incremental Great Lakes-Seaway Traffic

Rail	Base Footprint		Marginal Footprint With Great Lakes-Seaway Cargo	
	(km^2)	*(mi^2)*	*(km^2)*	*(mi^2)*
Total Footprint	1,687	650	667	257

km^2 = square kilometers.
mi^2 = square miles.

Source: RTG analysis.

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[8] The FRA's spreadsheet horn model is available at https://www.fra.dot.gov/Pages/254.shtml (2012).

10.5 Marine Mode's Noise Footprint

The noise footprint of the fleets operating in the Great Lakes-Seaway System is associated with the sounding of horns when vessels meet, and when mooring lines are dropped in preparation for departure from ports and locks. The marine horn is about 6 dB louder than a railway horn — the two are similar in SPL capability but locomotive horns are restricted in SPL due to community noise concerns. The marine horn also has a lower characteristic frequency/tone. The analysis of the noise impact is undertaken in the same way as the locomotive horn event, except that the sound patterns are different. On meeting, each vessel sounds two short blasts of the horn — which was modeled as 2 seconds each for a total duration of 8 seconds per meet. Upon dropping lines, a vessel makes one short sounding of the horn, which was modeled as a 2-second event. Mooring lines are dropped at the same location by all departing vessels and the impact analysis follows the same procedure as was applied to train horns at crossings. Meets of vessels can occur at any location in the system and noise disturbance is tied to the frequency of occurrence of a noise event at a specific location. Thus, the frequency of vessel meets occurring in any specific location needs to be assessed. Only meets of vessels in river segments are close enough to residential areas to have a noise impact, so the noise impact assessment was only conducted for river segments.

Rivers were divided into 1.69 kilometer-long segments to match the railway grade-crossing spacing, and the number of meets at a specific location was calculated on the basis of uniform probability of occurrence anywhere in river segment. The number of noise events in a given 1.69 kilometer segment are treated as equivalent trains per day and the Ldn severe noise impact boundary is calculated in the same way as a train horn event.

The results are summarized in Table 27 for each river in the Great Lakes-Seaway System. The second-last column of the table indicates the average number of horn sequences per day expected to occur due to cargo vessels meeting in the river. The last column indicates the number of events that can be expected to occur on average within any 1.69 kilometer segment of the river (i.e., the equivalent trains per day). The highest impact area is the St. Mary's River — at an occurrence frequency of 0.88 events/day/segment (equivalent to 0.88 trains per day). The Severe Noise boundary for one horn-sequence event per day is +/- 85 meters from the vessel. All river widths encountered are greater than 170 meters wide (the minimum width of the St. Mary's River is 610 meters and the minimum width of the Detroit River is 580 meters). St. Catharines, Ontario by the Welland Canal is the only community close to a vessel and at only 0.49 events/day/segment, it is still beyond the associated severe Ldn boundary of 64 meters. Thus, the severe noise impact boundary is within the buffer-zone for all river segments in the Great Lakes-Seaway System and the severe noise impact from meets is zero.

Table 27. Calculation of Air Horn Alerts for Vessel Meets in River Sections

Segment	Vessels per day each way	Trip Time (hr)	Expected Meets per Vessel	Horn Sequences per day	Sequences per day per 1.69-km-segment*
MLO	3.6	31.2	9.2	25.3	0.15
Welland	4.0	12.2	4.1	16.5	0.49
Detroit/St. Clair	6.2	10.3	5.3	33.0	0.56
St Mary's River	7.4	9.8	6.0	44.5	0.88

* Based on equal probability of occurrence in any 1.69 kilometer segment along the river.

Source: RTG analysis.

Every vessel going through the locks on the MLO and the Welland Canal, and at the Soo locks, will sound the horn upon dropping lines for departure. The footprint of these occurrences is calculated as the area of a circle less a +/- 30 meter-wide strip along the water. The results are summarized in Table 28. While the Soo locks have the highest traffic level and the largest severe noise boundary, they have only one lock segment and thus, a lower total footprint than the MLO and Welland sections, which have 7 and 8 lock segments respectively.

In total, the severe noise footprint of the fleets operating in the Great Lakes-Seaway System is estimated to be 1.91 square kilometers (0.74 square miles).

Table 28. Marine Noise Footprint due to Mooring Lines Release at Locks

Segment	Locks encountered in each direction	Number of events/lock/day	Severe noise boundary (m)	Exposure area/lock (m^2)	Total area (km^2)
MLO	7	7.1	197	0.11	0.77
Welland	8	8.1	205	0.12	0.96
Detroit/St. Clair	0	12.4	0	0	0
St Mary's River	1	14.7	250	0.18	0.18
Total					1.91

m = meters / m^2 = square meters / km^2 = square kilometers.

Source: RTG analysis.

10.6 Noise comparison Results

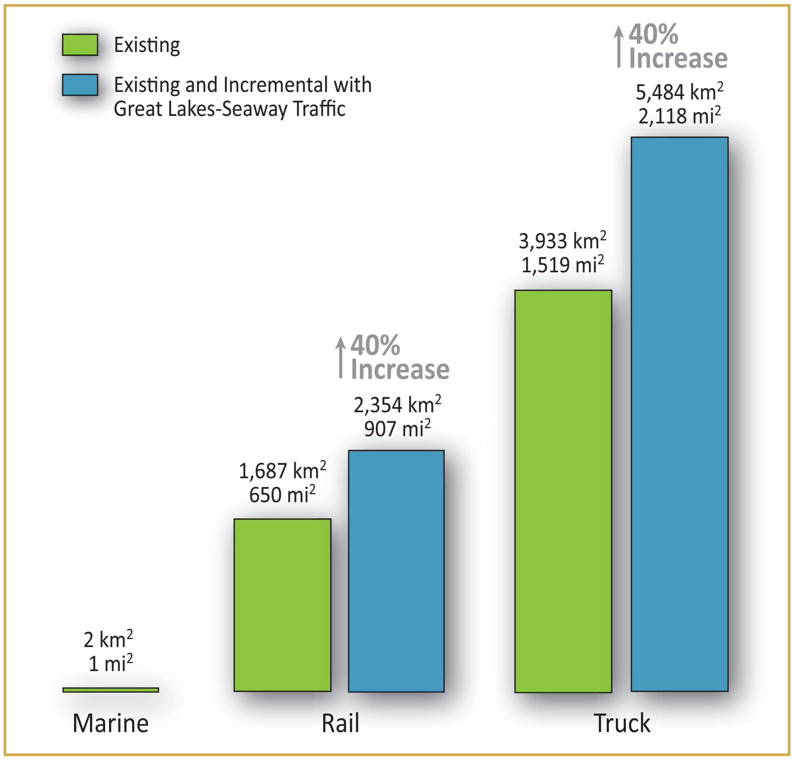
The noise footprints of the three modes as developed in the three previous subsections are summarized in Table 29 and illustrated in Figure 20.

Table 29. Noise Footprint for All Modes – Existing and Incremental Transporting Great Lakes Cargo Volume

Severe Ldn Footprint (square kilometers)				
	Existing Footprint	*Incremental with Great Lakes Cargo*	*Total*	*% Change*
Marine	2	–	2	–
Rail	1,687	667	2,354	+ 39.5%
Truck	3,933	1551	5,484	+ 39.4%
Severe Ldn Footprint (square miles)				
Marine	1	–	1	–
Rail	650	257	907	+39.5%
Truck	1,519	599	2,118	+ 39.4%

Source: RTG analysis.

Figure 20. Severe Noise Footprints



Severe Ldn Footprint (square kilometers) / Severe Ldn Footprint (square miles).

Source: RTG analysis.

10.7 Noise Impact Conclusion

Noise footprints for the three modes were developed on the basis of noise emitted during line-haul activity for each of the three modes. Noise emitted from loading/unloading activities was not included for any mode. Noise from trucks and trains at rail terminals and yards was also not considered. Noise emitted by vessels while at ports included the sounding of the air horn but not noise from loading/unloading activity.

On the basis of the analysis undertaken, we conclude that the noise footprint of the fleets operating in the Great Lakes-Seaway System is negligible in comparison with that of the other modes.

The analysis shows that the noise footprint for the rail and truck modes would increase by 40% if either mode were to transport the Great Lakes cargo volume currently handled by the marine mode.

11

Conclusions

11.1 Energy Efficiency and Emissions Intensity

The marine mode is the most efficient of the three modes and marine's efficiency relative to the two ground modes will increase in the future. A post-renewal scenario was developed for each mode, in recognition of the changes in emissions regulations and opportunities for economical advancements of propulsion technology and/or operational procedures. The truck mode was the focus of early regulatory standards and no further changes to the 2010 Criteria Air Contaminant (CAC) regulations have been identified. The truck is the only mode to have regulatory standards for Greenhouse Gas (GHG) emissions, requiring the use of fuel-saving technologies by highway tractor manufacturers over the 2014-2019 timeframe. The long-haul truck fleet is renewed more frequently than the other modes, so regulatory changes work into the system performance quite quickly.

The rail mode was the second focus of CAC regulatory standards and partial advances were in place by 2010. Additional reductions of hydrocarbon (HC) emissions, nitrogen oxides (NO_X), particulate matter (PM) and sulfur dioxide (SO_2) are required by 2015. Rail has been renewing its long-haul fleet, while its yard-switching fleet remains quite old. We see continued operational and equipment advances for rail but have not assumed any significant improvement in economically viable locomotive efficiency beyond the 2010 technology.

The marine mode has been the last mode to see CAC emissions regulations and all will take effect over the 2012-2025 timeframe. The regulations will require significant reductions of NO_X and SO_2, and the reductions of SO_2 will produce reductions in PM. The marine fleet is also the oldest of the three modes. The delay in renewal of the marine fleet has been influenced by the 25% duty on new ships in Canada and the *Jones' Act* restrictions on foreign-built vessels for U.S. operators. The repeal of the Canadian import duty and the introduction of the EPA assistance program for new power plants on existing U.S. vessels are stimulating fleet and power plant renewal that significantly improves the efficiency of both fleets.

As a consequence of the above factors, marine will see a much more dramatic improvement in the future than the two ground modes. Post renewal of all modes, the Seaway-size Fleet will be 74% more fuel-efficient than rail and 704% more efficient than truck. Similarly, the U.S. Fleet will be 53% more fuel-efficient than rail and 754% more efficient than truck.

The marine mode is already the lowest GHG emitter of the three modes and marine's performance relative to the two ground modes will improve in the future. In terms of incremental GHG emissions post renewal of all modes: the rail mode would produce 72% higher GHG emissions, and the truck mode 612% higher GHG emissions, than the Seaway-size Fleet in carrying a tonne of cargo one kilometer. Similarly, the rail mode would produce 57% higher GHG emissions, and the truck mode 698% higher GHG emissions, than the U.S. Fleet in carrying a ton of cargo one mile.

The marine mode was not the lowest CAC emitter in 2010. Of the three CACs of primary interest (NO_X, SO_X and PM): the U.S. Fleet was the lowest emitter of NO_X, while the Seaway-size Fleet was second to Rail; and both fleets were the highest emitters of SO_X and PM. Post renewal of all modes, marine will be the lowest emitter of NO_X and SO_X and will be second to rail in PM emissions.

We note that marine's CAC emissions when on open water are comprised of emissions from propulsion engines and auxiliary engines, while emissions when docked at port are only from auxiliary engines. CAC emissions consequences are dependent on the source location relative to areas of air quality concern. Marine's CAC emissions on open water (as well as at many ports in remote areas) will have significantly different consequences than emissions at ports located in urban areas. Similarly, CAC emissions from the ground modes while traveling through remote areas will have significantly different consequences than their emissions when traveling through urban areas. The consequences of each mode's CAC emissions relative to each other, and the relative consequences of transportation's emissions relative to fixed plant emissions are beyond the scope of this assignment. We believe that such a comparative evaluation would be in favor of the marine mode and recommend that such a comparative analysis be undertaken.

11.2 Congestion Impacts

We conclude that marine has a negligible impact on congestion delays for the traveling public. We also conclude that a shift of Great Lakes-Seaway traffic to the highway or rail modes would lead to increased congestion delays for the traveling public. We have attempted to quantify the costs of the delay impacts but note that the impacts would be highly sensitive to the specific cargo movements that shifted and to the value of time assumed for those delayed.

In our base case, the estimated cost of incremental urban congestion associated with shifting Great Lakes-Seaway marine traffic to trucks was in the range of $346 million to $380 million per year. The estimated cost of incremental delays at highway-railway grade crossings associated with shifting Great Lakes-Seaway marine traffic to rail was $46 million per year.

11.3 Maintenance Impacts

We conclude that a shift of Great Lakes-Seaway traffic from marine to truck would lead to a significant increase in highway maintenance costs (estimated to be $4.6 billion). However, we also note that some proportion of incremental fuel-tax revenues derived from the new truck activity would mitigate the incremental maintenance and other social costs. A full social cost and revenue analysis of the modes was beyond the scope of this assignment.

11.4 Noise Impacts

Noise footprints for the three modes were developed on the basis of noise emitted during line-haul activity for each of the three modes. Noise emitted from loading/unloading activities was not included for any mode. Noise from trucks and trains at rail terminals and yards was also not considered. Noise emitted by vessels while at ports included the sounding of the air horn but not noise from loading/unloading activity.

On the basis of the analysis undertaken, we conclude that the noise footprint of the Great Lakes-Seaway Fleet is negligible in comparison with that of the other modes.

The analysis shows that the noise footprint for the rail and truck modes would increase by 40% if either mode were to transport the Great Lakes cargo volume currently handled by the marine mode.

Appendix A

Acronyms and Definitions

List of Acronyms

AADT	Average annual daily traffic
AADTT	Average annual daily truck traffic
AASHTO	American Association of State Highway and Transportation Officials
CAC	Criteria Air Contaminant
CAN	Canada
Cd	Drag coefficient
CdA	The product of Cd and the Area (the ‘drag-area’)
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent global warming of Greenhouse Gases
COFC	Container on flat car
CTK/L	Cargo-tonne-kilometers per liter of fuel
CTM/US-Gal	Cargo-ton-miles per U.S. gallon of fuel
CTSB	Canadian Transportation Safety Board
dB	Decibel
dg	Dangerous goods
DOT	U.S. Department of Transportation
EC	Environment Canada
ECA	Emissions Control Area
EEDI	Energy Efficient Design Index
EPA	U.S. Environmental Protection Agency
ESAL	Equivalent single axle loads
FAF	Freight Analysis Framework
FMCSA	Federal Motor Carrier Safety Administration

FRA	Federal Railroad Administration
g	Gram
GETS	GE Transportation
GHG	Greenhouse Gas
GVW	Gross vehicle weight
hazmat	Hazardous materials
HC	Hydrocarbons
HCM	Highway Capacity Manual
HDDT	Heavy Duty Diesel Truck
HD-TEEM	Heavy duty truck energy and emissions model
hp	Horsepower
HPMS	Highway Performance Monitoring System
IFO	Intermediate fuel oil
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
Ldn	Time-of-day weighted sound level ($\text{Level}_{\text{day-night}}$)
LEM	Locomotive Emissions Monitoring reports of the RAC
Leq	Equivalent Sound Exposure Level of all noise over a defined duration
LH	Line haul
LOS	Level of service
m	Meter
MDO	Marine diesel oil
MEIT	Marine emissions inventory tool
mg	Milligram
MGT	Millions of gross tons
MLO	Montreal-Lake Ontario
MSD	Medium speed diesel engine
mt	Metric ton or tonne of 2,204 pounds
MTO	Ministry of Transportation of Ontario
MTQ	Ministère des Transports du Québec
N	Newtons
N_2O	Nitrous oxide
NMDC	Non-methane hydrocarbons

NO_X	Nitrogen Oxides
NTAD	National Transportation Atlas Database
OD	Origin-destination
ORNL	Oak Ridge National Laboratory
PCE	Passenger car equivalent
PM	Particulate Matter
PV	Present value
RAC	Railway Association of Canada
RFO	Residual fuel oil
RTG	Research and Traffic Group
SCR	Selective catalytic reactors
SEL	Sound Exposure Level
SLSDC	St. Lawrence Seaway Development Corporation
SLSMC	St. Lawrence Seaway Management Corporation
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
SPL	Sound pressure level
SSD	Slow speed diesel engines
STB	Surface Transportation Board
SU	Self-unloader
T	Net ton of 2,000 pounds
TC	Transport Canada
TOFC	Trailer on flat car
U.S.	United States
USACE	U.S. Army Corp of Engineers
USCG	U.S. Coast Guard
VKT	Vehicle-kilometers travelled
VMT	Vehicle-miles travelled

Definitions

Terminology	*Definition*
Ship's Ballast	A condition where a ship has no cargo and takes on enough "ballast" water to be able to submerge the propeller and safely maneuver.
Ballast Ratio	Ratio of travel distance with ballast over travel distance laden with cargo.
Cabotage Laws	Laws a country may impose to restrict domestic trade to domestic transportation firms.
Duty Cycle	A term used to describe the distribution of proportional times an engine spends at different power levels when performing a representative service. Thus, one engine can have several duty cycles depending on its intended service.
Lower St. Lawrence River	That part of the St. Lawrence River below (or east of) Montreal.
Poe-max	Maximum-sized vessel that can transit the Poe lock between Lake Superior and Lake Huron.
Seaway	The series of locks and channels on the Welland Canal between Lake Erie and Lake Ontario and on the St. Lawrence River between Montreal and Lake Ontario (MLO).
Seaway-max	Maximum-sized vessel that can transit the Seaway System.
Seaway-size Fleet	Defined for use in this study as those Canadian and international vessels that transit the Seaway system and/or operate on the Great Lakes.
Upper Great Lakes	Those lakes above (or west of) the Welland Canal (i.e. Lakes Erie, Huron, Michigan and Superior).
U.S. Fleet	Defined for use in this study as those U.S. vessels that operate on the Great Lakes (mostly sized for the Upper Great Lakes but including those that can transit the Seaway system).

Appendix B

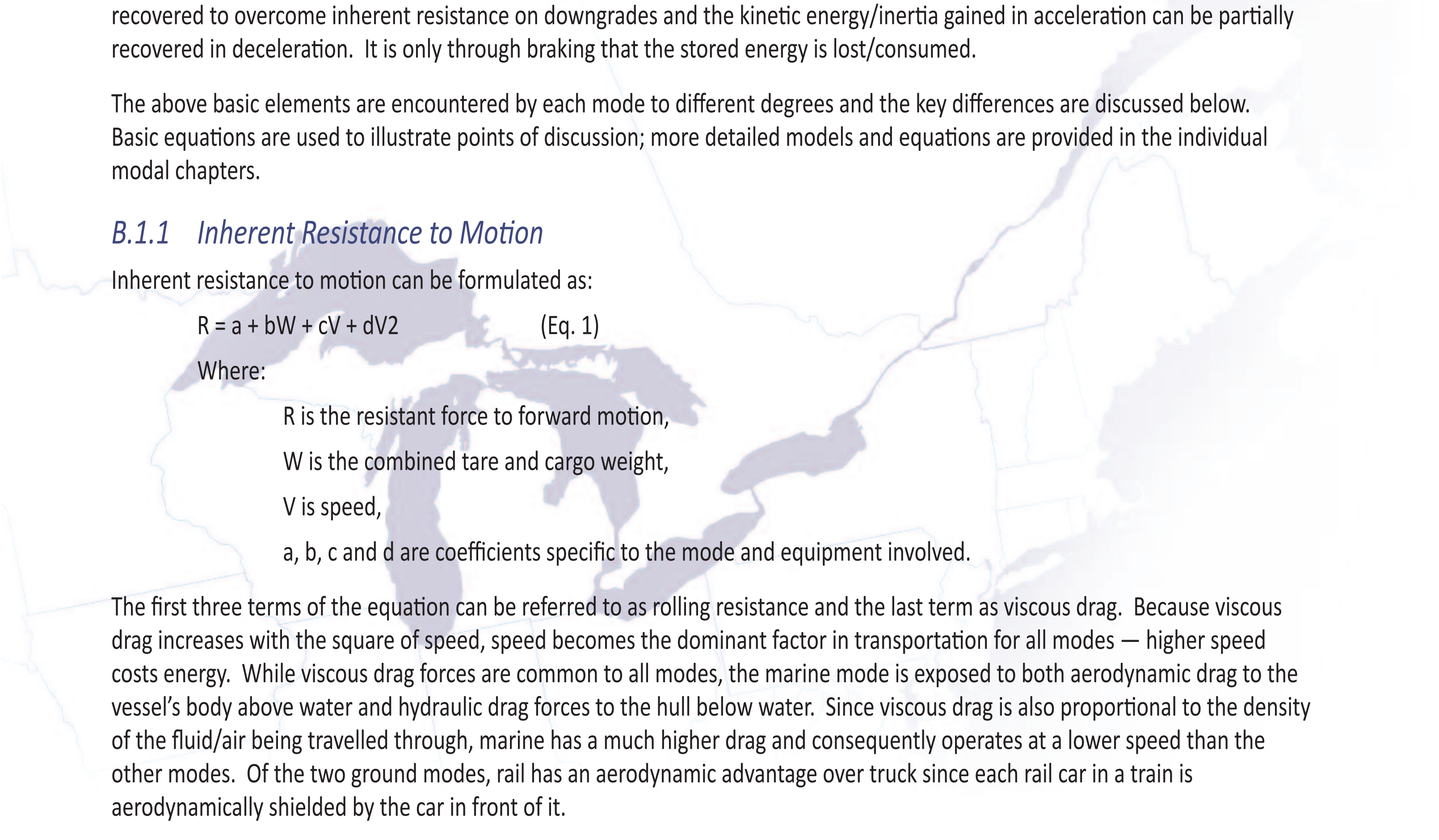
Air Emissions Modeling Details

B.1 Transportation Propulsion Modeling

Each mode has unique characteristics, but all modes of transport follow the same basic laws of physics and involve similar calculation procedures to derive power and energy required for propulsion. The fuel consumption and associated emissions of Greenhouse Gases (GHGs) and Criteria Air Contaminants (CACs) are also similar calculations for each mode.

All modes require power and consume energy to overcome inherent resistance to motion. This resistance to motion involves two main components: viscous drag (which is common to all modes) and rolling resistance (which is applicable to the ground modes). In addition to overcoming inherent resistance, power is required to accelerate the mass of the vehicle and the load it is carrying to a desired speed, and also to climb uphill grades encountered. These two additional power requirements do not directly translate into energy as they are essentially stored energy. The potential energy gained in climbing grades can be partially or fully recovered to overcome inherent resistance on downgrades and the kinetic energy/inertia gained in acceleration can be partially recovered in deceleration. It is only through braking that the stored energy is lost/consumed.

The above basic elements are encountered by each mode to different degrees and the key differences are discussed below. Basic equations are used to illustrate points of discussion; more detailed models and equations are provided in the individual modal chapters.



B.1.1 Inherent Resistance to Motion

Inherent resistance to motion can be formulated as:

$R = a + bW + cV + dV2$ (Eq. 1)

Where:

R is the resistant force to forward motion,

W is the combined tare and cargo weight,

V is speed,

a, b, c and d are coefficients specific to the mode and equipment involved.

The first three terms of the equation can be referred to as rolling resistance and the last term as viscous drag. Because viscous drag increases with the square of speed, speed becomes the dominant factor in transportation for all modes — higher speed costs energy. While viscous drag forces are common to all modes, the marine mode is exposed to both aerodynamic drag to the vessel's body above water and hydraulic drag forces to the hull below water. Since viscous drag is also proportional to the density of the fluid/air being travelled through, marine has a much higher drag and consequently operates at a lower speed than the other modes. Of the two ground modes, rail has an aerodynamic advantage over truck since each rail car in a train is aerodynamically shielded by the car in front of it.

To determine the power required at any speed, Equation-1 is multiplied by speed; thus, the power to overcome viscous drag increases in proportion to the cube of speed. The power required is important because more power means bigger engines and more tare (unladen) weight to be carried in transport. This in turn leads to trade-offs in engine selection. Engine weight can be reduced by using higher-speed engines, but the higher speed leads to more friction losses in the engine and higher transmission losses. Of the three modes, marine uses efficient low-speed engines in direct drive to the propeller. Rail with additional rolling resistance and higher operating speeds uses medium-speed diesel engines and an electric transmission. Trucks with much higher rolling resistance than rail (due to rubber tires on asphalt compared with steel wheel on steel rail), higher aerodynamic drag and higher operating speeds use high-speed diesel engines and mechanical transmissions.

B.1.2 Stored Energy Components

The role of stored energy components (potential energy in grade climbing and kinetic energy through acceleration) has significant differences across the modes. Marine is only affected by grades when operating in river sections and in tidal current areas, and shows up in a reduced/increased land-speed, in comparison with its water speed. The major lifts encountered at locks are achieved via gravity feed of water into lock compartments; the actual operating energy of lock gates is considered to be a negligible component. When operating in open water, the difference between water speed and land speed is negligible. For the Great Lakes-Seaway region, the other influences of grade are the delays encountered at the locks and operation at a lower efficiency point in the propulsion system passing through them. Rail is the mode most affected by grades — because rail has a much lower rolling resistance than trucks, trains use braking on downgrades, where trucks are recovering energy to overcome truck's higher inherent resistance to motion. Grades also influence the routing of railway tracks such that they tend to avoid grades, going around them, where a highway would tend to go over them (as rubber tires provide greater grade-climbing abilities). Railway tracks often follow along river banks and involve many more curves in the avoidance of grades. The more frequent curves lead directly to additional friction forces and energy dissipation in transiting the curves; however, there is also an indirect effect in requiring many more speed reductions to negotiate the curves.

While the rail mode has a significant advantage over trucks in being able to couple cars into long trains, the much reduced number of trains involved means that many rail routes are single-track lines that require one train to make a full stop and wait in a siding when a meet or overtake occurs with another train. These speed reductions, as with downgrades, are attained with loss of stored energy in the use of brakes. Another influence of these wide speed variations and more frequent stops is that the average performance velocity of trains is not an accurate reflection of the speeds to be used in calculating the aerodynamic drag forces.

Speed reductions are a major factor in local truck transport, but a much smaller influence in long-haul transport. Trucks encounter speed reductions due to traffic congestion and are often forced to use brakes — whether the driver wants to or not. Also, truck drivers are required to make stops for rest breaks and to refuel. A major factor in truck transport is the abilities of the driver in making speed changes. Because trucks use a mechanical transmission and drivers select the gear, the biggest influence of terrain and speed profile changes is non-optimal gear choices. The other two modes have a significant advantage over trucks in this respect. Marine vessels operate at a fixed speed for most of the journey and that speed is selected to coincide with the most efficient operating point for the propulsion engine. Locomotive engines have a predefined set of operating points which, although not always at the minimum fuel consumption point of the engine, are at the minimum available for the power being demanded by the operator. Truck drivers determine the engine's operating point by the gears they select and because trucks have a much higher power-to-weight ratio to attain speeds of automobile traffic on most grades, the average engine operating point of trucks is always farther away from the minimum brake specific fuel consumption (bsfc) point of the engine than either rail or marine modes. Driver performance can make this inherent disadvantage even worse; early studies have identified driver performance as the most significant factor to be addressed in improving truck fuel efficiency, with best to worst driver comparisons of up to 35% fuel increase [Bridgestone Tire, undated].

Even though marine vessels have a very large mass, the low characteristic speed and high characteristic viscous drag force mean that braking (i.e. propeller reversal) is seldom used in normal operations. Speed reduction is achieved via power reduction and “coasting” to a desired reduced speed. Only the final leg of a trip at port arrival requires the use of additional thrusters (or separate tug boats, in some cases) to manoeuvre into a dock.

B.1.3 Illustration of Modal Propulsion Differences

The consequences of the above-described factors are best illustrated in a comparison of propulsion requirements of the three modes in their characteristic operating speed range. Because the carrying capacity of the three modes varies significantly, it is best to normalize the power requirements by the unit transport size characteristic of each mode. The normalized comparison is made on a kW/net-tonnes-carried (hp/net-ton-carried) basis. Figure B-1 compares the propulsion-power-performance characteristic of the three modes; while Table B-1 summarizes the main assumptions in the comparison.

Figure B-1. Modal Propulsion Intensity Comparison for Grain Transport

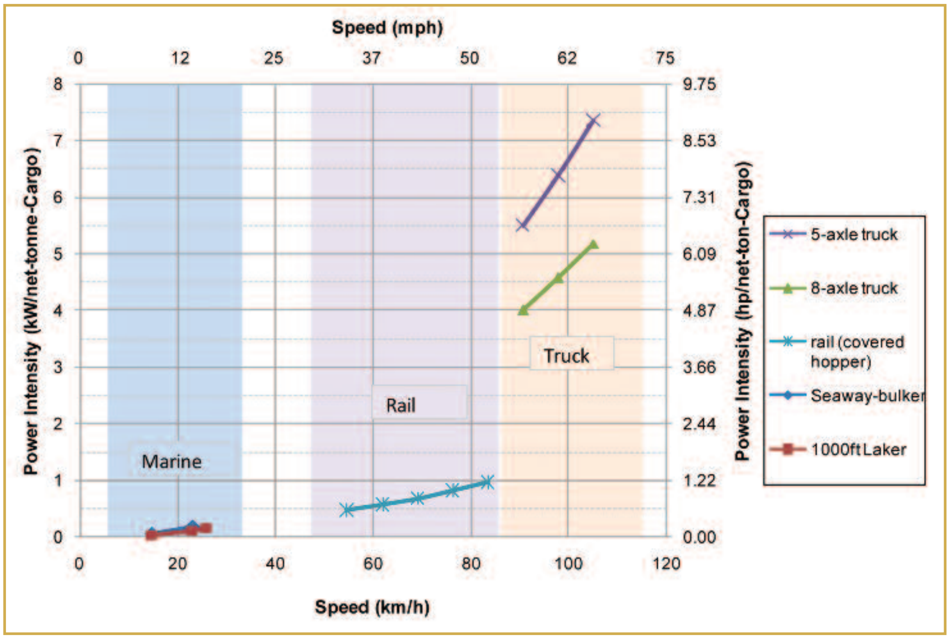


Table B-1. Modal Characteristics for the Propulsion Power Intensity Comparison

Mode		Marine		Rail	Truck	
Equipment		***1,000 ft. Laker***	***Seaway-bulker***	***Covered Hopper 90 cars/train 2 locomotives/train***	***8-axle (2 trailers)***	***5-axle (1 trailer)***
Cargo	Tonnes	56,364	28,000	7,721	44.0	22.7
Weight	Tons	62,000	30,800	8,493	48.4	25.0

B.1.4 Non-Propulsion Aspects

In addition to the above propulsion requirements, energy is consumed in auxiliary services, such as engine cooling, maintaining comfortable crew compartments and some modal-specific requirements (such as ballast water pumping for marine and electric traction motor cooling for rail). The final component of auxiliary energy consumption is the loading and unloading of the cargo being carried.

Energy consumption in auxiliary services has been a focus of energy savings for all modes. Truck and rail have seen improvements in this area for large portions of the active fleets. The marine fleets operating in the Great Lakes-Seaway System have not had the same level of fleet turnover but new vessels with improved auxiliaries (as well as other efficiency advances) have been ordered by Canadian carriers, and carriers on both sides of the border have been assessing areas of efficiency improvement and/or renewal of power plants on existing vessels.

Comparison of fuel consumption associated with auxiliary loads is a more difficult task than for propulsion aspects. Hotel power is a constant requirement for marine (both while underway and while at port) since crews live on board the vessel. Long-haul truck drivers often have sleeper cabs with heating and air conditioning, but meals and occasional overnight-stays involve ground facilities (hotels, or bunk stops). Railways also use hotels and bunk houses at some crew stops, and on lower-density lines use taxis to return crew to home stations. Hotel power is automatically included in the marine fuel consumption and to the extent it is provided by truck engines, it exists in truck fuel use. The energy consumption for those parts of the crew accommodation that are not met with onboard power for truck and for rail should be included in a like-for-like comparison; however, the assumptions and estimates involved are much less reliable than those made for the propulsion aspects.

Similarly, self-unloading vessels consume fuel to move materials from ship to shore. In some cases, the other modes use a gravity discharge, and the extra fuel required by marine is a true reflection of modal differences. In other cases (e.g. rotary dumping of rail cars by a wayside powered facility), the operation of wayside facilities and equipment would ideally be included in a like-for-like comparison. There are also cases where marine involves transfers from another mode at one or both ports, in which case the use of the alternate mode for the full trip would avoid the energy consumed in loading and/or unloading marine vessels. These aspects are only dealt with superficially in the generic comparison of overall performance in the Great Lakes-Seaway region. The case-study routes selected for more detailed comparison on a route-specific basis address these aspects in more detail.

Hotel services and auxiliary loads are a higher component of onboard fuel consumption for marine and in most cases involve the use of different fuel. Thus, it is much easier to separately account for hotel power and propulsion power. This separation is important because the fuel used at port is only for hotel and auxiliaries; the main propulsion engines are shut down. The fuel used at port is a smaller portion of overall vessel fuel consumption and is also a cleaner fuel than the intermediate fuel oil (IFO) that many vessels use as fuel in propulsion engines. While hotel power is required at all times, we segment the portion used while at port and reduce it by 10% — in recognition of the wayside energy consumed for hotel purposes by the two ground modes.

For trucks and freight locomotives, auxiliary loads are met by the prime engine and in some cases by smaller auxiliary power units that allow the main engine to be stopped during periods of extended idle. The fuel for auxiliary loads is not differentiated in the fuel statistics but can be estimated and modeled.

B.2 Air Emissions Definitions

B.2.1 Greenhouse Gas (GHG) Emissions

The effects of Greenhouse Gas (GHG) emissions are global and thus, the location of the emissions is not important in determining their impact. GHG emissions involve different weightings of several products of combustion (and incomplete combustion). Carbon dioxide (CO_2) is the largest component for all fuels/engines. Methane (CH_4) and nitrous oxide (N_2O) have proportionately higher impacts as GHG gases but are emitted in relatively low quantities. Their higher impacts are reflected with multipliers of 21 and 310 for CH_4 and N_2O respectively when aggregated as CO_2–equivalents (CO_2-e).

The above relative weightings are recommended by the Intergovernmental Panel on Climate Change (IPCC) and are common to all modes. However, the actual quantity of each of the GHG components varies with the specific type of fuel and engine technology used. The most recent data used in Canada came from Environment Canada's *National Inventory Reports* submitted to the United Nations Framework Convention on Climate Change. For consistency across modes, the mode-specific data in that report will be used in this study for each mode. We note that the values used in that report are the same as those used in the 2010 application of the marine emissions inventory tool (MEIT) model to the Great Lakes-Seaway region. The Canadian carriers provided this study with the same data being used in that inventory-model application. Those data are used to develop the CAC and GHG intensities by fuel type.

B.2.2 Criteria Air Contaminant (CAC) Emissions

Criteria Air Contaminant (CAC) emissions include: all oxides of nitrogen (NO_X), particulate matter smaller in size than 2.5 micro-metres or microns ($PM_{2.5}$), carbon monoxide (CO), sulfur oxides (predominantly SO_2),[1] and volatile organic compounds/hydrocarbons (VOCs/HC). Recent regulations have defined the emissions of hydrocarbons (HC) to consider only non-methane hydrocarbons (NMHC). Sulfur oxides are being addressed via fuel regulations, while all other CACs are addressed with engine regulations. The focus of regulatory initiatives has been on NO_X emissions and PM. Thus, much of the data on expected technology improvements is focused on NO_X and PM, with less information on other CAC emissions.

The effects of Criteria Air Contaminants (CACs) are local and thus, the location of the emissions is important in determining the impact. In addition, the generation of ground-level ozone (smog), which is the principal impact of NO_X emissions, is a photochemical process that requires sunlight and warm temperatures. Thus, it is a seasonal phenomenon. The level of hazard is tied to the consequences of the emissions, which are related to the number of people exposed to the emissions. Since large urban areas produce the density of emissions (from vehicle and stationary sources) to generate ground-level ozone in the summer and also have the population density to achieve a high exposure rate, CAC emissions are most acute in urban areas during the summer.

B.3 Rail Mode Air Emissions Characterization

B.3.1 Canadian and U.S. Similarities

Canadian and U.S. railways use locomotives from the same suppliers. The regulations enacted by the U.S. Environmental Protection Agency (EPA) for new locomotive equipment are applied to locomotives sold on both sides of the border — the Memorandum of Understanding between the Railway Association of Canada (RAC) and Government of Canada for 2006-15 includes commitment by Class I railways to purchase only locomotives meeting U.S. EPA standards.[2] The first U.S. locomotive emission standards were established through legislation signed on 17 December 1997 and became effective in 2000. That legislation defined three sets of emission levels (Tiers 0, 1 and 2). The three Tier levels relate to the date of original manufacture of the locomotives and must be met at any time the locomotive engine is subsequently remanufactured — replacement of cylinders and pistons at about 750,000 miles would constitute a “remanufacture”. The Tier 0 standards apply to locomotives manufactured between 1973 and 2001; Tier 1 standards apply to locomotives newly manufactured between 2002 and 2004; and the Tier 2 standards apply to locomotives newly manufactured in 2005 or later. Table B-2 and Table B-3 summarize the emission standards for line-haul and switching operations, respectively, as established by the U.S. EPA’s 1997 rule.

Table B-2. U.S. Environmental Protection Agency Tier 0–2 Line-haul Locomotive Emission Standards (1997 Rule)

Tier	Year Manufactured	Effective Date	HC g/bhp-hr*	CO g/bhp-hr*	NO_X g/bhp-hr*	PM g/bhp-hr*
Tier 0	1973 – 2001	2000	1.0	5.0	9.5	0.6
Tier 1	2002 – 2004	2000	0.55	2.2	7.4	0.45
Tier 2	2005 and later	2000	0.3	1.5	5.5	0.2

* g/bhp-hr = grams of emission per brake horsepower-hour

Source: Derived from data in LEM-2008 [RAC, 2010].

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[1] Sulfur oxides are being addressed via fuel regulations rather than engine regulations.

[2] http://www.ec.gc.ca/epe-epa/08C5701C-7847-4BC7-B406-185628230D44/LocomotiveEMissions_ProposedAgreement_EN.pdf

Table B-3. U.S. Environmental Protection Agency Tier 0–2 Switch Locomotive Emission Standards (1997 Rule)

Tier	Year Manufactured	Effective Date	HC g/bhp-hr*	CO g/bhp-hr*	NO_X g/bhp-hr*	PM g/bhp-hr*
Tier 0	1973 – 2001	2000	2.1	8.0	14.0	0.72
Tier 1	2002 – 2004	2000	1.2	2.5	11.0	0.54
Tier 2	2005 and later	2000	0.6	2.4	8.1	0.24

* g/bhp-hr = grams of emission per brake horsepower-hour

Source: Derived from data in LEM-2008 [RAC, 2010].

The main differences between U.S. and Canadian locomotive emissions intensity are the relative distribution of newer locomotives in the fleet and the proportion of older locomotives that have been upgraded to Tier 0 levels. The next two subsections develop the relevant fleet characteristics for the Canadian railways (Subsection B.3.2) and the U.S. railways (Subsection B.3.3) operating in the Great Lakes-Seaway region, and the related average emissions intensity for 2010. The overall emissions intensity on a cargo-carried basis is affected by the distribution of cargo types, as well as the severity of the terrain over which it is carried. In Subsection B.3.4, we estimate cargo-specific emissions intensity applicable to both Canadian and U.S. railways in the Great Lakes-Seaway region for the year 2010. The EPA's locomotive regulations were updated in 2008 for application to 2010 and later for rebuilds, and in 2011 and later years for newly built locomotives. We discuss the influence of these regulations in Subsection B.3.5 dealing with 2015 technology.

B.3.2 Canadian Class 1 Great Lakes-Seaway Region Average Characteristics (2010)

The Railway Association of Canada (RAC) reports annual air emissions to Environment Canada under the terms of its Locomotive Emissions Monitoring (LEM) agreement. The last LEM report available at the beginning of our analysis was for 2008 [RAC, 2009]. However, LEM 2009 was issued midway through the study — with some numbers in the LEM-2008 changing and some staying the same. We have updated data to the LEM-2009, where we believed it was appropriate, and have explained our use of LEM-2008 where it was retained. LEM-2008 made a number of updates to the locomotive duty cycle and to the GHG intensity numbers used in the LEM accounting practices, and these have remained the same in LEM 2009.

Table B-4 summarizes the distribution of locomotives in each EPA tier group for the Class 1 freight railways — CN and Canadian Pacific (CP) — which are the main operators in the Great Lakes-Seaway region. While CN and CP have purchased additional Tier-2 locomotives since 2008, both railways tend to assign the newest locomotives in their fleet to western unit train and intermodal operations. We believe that the 2008 locomotive distribution is a conservative estimate of the types of locomotives that would have been operating in the Great Lakes-Seaway region in 2010 and therefore, we have not updated the locomotive distribution reported in the 2008 LEM report. No switch locomotives had been converted to Tier 0 and only a couple of new demonstration locomotives were mentioned. The distribution shown in Table B-4 is for illustrative purposes only; the CAC emissions intensities shown in LEM-2009 are used in our analysis.

Table B-4. Canadian Class 1 Railway Line-haul Locomotive Engine Distribution by EPA Tier Level and Engine Type

EPA Tier Level	Distribution (% of total hp) by Engine-Name				
	710	*645*	*GEVO*	*7FDL*	*Total*
None	5.1%	18.9%	0.0%	6.0%	30.0%
Tier 0	14.3%	0.9%	0.0%	24.4%	39.6%
Tier 1	0.0%	0.0%	0.0%	11.4%	11.4%
Tier 2	5.8%	0.0%	13.2%	0.0%	19.0%
Total	25.2%	19.8%	13.2%	41.8%	100.0%

Source: Derived from data in LEM-2008 [RAC, 2010]; we believe the distribution for LEM-2008 is a conservative estimation of what the fleet distribution would look like in the Great Lakes-Seaway region for 2010 (see text).

Table B-5 presents some of the key operating statistics for CN and CP, as derived from data presented in Statistics Canada's *Rail in Canada* Series [Statistics Canada, 2009].

Table B-5. Key Canadian Class 1 Railway Characteristics (2009 CN and CP)

Year	Net-tonne km / litre	Net-ton-miles / US-gallon	Average Train Length (No. Cars)	Empty-miles / Loaded-miles	Average Car Load	
					Tonnes	*Tons*
Line haul only	181.1	469.6	99.6	50.0%	53.6	59.0
With yard switching allocated	177.4	460.0	N.A.	N.A.	N.A.	N.A.

Source: Derived from [Statistics Canada, Rail in Canada, 2009].

The EPA regulations for all modes are based on grams emitted per hp-hr of engine output (g/hp-hr) over a defined duty cycle — a duty cycle defines the percent time an engine spends at various power levels. Engine duty cycles are defined separately for line-haul locomotives and yard switching locomotives. The EPA's engine duty cycle for line-haul locomotives is referred to as the EPA-LH duty cycle. Emissions certification tests are run on a locomotive engine for the relevant operational service for which it is intended. The resulting certification data is quite limiting in trying to assess the emissions associated with any specific service. The EPA results are applicable only to the duty cycle involved in the regulation. A specific transport operation of interest is only represented by the EPA data to the extent that the operation of interest conforms to the EPA duty cycle. The Canadian railways raised this issue of having representative engine duty cycles in reaching its first emissions agreement with Environment Canada, and it has been recognized in that agreement and subsequent agreements with both Environment Canada and Transport Canada. As part of those agreements, the Canadian railways monitored line-haul and switch locomotives over an extended period to produce duty cycles representative of Canadian operations.[3] For this reason, the Canadian emissions intensity might be different than one would derive for U.S. railways using the EPA's regulatory duty cycle. The EPA and LEM duty cycles are compared in Table B-6. CAC emissions from a specific type of diesel engine have been shown both by railway researchers [Dunn, 2001] and truck researchers [Scora and Barth, 2006] to be proportional to the fuel consumed by the engine. Thus, CAC emissions can be derived from fuel consumption by engine type. CO_2 emissions are also directly tied to fuel consumed; however, the GHG gases N_2O and CH_4 are not tied directly to fuel consumed and are often based on an activity base (per-hour or per-km) rather than a fuel basis.

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[3] The Canadian duty cycle was updated in the (2008) LEM report and remains the same in the LEM-2010 report, which was published after our draft report was submitted.

Table B-6. Comparison of Engine Duty Cycles

Source Description	Proportion of Time at Each Engine Setting (%)										
	DB	*Idle*	*N1*	*N2*	*N3*	*N4*	*N5*	*N6*	*N7*	*N8*	*Total*
LEM-Road-Sw/Regional (2008)	2.4	77.6	4.3	4.4	2.8	2.2	1.4	1.1	0.6	3.2	100
LEM-LH (2008)	8.0	51.3	4.7	5.7	4.7	3.8	3.2	3.0	1.6	14.0	100
EPA-LH	12.5	38.0	6.5	6.5	5.2	4.4	3.8	3.9	3.0	16.2	100
LEM-SW (2008)	0.2	84.9	5.4	4.2	2.2	1.4	0.6	0.3	0.2	0.6	100
EPA-SW	0.0	59.8	12.4	12.3	5.8	3.6	3.6	1.5	0.2	0.8	100

Note: DB is dynamic Brake, N1 through N8 are discreet throttle notch settings (N8 = maximum power). Each cell indicates the percent time spent at each power setting (EPA-LH spends 16.2% of its time at maximum power N8).

Source: Derived from RAC-LEM Report for 2008 (this duty cycle is still used in the RAC's LEM-2009).

The RAC's LEM reports apply EPA certification test results for each throttle setting and apply them to the fleet, on the basis of the duty cycle they have developed. The resulting estimate of air emissions intensity (in terms of g/Litre-of-fuel) for Canadian freight railway's CACs and GHGs in 2009 is presented in Table B-7. In addition to the fuel intensity, GHG operational intensity was reported in terms of kg of CO_2-e per cargo tonne-km (CTK) and was 16.94 kg/CTK (24.72 kg/CTM) for Class 1 line-haul operations. The number is slightly lower than the numbers we derived for CN and CP from Statistics Canada's *Rail in Canada* for 2009.

Table B-7. Emissions Intensity Reported for Canadian Line-haul Locomotives in 2009

Item	Intensity	
	(g/L)	*g/US-Gallon*
NO_X	50.41	190.82
CO	7.07	26.76
VOC/HC	2.47	9.35
PM	1.31	4.96
SO_X	0.18	0.68
GHG (CO_2-e)	3,007.15	11,383.0

Source: Derived from RAC LEM-2009 Report.

B.3.3 U.S. Great Lakes-St. Lawrence River Region Class 1 Average (2010)

The Norfolk Southern (NS) and CSXT railroads are the dominant U.S. Class 1 carriers in the Great Lakes and St. Lawrence River region. CN and CP also have some operations on the U.S. side of the border in this region— but it is their Canadian routes that are more involved in the bulk cargo traffic being assessed here. For the purposes of this comparison, we have combined data from NS and CSXT to characterize rail operations on the U.S. side of the border.

In comparison with Canadian railways, the data available for U.S. railroads is more detailed in some aspects and less detailed in others. U.S. railroads do not produce an annual emissions report like the RAC's LEM report. The locomotive fleet composition is reported by age groups in STB filings but the number of conversions of pre-2001 locomotives to Tier 0 is not shown. Also the hp distribution is not shown. Public data could not be found for the number of pre-2001 locomotives that have been upgraded to Tier 0 by CSXT and NS. Data provided by the Union Pacific Railroad (UP) on its 2007 locomotive fleet composition and Tier 0 upgrades was used to estimate the CSXT and NS conversion ratios [Eastern Research Group, 2007]. The UP indicated that about 50% of pre-2001 line haul locomotives and none of its pre-2001 yard switcher locomotives had been converted to Tier 0 by 2007. Union Pacific (UP) is a major U.S. Class 1 railroad and since it has operations in California, where additional pressures for conversion are exerted, we assume its conversion status is a conservative estimate to be used for the NS and CSXT. We increased the UP's 2007 line-haul conversion ratio from 50% to 55% as an estimate of the 2010 conversion ratio for NS and CSXT's pre-2001 line-haul locomotives. To get a power distribution comparable to the one available from the Canadian railway's LEM reports, we drew upon the age and power information portrayed on various rail-fan websites[4] and cross-checked against the U.S. Surface

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[4] http://www.nsdash9.com/roster.html and http://www.thedieselshop.us/CSX.HTML

Transportation Board (STB) filings by age groupings. The resulting portion of the overall locomotive fleet is 31.5%, which is very close to the 30.0% of the Canadian line-haul fleet (see Table B-4). The resulting distributions of line-haul and yard switcher locomotives by EPA Tier level is summarized in Table B-8.

Table B-8. Estimated NS and CSXT Locomotive Engine Distribution by EPA Tier Level

EPA Duty Cycle	Distribution (% of total hp) by Service Type				
	No Tier	*Tier 0*	*Tier 1*	*Tier 2*	*Total*
LH Locomotives	31.5%	38.6%	16.0%	13.9%	100.0%
Switch Locomotives	96.8%	0.0%	0.0%	3.2%	100.0%

Source: RTG estimate from various data sources (see text).

The operations data reported to the U.S. Surface Transportation Board (STB) by U.S. railroads are of more detail than that reported by Canadian railways to Statistics Canada. Some of the details provided in the U.S. reports are applied in characterizing Canadian railway operations. Since most aspects of railway operations are similar in the U.S. and Canada, and equipment interchange rules apply equally on a continental basis, we believe this necessary assumption will not significantly affect the Canadian results.

Table B-9 provides some key operating characteristics that are important to this evaluation. The first data row provides the fuel intensity of line haul operations, while the second row provides the fuel intensity of line-haul operations, with the fuel consumed in yard switching allocated to line haul movements. The first row is more relevant to unit train operations, where trains operate on a cycle from load point to destination and back again as one uniform train. The second row is more relevant to mixed train operations, where trains are assembled in yards with cars having different destinations and travel to another yard, where they are disassembled for final destination (and in some cases reassembled to move to another yard in another train). Another difference shown in the table is that unit trains are characteristically longer than general freight "through trains" (91.7 cars compared with 58.8 cars). While the average load per car is not separated by train type in the data, unit coal trains all have heavier car loads — the average coal carload for U.S. Class 1 railways in 2010 was 115 tons/105 tonnes [AAR, 2011a].

Table B-9. Key Rail Characteristics for NS and CSXT Combined (2010)

Service	CTK/L	CTM/ US-gal	Average Train Length (No. Cars)			Average Car Load	
			Unit trains		*Through trains*	*Tonnes*	*Tons*
Line haul (LH) only	186	481	91.7	58.8	73.6	81.0	
With yard switching allocated	170	442	N.A.	N.A.	N.A.		

Source: Derived by RTG from data in NS and CSXT Annual Reports to the Surface Transportation Board.

Another detail of train operations available from the U.S. data but not from Canadian data is the empty return ratio. Table B-10 indicates the average empty return ratios for different car types. Bulk commodity transport is seen to be close to 100% empty return, while other non-containerized freight has a 79.8% empty return ratio. Container on flat car (COFC) / trailer on flat car (TOFC) service is seen to have a very low empty return ratio. This is a consequence of two factors: a) empty containers are a revenue movement and treated as a load and many container "cars" are articulated multi-platform cars, carrying up to 20 containers per car-set. One platform with a container on it would be designated a loaded car. These U.S. cargo-specific ratios are considered to provide a reasonable representation of Canadian operations.

Table B-10. Empty Return Ratios by Car Type for CSXT and NS Combined (2010)

Service	empty-miles/ loaded-miles
Bulk (gondola and hopper cars)	99.4%
COFC/TOFC	9.5%
All other	79.8%
Overall	73.5%

Source: Derived by RTG from data in NS and CSXT Annual Reports to the Surface Transportation Board.

The main differences in average values shown for the U.S. operations in Table B-9 and Canadian operations in Table B-5 are largely attributable to traffic mix. The overall average empty return ratio of 73.5% in the U.S is much higher than the overall ratio of 50% reported by the Canadian Class 1 railways — and the average U.S. load of 73.6 tonnes is much higher than the Canadian value of 53.6 tonnes. Both these differences are most likely a reflection of a higher proportion of COFC traffic carried by the Canadian railways. The empty return ratio and average car loads for bulk cargo would be similar for Canadian and U.S. operations[5] and are assumed to be the same in our analyses. The higher efficiency of the NS/CSXT line haul operations (186 CTK/Litre versus 181 CTK/Litre) could be influenced by the year difference (2010 for U.S. versus 2009 for Canada) but would also be influenced by a higher proportion of bulk commodity transport by NS/CSXT. Another factor is the amount of yard switching: the U.S. railways have a higher proportion of fuel and activity associated with yard switching, which might be due to a definitional difference in what defines yard switching versus line switching. With yard switching fuel assigned to LH service, the Canadian railways have a higher efficiency than the U.S. railways (177 CTK/Litre versus 170 CTK/Litre). In either case, the differences are less than 5% and the detailed insights to cargo-specific intensities available from the U.S. data are assumed to apply to Canadian operations.

B.3.4 Cargo-specific Emissions Intensity (2010, U.S. and Canada)

The fuel efficiency of rail transport, like the other modes, varies with the type of cargo being carried. As previously illustrated in Equation 1 (Page 5), aerodynamic drag and part of the rolling resistance are independent of the cargo weight being carried. Thus, efficiencies are gained with higher load weights. In addition, some types of equipment have different aerodynamic profiles than others. Making a service-specific comparison of the three modes requires the estimation of the type of equipment and operating characteristics for the trains to be used in each service. To estimate the service-specific fuel intensity of the rail mode, we have used the equipment characteristics used by CN as presented in Chapter 16 (1992 update) of the *Manual for Railway Engineering*, by the American Railway Engineering and Maintenance Association (AREMA) in a simulation model based on Equation 1.

Simulations were performed for each car type, loaded and empty, with locomotive resistance to motion assigned on the basis of average number of locomotives per car as reported for unit trains and through trains. Fuel consumed at idle and during braking was added in relation to the EPA line-haul duty cycle. The average carload for coal is from the STB commodity load filings. Other carloads were estimated and adjusted to provide the same average carloads reported by NS and CSXT. The calculated fuel was aggregated for the car-specific trip miles reported for both loaded and empty condition by NS and CSXT. The total fuel consumption derived in this way was scaled with a gradient energy factor to match the total actual fuel consumption reported by NS and CSXT — the NS grade factor was about 11% more severe than the CSXT factor. Switching fuel consumption was allocated to non-unit trains on a car-mile basis. The resulting fuel intensities for the combined NS/CSXT operations are summarized by service type in Table B-11. As can be seen, bulk cargoes and unit train operations have a higher efficiency than other cargo types. The average fuel efficiencies derived for the cargo mix carried by the Seaway-size Fleet and U.S. Fleet are both seen to be more efficient than the averages reported by the railways for the actual mix of cargo carried. All GHG and CAC emissions are proportional to fuel consumed and thus all rail emissions derived in our comparisons are lower than those that would be derived for the rail mode carrying its own traffic.

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[5] The same equipment is used by railways on both sides of the border. CN and CP have large operations in the U.S.; unit train operations follow the same 100% empty return practice regardless of location, and the use of special cars for specific goods is a common practice both sides of the border.

Table B-11. System Average and Derived Cargo-specific Fuel Intensities

Average Base	Cargo	Car Load		Fuel Efficiency	
		Tonnes	*Tons*	*(CTK/L)*	*(CTM/US-gal)*
Actual System Averages	CN+CP average (2009)	54	59	177	460
	NS+CSXT average (2010)	74	81	170	442
Derived Cargo Specific	Coal unit train	101	111	268	696
	Grain/other-bulk	87	96	195	505
	COFC/TOFC	62	68	96	248
	Tanks (non-pressurized)	64	70	158	409
	Other general freight	49	54	135	349
	CN+CP average derived for Seaway-size Fleet cargo			213	554
	NS+CSXT average derived for U.S. Fleet cargo			212	551

Source: Actuals from StatsCan and STB-filings, others derived by RTG.

With fuel derived, emissions can be calculated using fuel-based intensity ratios. The U.S. intensities were calculated using the same procedure as was used to calculate the Canadian intensities in the LEM-2009 report — except the combined NS/CSXT fleet distribution and the applicable U.S. EPA duty cycles were used. The same EPA estimates of fuel consumption in those duty cycles were used. The intensities indicated in the RAC's LEM-2009 were shown previously in Table B-7. The results for the U.S. line-haul operations are compared with the Canadian values in Table B-12 and yard switching operations are compared in Table B-13. The differences are mostly due to the differences in fleet composition; however, the lower PM intensities in Canada also reflect a reduction due to the lower sulfur content of diesel fuel used by the Canadian railways. The U.S. SO_X levels are based on an assumed 250 ppm sulfur fuel being delivered in 2010, which is an accelerated reduction over that required by the EPA's phase-in regulation for railway diesel fuel (i.e. from 500 ppm in 2007 to 15 ppm in 2014). The Canadian SO_X levels are based on those reported in the LEM-2009 report, which indicates a level of 110 ppm SO_X was attained in Canada in 2009.

Table B-12. Estimated Line-haul Emissions Intensities in the Great Lakes-Seaway Region (2010)

Item	Canadian Emissions Intensity		U.S. Emissions Intensity	
	(g/L)	*(g/US-gallon)*	*(g/L)*	*(g/US-gallon)*
NO_X	50.41	190.82	51.5	194.83
CO	7.07	26.76	7.8	29.36
HC	2.47	9.35	2.4	9.00
PM	1.31	4.96	1.6	6.01
SO_X	0.18	0.68	0.41	1.55
GHG (CO_2-e)	3,007.15	11,383.0	Canadian value used	

Note: Based on the national fleet of CN and CP (2009) and the full network of CSXT and NS (2010).

Sources: RAC's LEM-2009 for Canada; RTG derivation from EPA and STB-filings data for the U.S.

Table B-13. Estimated Yard Switching Emissions Intensities in the Great Lakes-Seaway Region (2010)

Item	Canadian Emissions Intensity		U.S. Emissions Intensity	
	(g/L)	*(g/US-gallon)*	*(g/L)*	*(g/US-gallon)*
NO_X	69.42	262.78	68.5	259.26
CO	7.35	27.82	7.2	27.33
HC	4.06	15.37	4.0	14.99
PM	1.53	5.79	1.8	6.71
SO_X	0.18	0.68	0.41	1.55
GHG (CO_2-e)	3,007.15	11,383.0	Canadian value used	

Note: Based on the national fleet of CN and CP (2009) and the full network of CSXT and NS (2010).

Sources: RAC's LEM-2009 for Canada; RTG derivation from EPA and STB-filings data for the U.S.

B.3.5 Expected 2015 Performance Capabilities

The purpose of this section is to identify the expected performance available from 2015 technology. The 2015 modal comparison will be made for available technology in each mode, rather than for the expected fleet composition of old and new technology. It is essentially a long-term comparison of what each mode can attain after 2015, not what they will attain in 2015. This approach was chosen for a number of reasons. First, the 2015 locomotive technology will take some time to work its way through the railways' fleets of locomotives. Second, while the locomotive technology will be available to Canadian railways, the exact nature of the agreement reached between Environment Canada/Transport Canada (EC/TC) and the Canadian railways with respect to other tier levels is not known.

The SO_X requirement for U.S. and Canadian railways' diesel fuel is for 15 ppm by 2014, which will reduce the SO_X intensities to 0.025 g/L (0.09 g/US-gal).

The EPA updated its legislation on locomotive CAC emissions in March 2008. The 2008 rule builds upon the previous EPA 1997 rule by establishing two additional emission levels, Tier 3 and Tier 4, as well as strengthening the existing Tier 0 through Tier 2 standards to become more stringent when an applicable locomotive is remanufactured in the year 2010 or later.

Table B-14 and Table B-15 summarize the revised Tiers 0 to 2 emission levels[6] and the new Tier 3 and Tier 4 emission levels for line-haul and switch locomotives respectively. Line-haul locomotives under Tiers 0 to 2 are required to meet the switch standards (under the switcher duty cycle) at the same tier level while only Tier 1 and 2 switch locomotives must meet their respective line-haul tier level requirements. The Tier 3 standards become effective in 2011 for switch locomotives and in 2012 for line-haul locomotives. Tier 3 line-haul locomotives are required to meet Tier 2 switch emission levels. The Tier 4 emission standards become effective, and apply to, locomotives manufactured in 2015 or later.

Our basis of comparison is the best technology available in 2015 to reflect the long-term potential performance of each mode. The EPA has estimated the emissions performance of railway locomotives as the fleet evolves from 2006 to 2040 [EPA, 2009]. We use the 2040 values for CAC emission intensities as an indication of the performance of 2015 Tier 4- compliant technology (essentially the fleet is fully replaced by 25 years after the regulation). However, we develop GHG emissions intensities on the basis of estimated operational efficiency improvements. In addition, we develop a second scenario for NO_X emissions intensity, to reflect the higher uncertainty of the in-service effectiveness of NO_X reduction technologies. While the emission levels specified by the Tier 0 through Tier 3 standards may be achieved through engine design optimization, it is expected that achieving Tier 4- levels will require implementation of additional exhaust gas treatment technologies. Exhaust gas treatment technologies may include using urea-based selective catalytic reactors (SCR) to remove NO_X and particulate filters to remove PM. Both of these technologies have been used in heavy duty diesel (HDD) truck engines to meet Tier 3 on-road emissions regulations, which came into force earlier.

Table B-14. U.S. Environmental Protection Agency Tier 0–4 Line-haul Locomotive Emission Standards (2008 Rule)

Tier	Year Manufactured	Effective Date	HC g/bhp-hr*	CO g/bhp-hr*	NO_X g/bhp-hr*	PM g/bhp-hr*
Tier 0+	1973 – 1992	2010	1.0	5.0	8.0	0.22
Tier 1+	1993 – 2004	2010	0.55	2.2	7.4	0.22
Tier 2+	2005 – 2011	2010	0.3	1.5	5.5	0.10
Tier 3	2012 – 2014	2012	0.3	1.5	5.5	0.10
Tier 4	2015 and later	2015	0.14	1.5	1.3	0.03

* g/bhp-hr = grams of emission per brake horsepower-hour

Source: Derived from RAC's LEM-2008.

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[6] Tier 0 through 2 denoted as Tier 0+ through Tier 2+ in these tables to signify increased stringency, as established by the EPA 2008 rule.

Table B-15. U.S. Environmental Protection Agency Tier 0–4 Switch Locomotive Emission Standards (2008 Rule)

Tier	Year Manufactured	Effective Date	HC g/bhp-hr*	CO g/bhp-hr*	NO_X g/bhp-hr*	PM g/bhp-hr*
Tier 0+	1973 – 2001	2010	2.10	8.0	11.8	0.26
Tier 1+	2002 – 2004	2010	1.20	2.5	11.0	0.26
Tier 2+	2005 – 2010	2010	0.6	2.4	8.1	0.13
Tier 3	2011 – 2014	2011	0.6	2.4	5.0	0.10
Tier 4	2015 and later	2015	0.14	2.4	1.3	0.03

* g/bhp-hr = grams of emission per brake horsepower-hour

Source: Derived from RAC's LEM-2008.

The efficiency impacts of meeting the 2015 regulations will not be known until 2015. The EPA believes that exhaust gas treatment methods can be used to meet Tier 4 locomotive regulations without fuel penalty [EPA, May, 2008]. GE Transportation (GETS), in its comments on the proposed regulations disagreed with the EPA's assumption, indicating an 8% fuel consumption penalty was necessary to compensate for deterioration over time [EPA, March, 2008]. Eggleton has noted that the suppliers indicated a fuel penalty would be required to meet the original 1997 regulations but that many retrofit kits were developed to attain the standards without a fuel penalty [Eggleton, 2003]. Nonetheless, we note that the EMD 710 engine, which was the most fuel-efficient engine prior to regulation, did incur a fuel penalty while the less efficient engines of that vintage (the EMD 645 and the GETS FDL) were able to offset the fuel penalty with other efficiency enhancements. The Tier 2 GETS engine (GEVO) met the Tier 2 standard with a 3% engine efficiency improvement (still 3% above the minimum bsfc of the original EMD 710 engine before Tier 0 efficiency penalty). We also note that if exhaust after treatment is used, suppliers will be able to recover some of the engine efficiency losses by emitting higher levels of NO_X from the engine and allowing the SCR to remove it from the exhaust. Given the range of possible outcomes, our assumption for the 2015 technology is that average line-haul locomotive engine efficiency of 2010 technology will not be affected but the most efficient 2010 engines might suffer a fuel penalty, offset by gains from less efficient 2010 engines.

There will be an efficiency gain in comparing 2015 technology with the 2010 operational fleet, since the 2010 fleet includes a portion of older 645 and 7FL engines that had lower efficiencies than the 2010 locomotive technology. This efficiency advantage of 2015 technology over the 2010 fleet average will be even more exaggerated for yard switching locomotives, as the locomotives used in this low-utilization service have very long service lives and seldom require engine overhauls.

There are other potential areas of efficiency improvement from line-haul operations. We assume that axle loads for coal cars will increase from the 111.5 tons on average in 2010 to 115 tons, which is the present maximum axle load limit for interchange cars. We do not expect any further increase in high-density cargo axle loads for eastern railroads; however, the average axle load of other bulk commodities might increase as newer high-volume cars are introduced to take advantage of the high axle load limits. For grains and the other bulk categories, we assume an available improvement of another 5% in average axle load (from 96 tons to 100 tons). In addition, we assume that average train length will increase by 10% and average locomotive idle consumption will decrease by 20%.

To the extent that urea-based selective catalytic reactors are used to attain the Tier 4 regulations, additional GHG emissions (in the form of CO_2) will arise. However, the incremental CO_2 emissions are less than 0.01% of the CO_2 produced by the combustion process and can be ignored.[7]

We note that meeting the EPA regulations might not result in NO_X reductions proportional to the regulatory reduction. Selective catalytic reactors (SCRs) require a threshold exhaust temperature to attain their effectiveness. The EPA recognizes this fact in its modeling of HDD truck emissions, by excluding its effect for extended periods of idling (estimated to be of 8 hr duration for long-haul trucks). EPA's MOVES model assumes that the SCR is 100% effective for the first hour of idling and 0% effective afterwards (i.e. 7 hrs out of 8 at extended idle are ineffective) [EPA, 2009-b)]. The extended idle impact will be somewhat lower for locomotives, since the EPA 2008 regulations also require automatic shutdown devices to be installed on Tier 4 locomotives. On the other hand, in-use idle is much higher for locomotives than for long-haul trucks. The 51% of time shown at idle in the LEM-2008 duty cycle (see Table B-6) is based on locomotive operating time and excludes layover time.

If the EPA's estimate of 1 hr of SCR effectiveness under idle is optimistic, SCR performance might be lower for locomotives. In addition, the in-service performance of SCRs in truck engines demonstrates reduced performance at low speeds (see subsection B.4.2.3). Initial testing of locomotive SCR's by Southwest Research Institute resulted in similar results with long segments of line-haul having exhaust temperatures too low to get full SCR effectiveness [Osborne, Dustin T. and Christopher A. Sharp, 2010]. The average in-service performance of SCRs will depend on how close the locomotive duty cycle approaches the EPA regulatory duty cycle — more time at higher power settings will enhance the effectiveness, while more time at lower power settings will reduce the effectiveness. Ambient temperature will also have an effect. Thus, we assess NO_X emissions rates with 2015 technology at two levels — those directly associated with the EPA regulatory reductions and an estimated rate that considers reduced SCR performance in the railway duty cycle. Without operational details, we assume that SCR performance for railway locomotives will be influenced in a similar fashion as HDD trucks and apply a 15% increment to NO_X emissions in the alternate scenario. We note that marine propulsion engines using SCRs would not have significant exhaust temperature problems, as the marine propulsion duty cycle is much more constant at high power settings. Marine auxiliary engines have a wider load range than propulsion engines, but vessels have multiple auxiliary engines which are brought on and off line to meet the load variations.

The two scenarios for 2015 NO_X emission intensity and the base case for all other emissions intensities from locomotives are summarized in Table B-16. As previously noted, the base case factors are drawn from the EPA's estimated emissions factors for the locomotive fleet — where the fleet is considered to have been largely upgraded to 2015 technology after 25 years.

The above emissions coefficients on a g/L basis are multiplied by the energy intensity values in L/CTK for each jurisdiction and time period, to get the emissions intensity in terms of grams emitted per unit of transportation work performed (g/CTK). The results are summarized in Table B-17. Note that the CAC emissions use emissions units of milligrams (mg), while the CO_2-e units are grams and lb. One mg/CTK is the same as one g/thousand-CTK.

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[7] The equation recommended by the IPCC for emission from urea-based selective catalytic reactors is:

$E = 0.2333 \bullet M \bullet F$

Where:

E is CO_2 (kg)
M is the mass of catalyst consumed (kg)
F is the fraction of urea in the catalyst.

According to one of the suppliers of DEF, the catalyst consumption is about 3% of fuel consumption (on a volume basis) and urea is 32.5% of the aqueous solution [http://canada.air1.info]. On this basis, the use of SCR systems adds 0.00248 kg/litre of diesel fuel to the CO_2 emissions, derived with the above equation and using the following factors:

M = 0.03 (L/L) ● 1.091 kg/Litre for 32.5% urea solution = .03273 kg-DEF / Litre-fuel
F = .325

The incremental 0.00248 kg/L is 0.09% of the 2.663 kg/L emitted from the engine's diesel fuel via the combustion process.

Table B-16. Estimated Emissions Coefficients for circa-2015 Locomotive Technology

Item	Line Haul		Yard Switching	
	(g/L)	*(g/US-gallon)*	*(g/L)*	*(g/US-gallon)*
NO$_X$	7.41	28.0	15.87	60.0
NO$_X$ (+15% scenario)	8.52	32.2	18.25	69.0
CO	8.24	31.2	9.64	36.5
HC	0.26	1.0	0.85	3.2
PM	0.11	0.4	0.32	1.2
SO$_X$	0.025	0.093	0.025	0.093
GHG (CO$_2$-e)	3,007.15	11,383.0	3,007.15	11,383.0

Source: CAC factors derived from EPA's estimated year-2040 emissions factors [EPA, 2009]; GHG and SO$_X$ are fuel based rather than engine based. GHG is based on RAC's LEM-2008 and SO$_X$ is based on attaining EPA limits of 15 ppm.

Table B-17. Derived Fleet Average Rail Emissions Intensities for Great Lakes-Seaway Cargo

Jurisdiction*	Year/Scenario	CO$_2$-e		NO$_X$		CO		HC		SO$_X$		PM	
		(g/ CTK)	*(lb/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*
CAN	2010	14.1	45.1	237.1	346.2	33.0	48.2	11.7	17.1	0.8	1.2	6.1	9.0
	Post-Renewal	13.3	42.7	33.4	48.8	36.5	53.3	1.2	1.8	0.108	0.158	0.5	0.7
U.S.	2010	14.2	45.7	251.8	367.4	36.5	53.3	12.0	17.5	1.9	2.8	7.6	11.1
	Post-Renewal	13.4	43.0	36.4	53.1	37.3	54.4	1.4	2.1	0.10	0.15	0.6	0.8

* The Canadian values reflect Canadian railways' intensities carrying cargo typical of the Seaway-fleet, while the U.S. values reflect U.S. railways' intensities carrying cargo typical of the U.S. Fleet.

Source: RTG calculations.

As previously noted, the intensities derived for the scenario of railways carrying the mix of cargo now carried by the fleets operating on the Great Lakes-Seaway System are lower than those exhibited by the railways in carrying their own mix of cargo. The bulk cargoes typical of these fleets can be hauled more efficiently than is the typical mix of railway cargo. Thus, all GHG and CAC emissions intensities are lower than one would derive from a simple average of railway emissions, divided by railway cargo tonne-km of activity. Referring back to the system average fuel efficiencies shown in Table B-11 — to get the railway emissions that are characteristic of the railway's carrying its own cargo mix — the emissions shown in Table B-17 need to be scaled up by 1.21 (i.e. 177/213) for Canada and 1.25 (i.e. 170/212) for the U.S. Thus, CO$_2$-e for example would be 17.0 g/CTK for Canada and 17.7 g/CTK for the U.S.

B.4 Truck Mode Air Emissions Characterization

B.4.1 Canadian and U.S. Similarities and Differences

Canadian and U.S. trucking companies use engines and equipment from the same suppliers. The engine regulations enacted by the U.S. EPA for new trucks are effectively applied to trucks sold on both sides of the border, as Canada has adopted equivalent regulations. The history of EPA regulatory limits for heavy duty diesel (HDD) truck engines is summarized in Table B-18.

Table B-18. EPA Emissions Limits for HDD Truck Engines by Model Year

EPA Model Year	CAC Emissions Limits (g/bhp-hr)					
	CO	*HC*	*NMHC*	*NO_X*	*NO_X+NMHC*	*PM*
1988	15.5	1.3	-	10.7	-	0.60
1990	15.5	1.3	-	6.0	-	0.60
1992*	15.5	1.3	-	5.0	-	0.25
1994	15.5	1.3	-	5.0	-	0.10
1998	15.5	1.3	-	4.0	-	0.10
2004 (option a)	15.5	-	-	-	2.4	0.10
2004 (option b)	15.5	-	0.5	-	2.5	0.10
2010**	15.5	-	0.14	0.2	-	0.01

* phase-in starting in 1991 required,
** phase-in starting in 2007 required.

Source: Derived from EPA website and Delphi, Worldwide Emission Standards Delphi-Heavy-Duty-Emissions-Brochure-2011-2012.

The principal differences between Canada and the U.S. are the weight and dimension limits applied by the states and provinces. Canadian provincial regulations permit heavier and longer vehicles than are generally allowed in the U.S. In Canada, second trailers and extra axles can be used to a gross vehicle weight (GVW) limit of 63,500 kg (139,700 lb). In the U.S. the GVW limit on Interstate highways is generally 80,000 lb (36,3636 kg). Some states permit one extra axle to a GVW of 90,000 lb (40,900 kg) and the State of Michigan has grandfathered highway regulations that permit multiple trailers and load limits up to 109,000 lb (49,4545 kg) [Michigan Department of Transportation, 1949]. A recent federal initiative, if adopted, would allow all states to permit second trailers and raise the GVW limit to 97,000 lb (44,091 kg) for the U.S. National Highway System. The types of trucks simulated in the present modal comparison are illustrated in Figure B-2 and include:

a) 4 axle straight truck (top illustration);

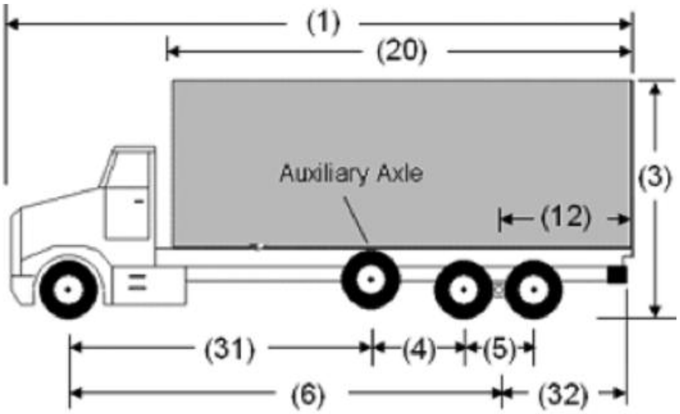
b) straight truck with pony trailer;

c) 5 to 7 axle, tractor-trailer combination; and

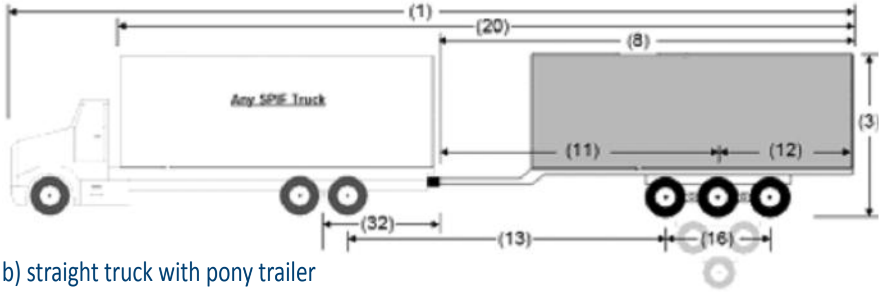
d) 6 to 9 axle, tractor-twin-trailer “B-train” combinations (lower illustration).

While the body style in the four illustrations is that of a van, the simulation model we are using (described in the next section) adjusts the aerodynamic drag on the basis of actual body styles (e.g. dump, hopper, tank, flatbed) used to transport specific types of cargo.

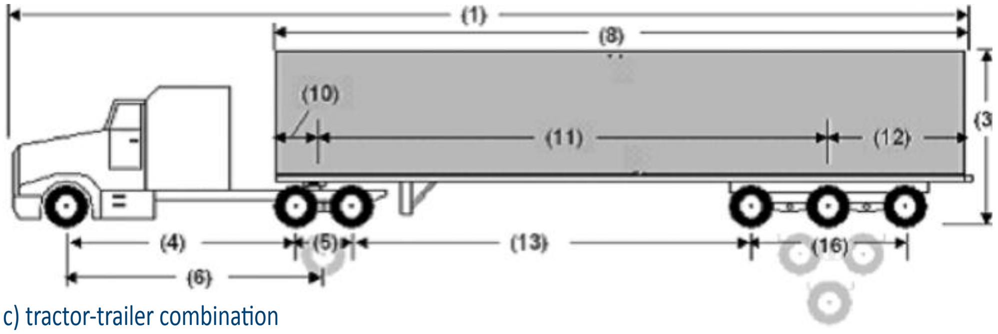
Figure B-2. Illustrations of Truck Configurations Simulated in this Comparison



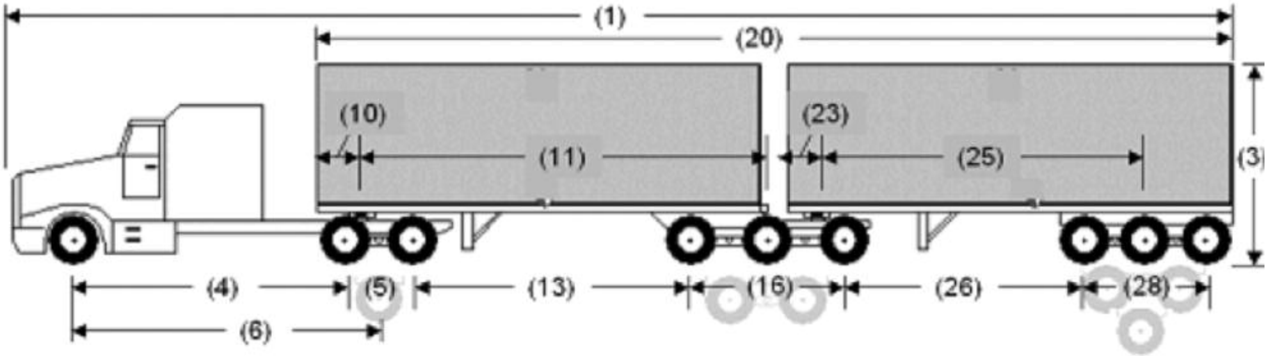
a) straight truck



b) straight truck with pony trailer



c) tractor-trailer combination



d) tractor twin trailer “B-train” combination

Note: the numbers refer to dimensional notes in the regulations; they are not relevant here.

Source: Province of Ontario, *HighwayTraffic Act*, Regulation 413, Vehicle Weights and Dimensions.

B.4.2 Simulation Model Used to Simulate Truck Emissions

B.4.2.1 Model Overview

The wide range of truck styles and configurations used in the Great Lakes-Seaway region, and significant differences between the trucks used to haul bulk commodities and the most common truck configurations, mean that a robust simulation model is required. RTG has developed a heavy duty truck energy and emissions model (HD-TEEM) for Transport Canada. The model uses a detailed time-step simulation similar to the EPA's time-step simulation model "PERE". The EPA's PERE model is used to generate data for the MOVES 2010 inventory model. HD-TEEM takes an approach similar to many duty cycle models but with some enhancements. Many duty cycle models assume that a vehicle can meet the required power/acceleration demands of the drive schedule — but introduce errors in energy accounting, when a vehicle cannot meet the acceleration demands. This is a more significant problem when modeling heavy duty vehicles. HD-TEEM is a responsive simulation — it does not force a vehicle to meet a drive schedule; it performs a second-by-second time-step simulation, which is bounded by the engine performance in response to vehicle and road characteristics. If the acceleration associated with a drive schedule/duty cycle cannot be met, the vehicle lags the speed profile.

We note that gradient is ignored in most highway models. This is possibly a reasonable approach for light duty vehicles (LDV) and for HHD vehicles in urban areas. However, ignoring grades becomes more problematic in rural areas for heavy vehicles with lower power/weight ratios. The approach taken by HD-TEEM for urban activity is to ignore gradient and use representative duty cycles for the urban area of interest. The vehicle engine and operator parameters that influence a truck's efficiency and emissions in those duty cycles is retained but (like most aggregate truck models), gradient is ignored. For the long-haul module, HD-TEEM retains the sensitivities to all vehicle engine and operator parameters that influence a truck's performance, efficiency and emissions, as well as road gradient as characterized for a specific corridor. However, the long-haul simulation is in an analytic formulation rather than a step-by-step formulation. The analytic formulation aggregates road segments by gradient, stop-frequency and speed-limit properties. The aggregate fuel consumption and emissions for these major segments are calculated, rather than the step-by-step instantaneous performance as would be done with a time-domain micro-simulation model.

Both the long-haul and urban simulation modules reflect differences in seasonal performance. Winter, summer and transition seasons are recognized in the HD-TEEM. The main influence in urban areas include: the lower density of diesel fuel used during winter in cold climates; the more intense accessory loads in winter and summer seasons; and extended use of idling in winter. The long-haul sub-module has these same sensitivities, but is also influenced by the significantly higher density of air in cold temperatures and the associated higher aerodynamic drag in the winter.

The four principal modules of HD-TEEM are the trip module, the resistance module, the engine module and the emissions module. Each is discussed in turn in the following subsections.

B.4.2.2 Trip Module

The trip module specifies the types of duty cycles encountered in urban areas. A series of fixed drive schedules (speed – time) are used to represent urban travel. Speed is specified at 1-second intervals for each representative drive schedule. All are derived from EPA drive schedules, either as direct copies or with slight modifications. HD-TEEM simulates the movement of a truck over each drive schedule and scales the litres/km fuel intensity output to the total distance for that road condition, as specified by the user for a given trip. The model is responsive and thus, acceleration and braking rates are held within the capability of the truck, rather than purely following the speed-time profiles. Traffic congestion is typically characterized by the level of service (LOS) which is based on the level of reduction below free-running speed of the traffic. For a freeway with an average 100 km/h free-flow speed, increasing congestion leads to decreasing average speed. LOS A through LOS D involve modest decreases, while LOS E depicts traffic at capacity conditions and LOS F depicts traffic beyond capacity with possible stop-and-go progress. Non-freeway travel involves intersection stops and idle periods. The drive schedules summarized in Table B-19 are used to characterize urban conditions by time of day in HD-TEEM.

Table B-19. Drive Schedules Used in HD-TEEM

Road Type	Drive Schedule Name	Characteristics
Non-Freeway	Creep	Queuing delays (146 m travel distance in 10 minutes).
	Arterial	41 km/h (26 mph) average speed with stops at 2 km intervals.
Urban Freeway	Free-flow	97 km/h (60 mph) average speed with 80 km/h to 105 km/h range.
	LOS-E75	74 km/h (46 mph) average speed with 0 km/h to 105 km/h range.
	LOS-E50	49 km/h (30 mph) average speed with 0 km/h to 100 km/h range.
	LOS-F15	15 km/h (9 mph) average speed with 0 km/h to 75 km/h in stop-and-go.
	LOS-F17	17 km/h (11 mph) average speed fewer stops/longer idle than LOS-F15.

Source: Derived from drive schedules used in EPA's MOVES model (MOVES2010).

The user designates the proportion of each drive schedule to the 5 time-of-day congestion periods. The drive schedules have decreasing average speeds with increasing congestion, and proportional allocation of different drive schedules can be made to attain a close relationship to average speed observations on the urban highway segments of interest. Table B-20 indicates the duration and duty cycle composition for each of the five time-of-day periods depicting urban freeway and arterial congestion; these are the default values specified in HD-TEEM for large urban areas. In addition, information on the proportion of drivers avoiding congestion and proportion of drivers using overnight hours are user inputs.

For the intercity trip, data are input for the number of stops made, cruise speed distribution, gradient information and extended idle time relevant to a trip of interest.

In addition, the distribution of body styles, tare (unladen) weights, load weights and empty/loaded distance ratios are specified by the user. A range of defaults are derived from Transport Canada's 2006 Truck National Roadside Survey[8] (the relevant values to marine-competitive cargoes are discussed in Section B.4.3 of this report).

Table B-20. Application of Drive Schedules to Urban Travel by Time of Day

Time Period Name	Duration (hrs)	Drive Schedule Allocation (%)					
		For Freeways				For Arterials	
		LOS-E75	***LOS-E50***	***Free-flow***	***LOS-F17***	***LOS-F15***	***Arterial***
a.m. peak	2	30	35	15	20	35	65
p.m. peak	3	20	35	45		25	75
Midday	3		30	70		5	95
Shoulders	6		30	70		5	95
Overnight	10		5	95			100

Source: RTG estimates from GPS Vehicle Tracking data provided by MTO for truck travel on Highway 401 across Toronto [see RTG, 2008].

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[8] The survey was a joint federal/provincial/territorial project coordinated by Transport Canada.

B.4.2.2.1 Resistance Module

The resistance module draws from research and test results reported by the Australian Road Research Board [Biggs, D.C., 1987]. Australia is one of the few countries that have axle loads, gross vehicle weights and multi-trailer configurations similar to those used in Canada. The Australian model was the only model found to permit characterization of wide ranges of weight and trailer characteristics for HHD trucks. Most other country-specific models were developed in support of inventory models based on five-axle loaded trucks in a single van configuration. A drawback of the Australian model is that it is older than many other models. The coefficients have been updated in HD-TEEM, where more recent relevant data are available and appropriate. The weight dependent, weight independent and aerodynamic terms in the resistance model are:

$$R = C_{ra} + \mathrm{C}_{\mathrm{rb}}\,\mathrm{M} = {}^{1}/_{2} \bullet p \bullet C_{d} \bullet A \bullet V^{2}$$

Where:

R = Resistance Force (N)
ρ = density of air (kg/m3)
C_{d} = drag coefficient
A = Frontal Area (m2)
V = speed (m/s)
M = mass (kg)

and

$$C_{ra} = \mathrm{C}_{\mathrm{r2}} \bullet 37 \bullet N_{w} \bullet D_{w}$$

$$C_{rb} = \mathrm{C}_{\mathrm{r2}} \bullet C_{r2}\,{}^{.0.067}/_{D_{w}}$$

Where:

C_{r2} is a road-surface dependent parameter,
C_{r1} is a tire-type dependent parameter,
N_{w} = number of wheels,
D_{w} = diameter of the wheels (m)
M = total mass of the truck (kg)

RTG has modified the coefficient values associated with tire type to reflect modern energy-efficient treads and the relationship with tread wear. HD-TEEM uses an average tread wear to represent the rolling resistance. The coefficient values for Cr1 used by Biggs (Biggs, 1987) and RTG's wear-modified values are shown in Table B-21. New energy efficient treads are assumed to have an initial resistance that is less than standard tires but having a tread-life effectiveness of 95%. The road surface coefficient values for Cr2 are shown in Table B-22.

Table B-21. Original and Modified Tire Coefficients (Cr1)

Tire Type	Original Cr1	Average mitigation factor over tread life	Modified Average Cr1
Cross Ply	1.30	0.875	1.138
Radial	1.00	0.900	0.900
Fuel Efficient Radial	0.80	0.950	0.760
Bias ply, super single	0.91	0.875	0.796
Radial, super single (SS)	0.84	0.900	0.756
Fuel Efficient Radial SS	0.70	0.950	0.665

Source: RTG update from original by [Biggs, 1987].

Table B-22. Road Surface Resistance Coefficient (Cr2)

Road Surface	Cr2 value
smooth concrete	0.74
smooth asphalt	0.90
medium asphalt	1.00
rough asphalt	1.10
hot asphalt	1.20
gravel	1.60

Source: Biggs, 1987.

The aerodynamic drag coefficient increases with the roughness of a body shape. For HD trucks, most (about 80%) of the drag is associated with front and rear pressure drag, and 20% is associated with skin friction. The HD-TEEM default drag coefficients and frontal areas for a range of body styles are presented in Table B-23. The fourth column in the table shows the CdA, which is the drag-area — a product of the drag coefficient "Cd" and the frontal area "A". Aerodynamic drag is usually determined from either coast-down tests or from wind tunnel tests. Wind tunnel tests indicate that cross winds can have a significant impact on the aerodynamic drag force. Biggs indicates that a 10-degree effective yaw angle raises aerodynamic drag by 40%, a sensitivity that is consistent with other sources. Since most wind angles lead to a net yaw angle, only winds very close to a pure tailwind lower drag forces. Thus, we add an average wind factor to encompass the average net effect of cross winds. Since cross winds have a more significant influences on gaps between body elements (axle groups and tractor-trailer gap and trailer-trailer gap), two factors are applied:

a) a 1.035 multiplier for base trucks; and

b) a 1.07 multiplier for a second trailer's incremental drag.

Table B-23. Aerodynamic Drag Parameters by Body Style

Body Style	Cd	Area (m^2)	CdA (m^2)	Source Notes
Van	0.69	9.8	6.76	EPA GEM-model high-sleeper
Flatbed	0.63	6.1	3.84	RTG est. from [Biggs,1987]
Container Carrier	0.72	9.8	7.06	RTG est. from EPA GEM model
Tanker	0.85	7.1	6.04	[Biggs,1987] scaled up to reflect rougher body
Dump/Hopper	0.81	7.1	5.75	RTG est.
Tractor Only (low-profile)	0.56	6.1	3.42	[Biggs,1987]
Tractor Only (mid-profile)	0.76	7.7	5.85	RTG estimate
Incremental Drag of 2nd Trailer	0.07			[Biggs,1987]

Note: Cd is the drag coefficient; CdA is the product of Cd and the Area (the 'drag-area').

Source: Derived by RTG from sources noted.

B.4.2.3 Engine and Emissions Module

The engine module provides the fuel consumption associated with a specific operating point of the engine in terms of its speed and torque, as determined by the resistance equation following a given drive schedule — with auxiliary load and transmission losses added. The gear ratio is selected by a logic that tries to stay close to the most efficient operating point for the engine while at cruise speed. The model uses EPA-representative fuel maps for 2010 HDD truck engines — for 350 hp and 455 hp engines in the EPA's GEM model. The engine maps are fuel maps normalized to the engine's minimum brake-specific fuel consumption (bsfc), to allow different engine powers and fuel efficiency data to be used.

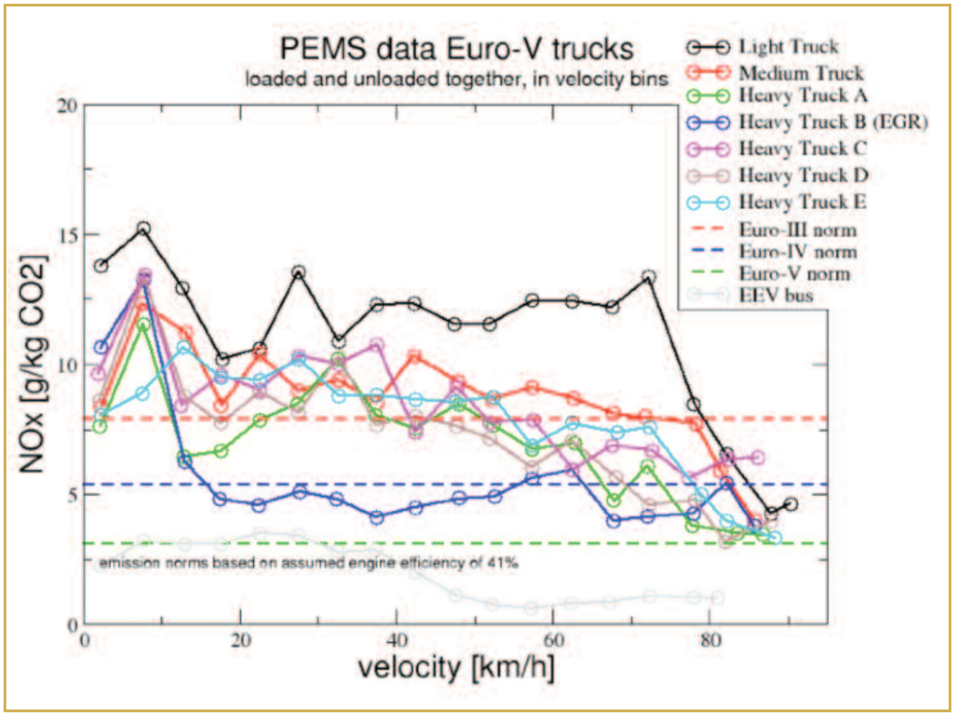
As with the locomotive engines, truck diesel engines' emissions of GHG and CAC contaminants are closely related to fuel consumption. The College of Engineering Center for Environmental Research & Technology at the University of California at Riverside derived linear relationships with fuel consumption for all emissions components [Giannelle, et. al., 2005]. However, the truck sample is dated — spanning 1997 to 2001 model years. EPA certifications test data are the main source for tail-pipe emissions performance for a wide range of engine types and model-years; however, the EPA certification data cannot be used as direct inputs to the model. Emissions are tied to fuel consumption, whereas EPA regulations tie emissions rates to engine energy consumed over a defined test schedule. For HDD trucks, the regulations are specified in grams-emitted per horsepower hour of energy accumulated at the engine shaft (g/hp-hr), over the federal test protocol (FTP) test duty cycle. One can only use the regulatory intensity to predict emissions for trucks that operate over a similar duty cycle to the FTP-defined duty cycle. The main problems with applying the EPA certification data directly (i.e. g/bhp-hr) are that emissions associated with idle activity would be grossly understated and emissions associated with long-haul activity would be overstated.

HD-TEEM relates emissions to fuel consumption, by applying the fuel consumption reported by the EPA in its GEM model for the FTP certification test cycle. Since the fuel consumption is only reported for 2010 engines, the data are normalized to the reported minimum bsfc for 2010 engines, and multiplied by the minimum brake-specific fuel consumption (bsfc) for other years as appropriate. HD-TEEM builds a database of emissions intensity from EPA certification data for each of the regulatory model-year ranges.

For those model years requiring exhaust after-treatment devices, the effectiveness is considered. The use of particulate filters led to regeneration cycles where fuel was injected into the exhaust stream to burn off deposits that plug the filter intake. A 3% fuel consumption increment is imposed for the relevant model years (2007–2010).

Testing of HDD trucks has shown that SCR's performance deteriorates at engine duty cycles above idle. SCRs have been in use in European trucks for a number of years and SCR on-road effectiveness has been measured. A Dutch investigation of NO_X emissions during on-road testing of Euro V and Euro III HDD trucks found that NO_X emissions during real driving conditions tend to be significantly above the applicable certification test levels. They conclude that NO_X emissions under urban driving conditions are three times higher than would be estimated based on the certification levels [Ligterink, et al., 2009]. Figure A-3 depicts the variation in NO_X emissions measured at different truck speeds (where the measured data points have been "binned").

Figure B-3. On-Road NO_X Emissions Measured from Euro V Trucks



Source: Ligterink, et al., 2009.

One can see that the NO_X emissions from the heavy duty Euro-V trucks are often above the Euro III level while traveling at speeds below about 50 km/h, and that they don't approach the Euro V emission standard until speeds above 80 km/h are reached. The exception is the Heavy Truck B (solid blue line), which uses massive EGR instead of SCR technology and is able to maintain better than the Euro IV-level of NO_X emissions. The observed trend supports an assertion that the SCR technology is not effectively removing NO_X from the exhaust stream when the engines are not fully loaded (and therefore exhaust temperatures are lower).

EPA regulatory limits are assumed to be attained at speeds of 100 km/h, drop off to 67% at 50 km/h and further decrease to 55% at 15 km/h. In addition, lower winter ambient temperatures are considered to lower the effectiveness by an additional efficiency factor of 95%. Extended idle is assumed to perform in the same way as assumed in the EPA-MOVES model — zero effectiveness for 7/8ths of the time [EPA, 2009-b), p.64]. The EPA estimates for the effects of SCR "tampering and malmaintenance" are adopted — indicating that on average over the lifetime of HHD trucks, NO_X emissions are 87% higher than the certified performance [EPA, 2011 -b), p.19].

EPA certifications test data are the main source for tail-pipe emissions performance; however, EPA regulations tie emissions rates to engine energy output over a defined test schedule. For HDD trucks, the regulations are specified in grams-emitted per horsepower hour of energy accumulated at the engine shaft (g/hp-hr) — over the FTP certification test duty cycle. The Comprehensive Modal Emissions Model (CMEM) developed by researchers at the University of California, Riverside, includes emissions sensitivities in terms of g/kg that were developed from the test engines and in-service trucks associated with CMEM's development. However, the test data only included older vintage trucks and the model did not provide a basis to relate to EPA certification test data for more recent or future years.

HD-TEEM allows an emission/fuel relationship, while also supporting inputs of past and future EPA certification data on emissions. The EPA certification data do not include the amount of fuel consumed during the FTP test and rarely report CO_2 emissions (from which fuel consumption could be derived). However, the performances of the representative 2010 engines used in EPA's GHG model (GEM) were reported. As these are the engine fuel maps used in HD-TEEM, the fuel consumption data for the FTP test can be used to convert the (g/hp-hr) emissions reported in the certification test to g/kg fuel consumed during the FTP test. The fuel maps are normalized to 2010 fuel efficiencies and scaled to the fuel efficiencies of other model years, as derived from EPA certification data. The emissions intensities are scaled with the same fuel efficiency ratios.

The emissions intensity of a truck fleet for any specific year depends on the age distribution of the engines used in the fleet. The types of truck fleets relevant to this modal comparison include very short-haul dump trucks and long-haul tractors used in a range of tractor-trailer combinations. The age distribution adopted for the 2010 long-haul fleet is assumed to be the same on both sides of the border and is the one used for long-haul combination tractor-trailers in the MOVES 2010 model. The age distribution of the very short-haul dump truck fleet is assumed to be the average of: the MOVES 2010 short-haul combination tractor-trailer fleet and the very short-haul drayage fleet age composition, as surveyed for the port of Los Angeles-Long Beach [Tioga Group, 2008]. Trucks exhibit a declining relative usage with age, such that the effective composition of the fleet is newer than the actual age distribution. The relative usage characteristics are those adopted in MOVES 2010. The resulting effective age distribution of the fleet is illustrated in Figure B-4 for the long-haul and very short-haul truck fleets used in this comparison.

Figure B-4. Truck/Tractor Effective Age/Usage Distributions

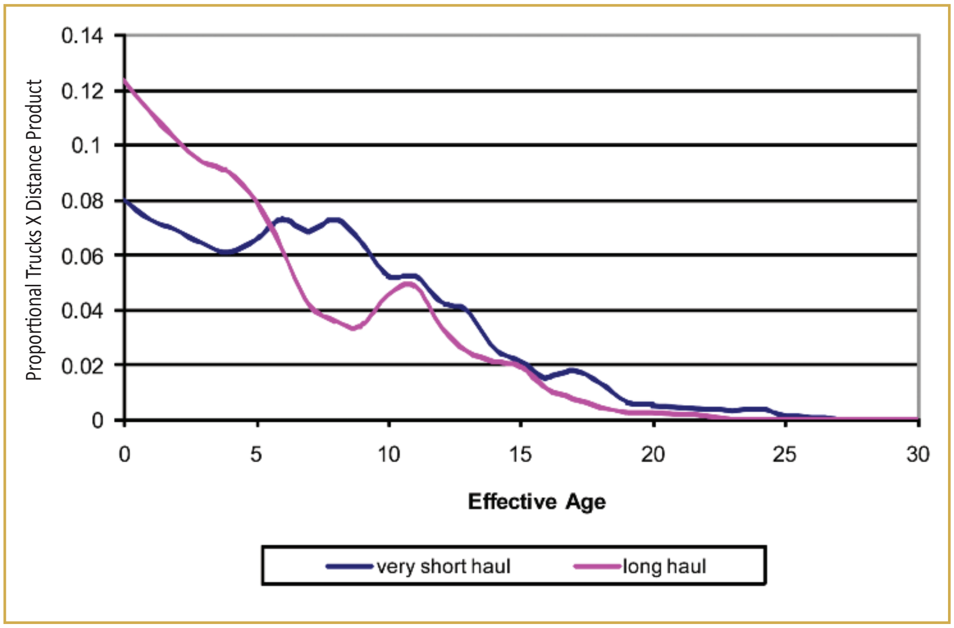


Table B-24. Derived Emissions Intensities for the 2010 Truck Fleet

Item	Long-haul Fleet Emissions Intensity		Very Short-haul Fleet Emissions Intensity	
	(g/L)	*(g/US-gallon)*	*(g/L)*	*(g/US-gallon)*
NO_X[a]	13.51	51.12	13.51	51.14
CO[a]	4.09	15.49	4.27	16.18
HC[a]	0.51	1.94	0.62	2.34
PM[a]	0.40	1.51	0.40	1.52
SO_X[b]	0.025	0.093	0.025	0.093
GHG (CO_2-e)[b]	2,691	10,187	2,691	10.187

Source: a) - RTG analyses of EPA certification data and GEM engine model data (see text).
b) - SO_X and CO_2-e - Environment Canada (see text).

The resulting emissions intensities for the year-2010 long-haul fleet's age distribution are summarized in Table B-24. The four CAC emissions at the top of the Table are sensitive to EPA model-year performance. The last two rows in the table (SO_X and CO_2-e) are related to fuel properties. The CO_2-e intensity is based on Environment Canada's 2008 National Inventory [Environment Canada, 2010], as are the rail mode and marine mode.[9] The SO_X intensity is based on EC's regulatory requirement for ultra-low sulfur diesel fuel of 15 ppm sulfur for highway diesel fuel.

In addition to exhaust emission, the model considers PM emissions associated with brake pad and tire-tread wear. The wear-rate test data documented in the EPA's computer model Mobile 6.1 are used in these calculations [Heirigs, Philip L., Siona S. Delaney, Robert G. Dulla, 2004]. The brake energy of the light-duty truck used in the original tests was estimated, to get a ratio of PM to brake energy. This ratio is applied to the cumulative brake energy, which is monitored for each drive schedule simulation. The PM per-wheel-per-km tire wear factor used in Mobile 6.1 for all vehicles is scaled up, to reflect the fact that HDD trucks have a wider tread and larger footprint than automobiles.

B.4.2.4 Model Validation

The original formulation of the resistance equation was validated with test oval data (collected under controlled conditions) and other field test data, which were analyzed and reported by the Australian Road Research Board [Biggs, 1987]. However, the engine and tire technologies were of pre-1990 vintage. To validate the updated engine and tire representation used in HD-TEEM, more recent test data were reviewed and compared. HD-TEEM was used to simulate the equipment and conditions described in a number of recent field tests and test-track measurements. In addition, it has been validated against a range of other simulation models and engine-dynamometer test results.

The most relevant validation data are real-vehicle tests with multiple test runs and three such detailed tests were undertaken by FP Innovations, the operator of Transport Canada's Motor Vehicle Test Centre in Blainville, Quebec. Two of the tests were undertaken under controlled conditions at the test track — while the third was a field test where the distance, loads and fuel consumption of a fleet of 18-axle, combination tractor dual-trailer woodchip trucks (see Figure B-6 in later discussion of the test) were monitored over a 12-month duration. In each case, the tests were undertaken to assess the benefits of add-on technologies. However, for our purposes, the base case control and pre-test condition results were of primary interest. The three tests provide a wide range of conditions in both the equipment used and the duty cycles involved. The test characteristics and HD-TEEM simulation comparisons are summarized in Table B-25.

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[9] Updates for 2009 and 2010 have been published since the study began; however, the intensity numbers cited were not changed.

The first test shown in Table B-25 involves a 5-axle tractor trailer (aerodynamic profiled tractor with 53 ft. van) loaded to a gross vehicle weight of 30,257 kg (66,565 lb), tested at highway cruise speeds on the Blainville test loop [Surcel, M.D., 2008]. Details were provided for the 395 hp (295 kW) engine, 13-speed transmission and tire types used on each truck tested. Air density was measured for each test and the fuel consumed during the test circuit was measured by weight. The test involved acceleration to a constant cruise speed of 98 km/h (61 mph) and final stop with 97.5 km (60.5 miles) total distance travelled. Constant cruise speed test results are sensitive to the gear selected by the driver and the match of transmission with the engine's fuel map. HD-TEEM uses a generic fuel map and a transmission which might or might not provide as good a match as the real test engine/transmission, at the constant cruise speed involved in the test. Thus, two simulations were performed — one with cruise speeds in gear 12 and another in gear 13. Gear 12 resulted in simulated fuel consumption being 1.3% higher than the reported average —while gear 13 resulted in simulated fuel consumption being 1.6% lower than the reported average. Both are within the 3% standard deviation of the 6 base-case vehicle test results.

Table B-25. Example HD-TEEM Validation Data Characteristics

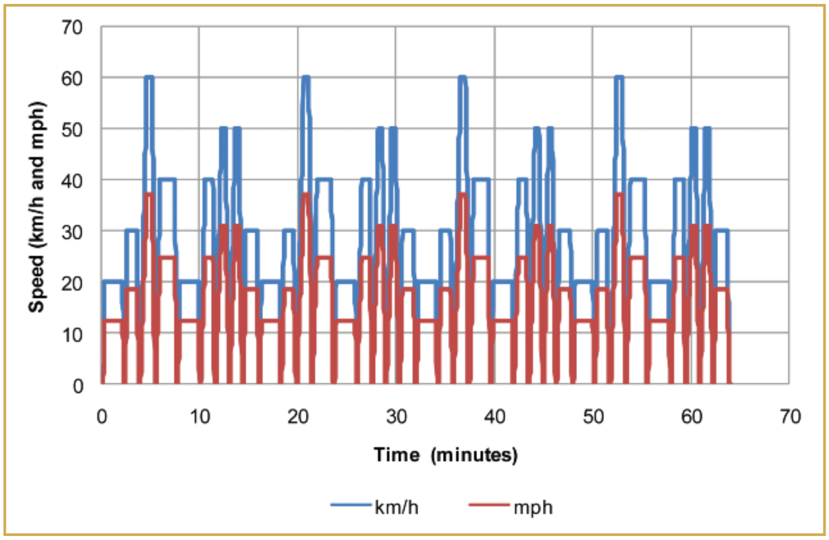
Test Type	Test Location	Truck Style	Known Factors	Simulation error (see text for ranges)
Loaded Constant Cruise	Blainville, QC Test Oval	Loaded, 5-axle combination tractor trailer (van)	Body style, engine make and power, transmission make/# gears, tire types, air-density, test drive schedule, measured fuel consumed by weight.	+ 1.3% to -1.6% depending on gear selected for 'cruise'
Empty-stop/go	Blainville, QC Test Oval	Empty, 5-axle combination tractor trailer (van)		Average -0.85% (+6.8% and -8.5% depending on fuel-map used)
Revenue service field test between two locations 167 km apart.	15-month monitor of service in British Columbia.	8-axle, combination tractor/dual woodchip trailers	– Body style, engine make/power, transmission make/#gears, tire types. – Daily log of: mileage, total loads and fuel volume added.	Average -0.93% for 15-month season

Source: Derived from three test reports by Surcel [Surcel, M.D., 2008, 2010a and 2010b].

The second test shown in Table B-25 involves a 5-axle tractor trailer (no roof-top aero treatment) and an empty 53 ft. van with a combined gross vehicle weight of 13,274 kg (29,203 lb) tested with frequent stops and short low-magnitude cruise speeds on the Blainville test loop [Surcel, M.D., 2010a]. The speed profile is illustrated in Figure B-5. Details were provided for the 410 hp engine, 6-speed transmission and tire types used on each truck tested. Air density was measured for each test and the fuel consumed during the test circuit was measured by weight. The test involved relatively low cruise speeds which, when combined with the no-load condition, meant the engine was operating at a very inefficient region of the engine's fuel map, and also a region where the 455 hp fuel map is worse than the 350 hp fuel map. Since the actual test engine was almost half-way between the two engines, simulations were run for each of the engines. The normalized fuel map for the larger engine resulted in simulated fuel consumption being 6.8% higher than the reported average — while the normalized fuel map for the smaller engine resulted in simulated fuel consumption being 8.5% lower than the reported average. The differences are relatively large; however, the average of the two fuel maps is within 1% of the test results. We do not believe this low-speed/empty-truck test condition would be encountered in any of the line-haul services being simulated with HD-TEEM. Thus, the model is used with the normalized fuel map of the 455 hp engine for trucks using engines of 400 hp or more, and with the normalized fuel map of the 350 hp engine for trucks using engines less than 400 hp. For low power urban applications, the model can be used with an interpolation of the two fuel maps, rather than simply selecting one or the other.

The third test shown in Table B-25 involves a field test of a fleet of high-volume woodchip trucks, in a shuttle service between Fraser Lake and Prince George, BC [Surcel, M.D., 2010-b)]. The service involved an 8-axle, tractor-twin trailer (B-train) configuration (see Figure B-6) taking loads to Prince George and running empty back to Fraser Lake. The normal round trip was about 340 km, except that about 20% of the trips involved a shorter round trip of 210 km on the same highway. The data logged each workday included fuel taken on, total distance traveled and total cargo loaded. The average fuel intensity of the control vehicles over the 15-month test period was 53.8 L/100 km). HD-TEEM simulated this service using all default values for a year-round service — with the following inputs estimated from the test information:

Figure B-5. Empty Truck Stop-And-Go Drive Schedule



Source: Derived from [Surcel, 2010-a)].

- The aerodynamic drag used for the tractor-twin trailer (B-train) configuration was that of a high cube van, lowered by 3% in recognition of the drop bottom configuration of the woodchip trailers (see Figure B-6):
  - an average load of 34 tonnes and a 100% empty return ratio derived from the test data;
  - each one-way trip estimated to involve 140 km of rural highway travel at an average speed of 103 km/h with two speed reductions to 70 km/h, each of 4 km length and 20 km urban travel, at: 14% free-flow, 31% LOS-E, 43% arterial and 12% LOS-F/plant access;
  - combined running and layover idle time assumed to average 8.5 hr per operating day.

The simulated average annual fuel intensity for the service was 53.3 L/100-km (4.4 mpg), comprised of 61.7 L/100-km (3.81 mpg) when loaded and 44.9 L/100-km (5.24 mpg) when empty. The simulation result is less than 1% lower than the average for the three trucks over 15 months of field data.

Figure B-6. Woodchip Combination Tractor and Dual Trailers (B-train)

Source: Surcel, M. D., and R. Jokai, 2010.

In addition to validation against the above three test conditions, the model has been cross-validated with other time-step simulation models involving grades and with engine dynamometer test data. Given the demonstrated accuracy of the simulation model in predicting the fuel efficiency of a wide range of truck configurations and duty cycles, we conclude that the model can be used to make reasonable performance estimates for the range of trucks used in the Great Lakes-Seaway region.

B.4.3 Cargo-Specific Truck Characteristics (2010, Canada and U.S.)

B.4.3.1 Truck Configurations

Truck competitive cargoes in the Great Lakes-Seaway region include bulk commodities, such as construction aggregate and salt; general cargo, such as unfinished steel and aluminum and metal products; and project cargo, such as windmill components. Due to different axle load limits in Canada and the U.S., the truck styles used to transport bulk commodities and general cargo will differ on each side of the border. Project cargo is often a dimensional load that requires special handling, and permits must be obtained from provincial or state authorities. Where permits are provided, similar truck configurations are involved.

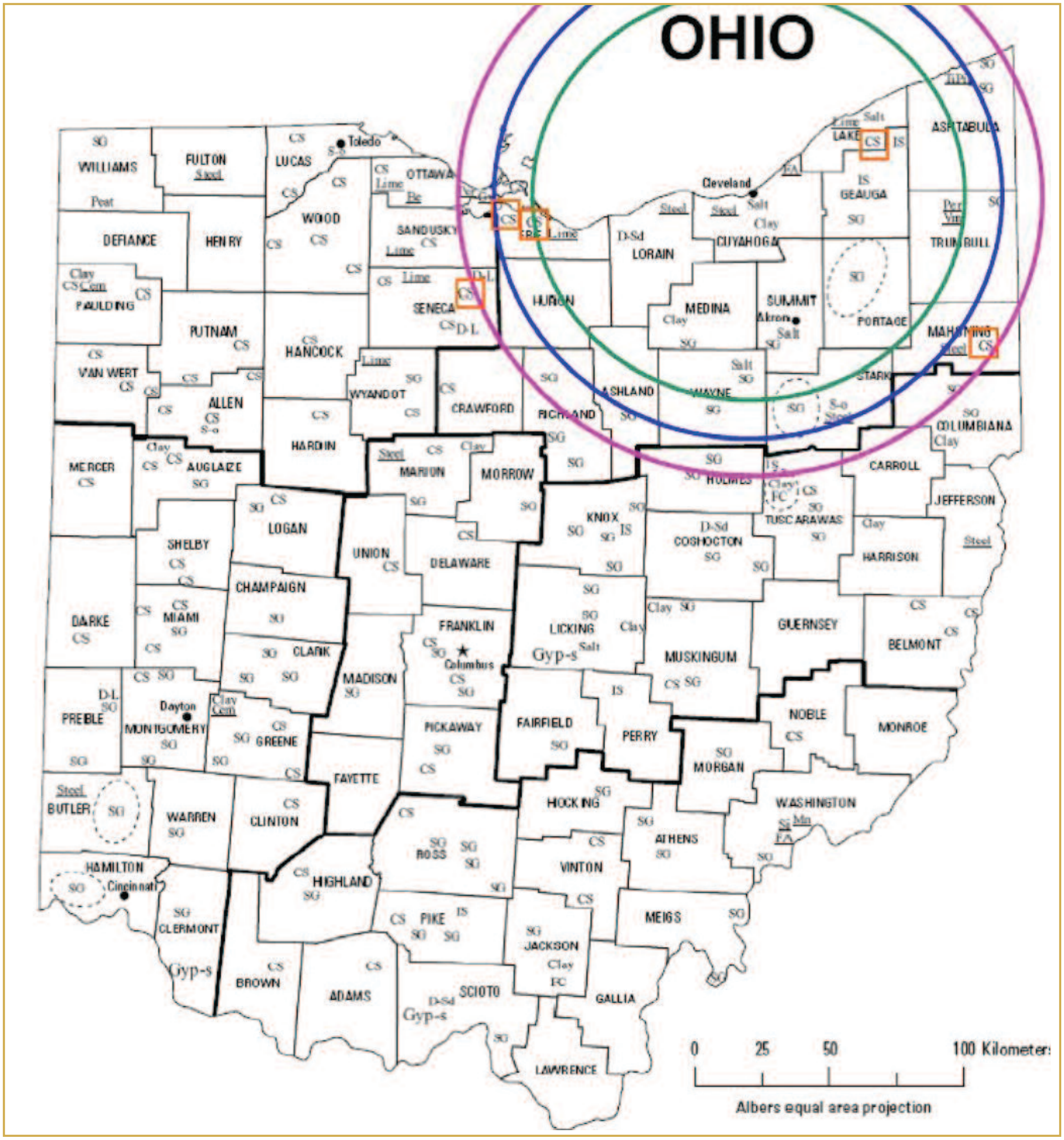
B.4.3.1.1 Bulk Cargo Truck Characteristics

Trucks are seldom cost-competitive with marine for the same origin-destination movement of bulk cargoes, but can be competitive from a closer source location. This was illustrated in a scenario assessed for the Canadian Shipowners Association (CSA) by RTG for aggregate supply in Ohio [Research and Traffic Group, 2009]. The study assessed the potential mode-shift impacts of the extension of Emissions Control Area (ECA) regulations into the Great Lakes-Seaway region. Using Ontario GVW limit for trucks, it was estimated that each $1.00 increase in marine rates would expand the competitive radius of a land-based quarry by 13 to 16 km. Figure B-7 illustrates the truck-competitive radius with marine shipments brought into Cleveland from northern Lake Huron. The green arc is the existing boundary within which trucks can bring aggregate to Cleveland for the same or lower cost than can marine. There is one crushed-stone facility inside that arc and one close to the boundary. The post-ECA rates for the average fleet composition would expand the competitive radius (the blue ECA-Avg line), such that there are three crushed-stone facilities inside the competitive radius. Similarly, the ECA-Hi rate adds one more crushed-stone source and places an additional one on the boundary.

A similar situation of alternate closer sources being competitive by truck exists for corn, and to some degree, salt. Short hauls of aggregate are often carried by 4-axle dump trucks on both sides of the border, sometimes with long-tongued pup-trailers. Longer-haul services might use tractor-trailer configurations with 5 or more axles and dump-style trailers. In some U.S. states one extra axle is permitted to a GVW of 90,000 lb (40,900 kg) and in Canada, 4 extra axles can be used to a GVW limit of 63,500 kg (139,700 lb). Lower-density agricultural commodities can be hauled in 8-axle “B-train” hopper configurations in Canada with the same GVW limit. Receiving pits are required to use the bottom-dump hopper trucks, so they are mostly used for grains.

The HD-TEEM simulation model is sensitive to the use of second trailers, the total number of axles for the truck, and the aerodynamic drag associated with the body style and configuration. The average truck configurations for three bulk commodities, as derived from the 2006 Truck National Roadside Survey, are summarized in Table B-26. In addition to the data from the survey, the estimated average aerodynamic drag for the body-style and configuration of the trucks involved is shown in the last column. The model uses the fractional averages of axles in the simulation — an input of 5.5 axles produces the same results as the average of separate simulations of one 5-axle truck and one 6-axle truck. The empty trip ratio shown is the ratio of empty-distance/total distance. Thus, a 50% empty trip ratio reflects a service with 100% empty-return ratio (empty-distance/loaded-distance).

Figure B-7. Illustration of Increasing Truck-Competitive Radius with Higher Marine Costs



Source: [Research and Traffic Group, 2009].

Table B-26. Truck Characteristics for Long-haul Bulk Cargo in Ontario and Quebec

Cargo Description	Average Cargo Weight		Average Number of Axles	% with an Extra Trailer	Average Tare Weight		Empty/ Total Trip-ratio (%)	Aerodynamic drag 'CdA' (m²)	
	Tonne	*Ton*			*Tonne*	*Ton*		*Loaded*	*Empty*
Cereal grains[1]	29.95	32.95	6.21	9	17.92	19.71	0.26	6.00	7.2
Metallic ores and concentrates[2]	38.22	42.04	7.03	45	18.28	20.11	0.26	6.19	7.5
Sand/gravel/non-metallic minerals[3]	33.73	37.10	7.36	46	16.45	18.10	0.26	6.20	7.5

Notes:
1. e.g. wheat, canola, corn, rye, barley, oats
2. e.g. iron, copper, nickel, aluminum, lead, zinc
3. e.g. salt, clays, sulfur, gypsum

Source: Derived from the 2006 *Truck National Roadside Survey* for trips in Ontario/Quebec greater than 5 hours ("Adjusted CdA" or aerodynamic drag area is estimated by RTG on the basis of data and field test results for similar vehicles).

As noted, many of the marine-competitive services by truck are from a different source with a shorter trip. These types of trips are not captured by the Intercity National Roadside Survey and need to be estimated. For most of the short-distance bulk movements, a shuttle service would be used with no backhaul opportunities and some dump-style straight trucks would be used. The estimated characteristics of local short-haul services are summarized in Table B-27.

The characteristics in the last row (Tractor Trailer Combination — US) are also applicable to U.S. long-haul bulk service.

Table B-27. Estimated Characteristics of Short-haul Dump Trucks (Canada and U.S.)

Body Style/ Location	Average Cargo Weight		Average Number of Axles	% with an Extra Trailer	Average Tare Weight		Empty/ Total Trip-ratio (%)	Aerodynamic drag 'CdA' (m²)	
	Tonne	*Ton*			*Tonne*	*Ton*		*Loaded*	*Empty*
Straight/Single-Frame (CAN and US)	21.4	23.5	4.8	20	13.3	13.8	50	6.2	6.8
Tractor Trailer Combination (CAN)	39.0	42.9	6	0	16.45	18.1	50	6.0	6.4
Tractor Trailer Combination (US)*	24.1	26.5	5.5	0	14.1	15.5	50	5.8	6.2

* The Semi-trailer Dump (US) characterization is also applicable to U.S. long-haul bulk service.

Source: Estimated by RTG.

B.4.3.1.2 General Cargo Truck Characteristics

Much of the type of general cargo carried by the marine mode is carried with flatbed semi-trailers on highways, although some machinery and parts are carried with semi-trailer vans. In Canada, a wide range of configurations are involved. The average truck configurations for three types of general cargo, as derived from the 2006 Truck National Roadside Survey, are summarized in Table B-28. The estimated average aerodynamic drag for the style and configuration of the trucks involved is shown in the last two data columns.

Table B-28. Truck Characteristics for Long-haul General Cargo in Ontario and Quebec

Cargo Description	Average Cargo Weight		Average Number of Axles	% with an Extra Trailer	Average Tare Weight		Empty/ Total Trip-ratio (%)	Aerodynamic drag 'CdA' (m^2)	
	Tonne	*Ton*			*Tonne*	*Ton*		*Loaded*	*Empty*
Base Metals	29.7	32.7	7.04	21	17.6	19.4	23	4.75	4.75
Articles of Base Metal	21.4	23.5	5.90	9	16.7	18.4	13	7.13	5.5
Machinery	12.6	13.9	5.72	9	16.6	18.3	20	6.60	5.5

Source: Derived from the 2006 Truck National Roadside Survey for trips in Ontario/Quebec greater than 5 hours ("Adjusted CdA" estimated by RTG).

In the U.S., 5- and 6-axle tractor-trailer trucks are used. Much of the national highway system has an 80,000 lb (36,3636 kg) load limit, although some states in the Great Lakes-Seaway region have 90,000 lb (40,9090 kg) limits for 6-axle trucks. To estimate the characteristics of trucks on the U.S. side of the border for the same types of general cargo shown in Table B-29, we assume the same loads per non-steering axle as in Canada, but with a reduced number of axles in the U.S. and no second trailers.

Table B-29. Estimated Average Values for U.S. HDD Truck Trips for General Cargo

Cargo Description	Average Cargo Weight		Average Number of Axles	% with an Extra Trailer	Average Tare Weight		Empty/ Total Trip-ratio (%)	Average Adjusted CdA	
	Tonne	*Ton*			*Tonne*	*Ton*		*Loaded*	*Empty*
Base Metals	21.6	23.76	5.4	0	12.8	14.1	23	4.63	4.63
Articles of Base Metal	18.3	20.13	5.4	0	12.8	14.1	13	7.08	5.45
Machinery	10.9	11.99	5.1	0	13.2	14.5	20	6.55	5.45

Source: Estimated by RTG (see text).

Project cargo is a special component of the general cargo category. As noted, truck configurations used to transport project cargo often involves special permits for dimensional loads. For example, windmill components are transported by special trucks with 7 to 11 axles. An 11-axle configuration uses two 3-axle centre dollies (see Figure B-8), which can be removed and transported by the remaining 5-axle flatbed on the return trip. As illustrated in Figure B-8, the loaded trip involves escort vehicles, when oversized loads are involved.

Another option for some types of project cargo is to disassemble or break down components for shipping by truck and reassemble at site. In this case, conventional flatbed trucks could be used.

The energy and emissions intensity of project cargo will be very sensitive to the dimensions of the specific cargo being carried. It will be characterized for a case study, if one is selected for this study.

Figure B-8. Illustration of an 11-axle Tractor-Trailer Hauling a Dimensional Load

Source: TBM Transport — subsidiary of Robert Transport (www.tbmtransport.com).

B.4.3.1.3 Liquid Cargo Truck Characteristics

The average truck configuration for liquid cargo is based on petroleum and petroleum products.[10] The average truck configuration, as derived from the 2006 Truck National Roadside Survey, is summarized in Table B-30. The first row is for Canada, while the second has the estimated characteristics for U.S. axle load limits. The estimated average aerodynamic drag for the style and configuration of the trucks involved is shown in the last column.

Table B-30. Estimated Characteristics of Long-haul Liquid Tank Trucks (Canada and U.S.)

Description	Cargo Weight		Number of Axles	% with an Extra Trailer	Tare Weight		Empty/ Total Trip-ratio	Aerodynamic drag 'CdA' (m^2)
	Tonne	**Ton**			**Tonne**	**Ton**		
Liquid Tank Truck (CAN)[a)]	34.6	38.1	7.88	0.90	17.2	18.9	0.37	6.78
Liquid Tank Truck (US)[b)]	23.4	25.7	5.80	0.00	14.5	15.9	0.37	6.50

Source: (a) Derived from the 2006 Truck National Roadside Survey for trips in Ontario/Quebec greater than 5 hours.
(b) U.S. data and adjusted CdA estimated by RTG.

B.4.4 Simulated Emissions Intensities

The truck simulations were run on the basis of 72% occurring on rural freeways for U.S. travel and 79% on rural highways for Canadian travel. The remainder of the travel was on urban freeways (except for 1.5% on urban arterials). The simulations were run for the fleet characteristics estimated for 2010 and for a hypothetical post-regulatory fleet comprised of 100% new vehicles. This is consistent with the post-regulatory scenario assumed for rail and for marine.

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[10] The 'chemicals' category for trucking data included some dry cargo as well as liquids so the chemical category was not included in this 'liquid bulk' comparison.

The EPA has no new CAC regulations in the works for trucks; however, it has introduced a rule requiring reductions of GHG emissions by 2014 and later [Federal Register, 2009, Federal Register, 2011]. As these reductions involve fuel-efficiency improvements to engines and tractors, CAC emissions from the engine will see a reduction in proportion to the fuel reduction. The average reductions sought from tractor suppliers include the savings required by engine suppliers and the combined reductions vary by class of truck and cab style. The U.S. EPA CO_2 emission standards, with reductions from baseline, are as shown in the Table B-31. The combined engine and tractor body reductions required by 2014 range from 7% to 20% and a further 3% is required by 2017. In April 2012, Canada proposed to adopt equivalent standards [Canada Gazette, 2012].

Table B-31. U.S. EPA CO_2 Emission Standards for Post 2014

Tractor Class	Tractor Cab Style	2010 Baseline (g/ton-mile)	2014-2016 Model Years		2017 and later Model Years	
			(g/ton-mile)	*Reduction*	*(g/ton-mile)*	*Reduction*
Class 7	Low-roof (all cab styles)	116	107	7.76%	104	10.34%
Class 7	Mid-roof (all cab styles)	128	119	7.03%	115	10.16%
Class 7	High-roof (all cab styles)	138	124	10.14%	120	13.04%
Class 8	Low-roof day cab	88	81	7.95%	80	9.09%
Class 8	Low-roof sleeper cab	80	68	15.00%	66	17.50%
Class 8	Mid-roof day cab	95	88	7.37%	86	9.47%
Class 8	Mid-roof sleeper cab	89	76	14.61%	73	17.98%
Class 8	High-roof day cab	103	92	10.68%	89	13.59%
Class 8	High-roof sleeper cab	94	75	20.21%	72	23.40%

Data Source: Federal Register/Vol. 76, No. 179/Thursday, September 15, 2011/Rules and Regulation (http://www.gpo.gov/fdsys/pkg/FR-2011-09-15/pdf/2011-20740.pdf)

It should be noted that the baseline and future CO_2 emissions intensities shown in Table B-31 are not necessarily indicative of a specific truck's in-service performance. Rather it is based on selected truck configurations in the loaded condition. Regulatory conformance is evaluated using the U.S. EPA's GEM computer program. The GEM software uses a standardized model, offering engine fuel maps representative of 2010, 2014 and 2017 model- year engines, and simple selection of the tractor class and cab configuration; it also allows the user to input the aerodynamic and tire rolling resistance coefficients to suit the particular tractor being evaluated. Additional tractor customization is input to the model in terms of an aggregate weight reduction value, which reduces the baseline tractor tare weight by an amount which corresponds to all of the non-standard mechanical components installed on the tractor, following the guidance as provided in Section 34 Subsection (2) of the Canadian regulations. When combination tractors are being evaluated, the GEM program assumes a standard 53 ft box trailer with a standard payload suitable for each regulatory tractor class (19 tons for Class 8 and 12.5 tons for Class 7). The overall fuel consumption and CO_2 emissions of a truck are then calculated as a truck-class specific weighted combination of individual fuel consumptions and emissions associated with operating over the ARB transient duty cycle, a 55 mph cruise duty cycle and a 65 mph cruise duty cycle. The additional impact of speed limiters on fuel consumption is facilitated by allowing the user to input the maximum speed imposed by installation of a speed limiter. An additional 5 gram CO_2/ton-mile credit applies for any sleeper cab combination tractor, equipped with an extended idle reduction technology and having a 5-minute automatic engine shutoff.

The GHG regulations do not have an enforcement mechanism for subsequent tire replacement by operators. The EPA view is that manufacturers will have to spend the money upfront to facilitate manufacture of low rolling resistance tires to supply on new trucks, and that these tires will therefore be available for replacement purchase at competitive prices and that truckers/companies will recognize the benefits in reduced fuel consumption when making purchasing decisions.[11] We note that the fact that regulations are required to enforce the use of low rolling resistance tires in the first place, is an indication that many operators will not continue to use them on renewal. Nonetheless, our post-regulatory scenario for trucks assumes the improvements required by the EPA for tractor manufacturers are adopted and maintained by operators. The resulting fleet-average emissions intensities for the 2010 fleet and the long-term post-regulatory performance are summarized in Table B-32. Note that the numerator is in g and lb for CO_2-e emissions and milligrams (mg) for all other emissions. The denominators are revenue tonne-km (CTK) and cargo ton-miles (CTM). A milligram per cargo-ton-mile (mg/CTM) is equivalent to a gram per thousand-net-ton-miles. The values are those derived for the specific body styles and cargo weights involved in hauling the Great Lakes-Seaway cargo mix of 2010 (see Table B-33 of the next Section for the Great Lakes-Seaway cargo mix). The underlying fuel efficiency values in Canada were 42.4 CTK/L for 2010 and 48.7 CTK/L post renewal. For the U.S. the fuel-efficiency values were 89.1 CTM/US-gal (34.3 CTK/L) in 2010 and 102.7 CTM/US-gal (39.57 CTK/L) post renewal.

Table B-32. Derived Fleet Average Truck Emissions Intensities for Great Lakes-Seaway Cargo

Jurisdiction	Term	CO_2-e		NO_X		CO		HC		SO_X		PM	
		(g/ CTK)	*(lb/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*
CAN	2010	63.4	203.5	315.2	459.9	95.3	139.0	11.9	17.4	0.6	0.9	11.4	16.6
	Post-Renewal	55.1	177.0	27.1	39.5	104.5	152.5	1.3	1.9	0.5	0.8	2.4	3.6
U.S.	2010	78.3	251.2	391.6	571.4	117.6	171.6	14.7	21.4	0.7	1.1	13.7	20.0
	Post-Renewal	67.9	217.9	38.5	56.2	128.7	187.8	1.6	2.4	0.636	0.928	2.7	4.0

Note: The increased intensity for CO in the post-renewal scenario appears to be related to the technologies used to meet the 2008-2010 NO_X and PM standards. While the CO emissions rates are well within the EPA standard for CO, the certification test data for HDD truck engines showed an increase over previous years in both the initial emissions levels and the life deterioration factors for CO. The increased intensity in g-emitted/kg-fuel to meet the 2010 CAC regulations more than offsets the fuel reductions due to GHG regulations for 2014-2019.

Source: RTG calculations.

Another factor that could affect truck efficiency in the U.S. is the potential for the federal government to mandate an increase in truck axle load limits from 80,000 lb to 97,000 lb and to allow multiple trailers.[12] The axle load increase would affect the fuel intensities of U.S. trucks for all categories of cargo considered here, except finished metal products and machinery. This change is not included in our post-regulatory scenario.

B.5 Marine Mode Air Emissions Characterization

B.5.1 Fleet Segmentation

The marine operations in the Great Lakes-Seaway System include Canadian, U.S. and internationally flagged vessels. The dimensions of the Soo locks at Sault St. Marie are larger than those in the Montreal-Lake Ontario (MLO) segment of Seaway and the Welland Canal between Lake Erie and Lake Ontario. A large portion of the U.S. Fleet is sized to fit through the Soo locks but is either too long or too wide to transit the Welland Canal and MLO locks. The Canadian fleet is sized to fit through the MLO and Welland locks and carries much of the traffic that moves into or out of the upper four lakes. International fleets are restricted by cabotage laws to carrying import/ export traffic and must transit the Seaway in the process.

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[11] Federal Register/Vol. 76, No. 179/Thursday, September 15, 2011/Rules and Regulation, p. 57278.

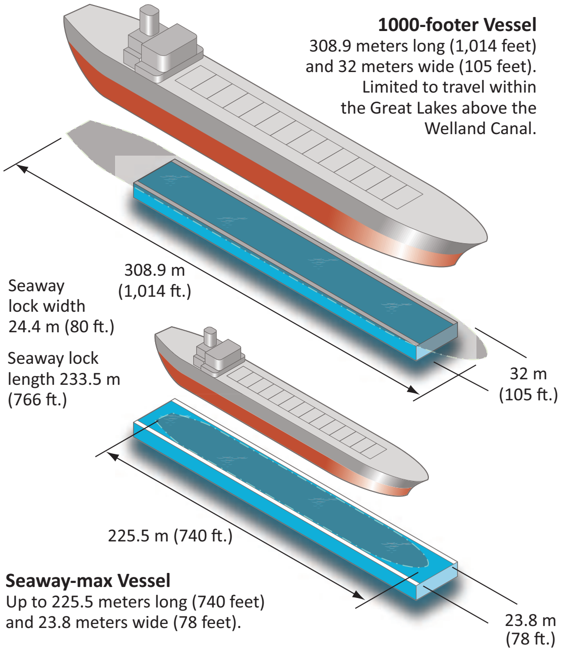
[12] Consideration of such a change has been deferred for at least three years, as the Department of Transportation has been ordered to "*...conduct a study on the potential impact of heavier trucks on safety and infrastructure*". Source: AAR Smart Brief, February 3, 2012.

The dimensional constraints of the Seaway locks are compared with the dimensional constraints of the Soo locks in Figure B-9. In this report, we refer to vessels sized to the Seaway limits as Seaway-max vessels and vessels sized to the limits of the Poe lock (one of the Soo locks) as Poe-max vessels.

Marine operational performance data are not publicly available. We were provided confidential data from U.S., Canadian and international carriers, on the agreement that the data would be aggregated and averaged in reporting. In order to keep confidentiality, the data are segmented into the U.S. Fleet (based on data from three carriers) and the Seaway-size Fleet (based on data from two Canadian carriers and two international carriers).

Figure B-9. Vessel Dimensions Constraints Imposed by the Locks of the Great Lakes-Seaway System

Source: Derived from *Great Lakes St. Lawrence Seaway Study*, Transport Canada, et. al., Fall, 2007.



1000-footer Vessel
308.9 meters long (1,014 feet) and 32 meters wide (105 feet). Limited to travel within the Great Lakes above the Welland Canal.

Seaway-max Vessel
Up to 225.5 meters long (740 feet) and 23.8 meters wide (78 feet).

Soo Locks Dimensions:*

Poe Lock:

Length	366.0 m	(1200 ft)
Width	33.5 m	(110 ft)
Depth	9.8 m	(32 ft)

MacArthur Lock:

Length	244.0 m	(800 ft)
Width	24.4 m	(80 ft)
Depth	9.4 m	(31 ft)

* Either the Poe lock or the MacArthur lock can be used to transit between Lake Superior and Lake Huron.

Seaway System Dimensions:**

Length	233.5 m	(766 ft)
Width	24.4 m	(80 ft)
Depth	8.2 m	(27 ft)

** Both the MLO and Welland Canal segments operate with these constraining dimensions.

B.5.2 Baseline Traffic

The major commodity movements in the Great Lakes-Seaway System are iron ore into the lakes, grain out of the lakes, and coal, iron ore and stone within the lakes. Other important movements include petroleum products, chemicals, salt and fertilizer. Table B-33 illustrates the distribution of cargo on a tonnage-loaded basis. On a tonne-km basis, grain would be a higher proportion and aggregate a lower proportion.

Table B-33. Cargo Load Distribution for 2010

Cargo Type	Distribution
Iron Ore	38%
Coal	25%
Aggregate/Other Bulk	20%
Grain	12%
General Cargo	3%
Liquid Cargo	2%

Source: Derived from USACE and SLSMC Traffic Data.

Most of the seven participating carriers provided confidential data for the following:

- Tonne-km of cargo moved by vessel;
- Total fuel consumed by vessel and by type of fuel; and
- Propulsion and auxiliary engine types by vessel.

Some carriers provided active days in 2010 by vessel, vessel engine types for each vessel, a breakout of typical activity (days-loading/unloading/in-transit) by vessel class and estimated emissions — from which we estimated tonne-km of cargo moved, fuel consumed and emissions generated. Total traffic for 2010 was available on a tonnage-carried basis from U.S. Army Corp of Engineers (USACE) and St. Lawrence Seaway Management Corporation (SLSMC) data. However, traffic activity on a tonne-km (ton-mile) basis had to be estimated, as the underlying vessel-trip data are confidential. We estimated total tonne-km travel on the basis of regional origin destination data that are published by USACE and SLSMC. International traffic was limited to those vessels that entered the MLO section of the Seaway and trip distances were limited to the Great Lakes-Seaway region west of Les Escoumins, QC. The resulting estimate, broken out by country, is provided in Table B-34. The corresponding sample size of the data provided by the seven cooperating carriers is shown in Table B-35. As indicated, the cooperating U.S. and Canadian carriers represent over 80% of the corresponding activity. The international sample was the lowest, but as can been seen in Table B-34, the international traffic is less than 5% (i.e. 7/147) of total tonne-km. Overall, the tonne-km weighted average sample size was 79%.

Table B-34. Traffic Distribution by Country for 2010

Country*	Tonnes	Tons
U.S.–U.S.	72,888,797	80,323,455
Cross-border	32,731,818	36,070,464
Canada–Canada	21,359,455	23,538,119
International	6,386,520	7,037,945
Total	133,366,590	146,969,982
	km	***miles***
Average Distance	1,090	677.5
	Million tonne-km	***Million ton-miles***
Total Activity	145,276	99,572

Source: Derived from confidential carrier data, as well as USACE and SLSMC Traffic Data.

Table B-35. Carrier Provided Data (% of Total Derived Traffic by Vessel Flag)

Source	Sample Proportion of Total Tonne-km
Canadian Carriers	80%
U.S. Carriers (full details*)	41%
U.S. Carriers (including partial details*)	83%
International Carriers	31%
Tankers (Canada and International)	66%
Overall	79%

* Carriers providing full details included fuel and cargo ton-miles, whereas those providing partial details included vessel characteristics, vessel usage and estimated emissions but not fuel and cargo tonnage.

Source: RTG analysis.

The vessel types included in the sample are summarized in Table B-36. The 12 Poe-max vessels represent 100% of the active fleet in 2010 — one of the 13 Poe-max vessels was out of service.

Table B-36. Carrier Provided Data (Number of Vessels by Class)

Vessel Class	Detailed Data[1]	Summary Data[1]	Total Number
Poe-max (1,000') SU[2]	6	6	12
>Seaway-max and <Poe-max SU	9	1	10
<=Seaway length (740') SU and Bulk[3]	47	6	53
International General Cargo	10	0	10
Tanker (domestic and International)	7	0	7
Total Vessels[4]	79	13	92

Notes:

1. Detailed data included fuel, trips and cargo-ton-miles. Carriers providing less detail, excluded fuel consumed and cargo moved but included the number of active days in 2010 by vessel, vessel engine types for each vessel and a breakout of typical activity (days-loading/unloading/in-transit) by vessel class; see text.
2. Self-unloader
3. Eight of the 53 were U.S. flag, 45 were Canadian flag.
4. Two self-unloaders were dedicated tug/barge configurations.

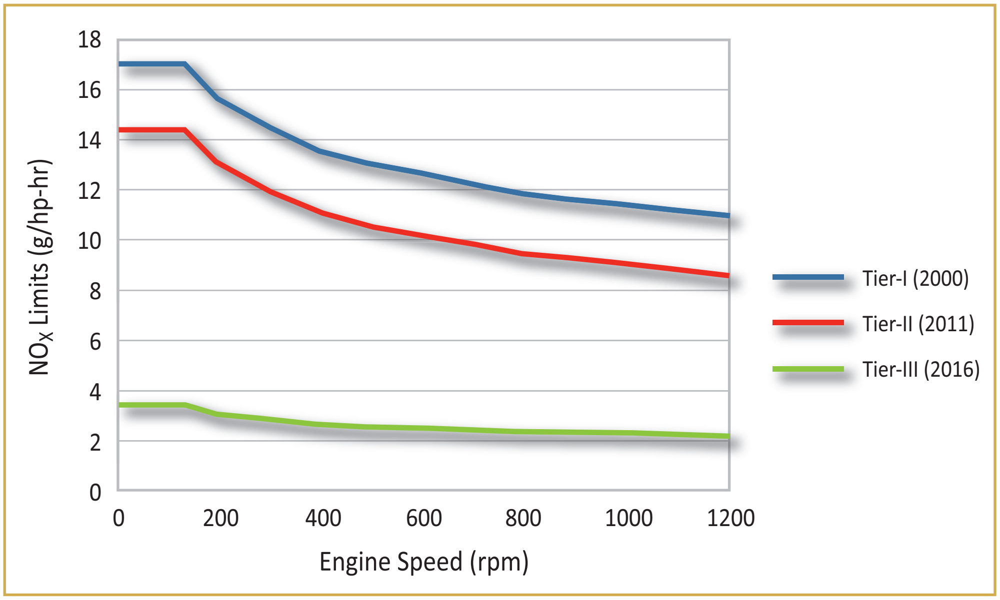
Source: RTG analysis of confidential carrier data.

B.5.3 Segmentation of Fuel Types

Emissions intensities vary across the engine types and fuels used by fleets operating in the Great Lakes-Seaway System. Figure B-10 illustrates the relationship of NO_X emissions with engine speed under the IMO/EPA regulations adopted for ECAs. The propulsion engine types used in the fleets include medium speed diesel (MSD) engines, slow speed diesel engines (SSD), and steamers. The types of fuel used by the diesel propulsion engines are intermediate fuel oil (IFO) and marine diesel oil (MDO), and the steamers use residual fuel oil (RFO). With the exception of steamers, auxiliary engines are medium speed diesel engines using MDO. Steamers use RFO in boilers to generate steam for both propulsion and auxiliary electrical generators. On the basis of sample testing conducted on a few Canadian vessels, it is believed that the diesel-powered vessels in the fleets are Tier I-compliant and possibly close to Tier II-compliance.

Table B-37 summarizes proportional breakout of the Great Lakes-Seaway System's fleets' engine types and fuels used.

Figure B-10. IMO's NO_X Limits for New Marine Propulsion Engines



Note: The IMO's tier levels are similar to the tier 0 through 4 levels used for rail regulations only to the extent that higher numbers are more stringent. The use of Roman numerals in place of Arabic numbers only reflects a style choice (or possibly in recognition of a Tier 0 in the rail regulations).

Source: RTG from IMO/EPA regulations.

Table B-37. Distribution of Fuel Types for the Great Lakes-Seaway System Fleets Sample in 2010

Fuel/Engine/Vessel Type	Proportion of Fleet
Auxiliary Engine Fuel	
MDO with self-unloader	75.9%
MDO with bulker	15.6%
Residual/#6 with self-unloader	8.5%
Main/Propulsion Engine Fuel	
MDO	24.6%
IFO	65.3%
Residual/#6	10.1%
Propulsion Engine Type	
Medium speed diesel	59.1%
Low speed diesel	30.9%
Steamer	10.0%

Source: Derived from USACE and SLSMC Traffic Data.

B.5.4 Emissions Intensity by Fuel Type

The Canadian carriers provided the emissions intensity parameters that were used in the 2010 application of Environment Canada's marine emissions inventory tool (MEIT) model to the Great Lakes-Seaway region. Sulfur content of marine fuels in 2010 was based on the average of a sample of fueling points in the Great Lakes-Seaway System. In addition to the 2016 tier III NO_X limits illustrated in Figure B-10, the EPA and Environment Canada will require reduced SO_2 content in marine fuels. The SO_2 content for fuel used in auxiliary engines will be 15 ppm and the particulate matter (PM) emissions limit for auxiliary engine exhaust will be 0.04 g/kWh; both are the same as those for railway locomotives. The SO_2 content for propulsion engines is set to 1,000 ppm (or exhaust scrubbers to achieve the equivalent result), with some transition arrangements that vary by country. In Canada, the propulsion requirement will be phased in (from 1.6% in 2011 to 0.1% by 2020). The U.S. requirement is for MDO-use in propulsion engines by 2015 with an exemption for steamers, which will have an extension to 2025 and a Grant Program to assist in conversion of steamers to diesel engines. The new regulations do not set a specific PM limit for propulsion engines, since sulfur content, which has a large influence on the PM content, will be significantly reduced. The PM equation used by the EPA [EPA, 2010] for non-road diesel engines is:

PM (g/kWh) = PM-base + 0.1573 (sulfur proportion-base – sulfur proportion-new)

We used the Canadian MEIT data to develop the CAC and GHG intensities on a g-emitted/kg-fuel basis by fuel type for 2010 for both fleets. We applied the circa-2016 regulatory limits to update the post-renewal intensities. The resulting emissions intensities are summarized in Table B-38 for 2010 and Table B-39 for the post-renewal scenario. The PM standard for auxiliary engines requires exhaust scrubbers, whereas propulsion engines do not, and thus, the PM intensity is different for the two engine types. The limits for CO and HC are higher in 2016 than the 2010 performance and we assume the 2010 performance is maintained.

Table B-38. Year 2010 Marine Emissions Intensity (Used for All Vessel Flags)

Fuel Type		min BSFC (g/kWh)	Emissions factors (g-emitted/kg-fuel)					
			CO_2e	NO_X	CO	HC	SO_2	PM
MDO-Auxiliary		210	3221.5	66.2	5.2	1.9	0.54	1.07
MDO-645 Engine		240	3221.5	57.5	4.6	1.7	0.54	1.07
IFO-MSD	Domestic	180	3221.1	62.8	6.1	2.8	33.40	5.49
	International	180	3221.1	62.8	6.1	2.8	29.40	5.36
IFO-SSD	Domestic	195	3217.6	82.6	7.2	3.1	33.40	5.49
	International	195	3217.6	87.2	7.2	3.1	29.40	5.36
Steam Boiler/Turbine		300	3218.7	12.3	4.6	0.4	37.50	2.17

Note: MSD – medium speed diesel, SSD – slow speed diesel.

Source: RTG analysis of carrier data inputs for Environment Canada's 2010 Marine Emissions Inventory Tool.

Table B-39. Post-renewal Emissions Intensity Factors (Used for All Vessel Flags)

Fuel/Engine Type	Regulatory Category[2]	min BSFC[3] (g/kWh)	Emissions factors (g-emitted/kg-fuel)					
			CO_2e	NO_X	CO	HC	SO_2	PM
MDO-Auxiliary	C2	210	3221.5	8.6	5.2	0.9	0.03	0.19
MDO-propulsion[1]	C3	170	3221.5	13.9	6.5	2.9	0.54	1.07
IFO-MSD-0.1%SO_2	C3	175	3221.1	15.2	6.3	2.9	1.9	1.29
IFO-SSD-0.1%SO_2	C3	175	3217.6	19.4	8.0	3.4	1.9	1.29

Notes:

1. Sulfur content is a fuel regulation and the MDO supplied for propulsion is assumed to be no worse than that supplied in 2010; however, the PM standard for auxiliary engines requires exhaust particulate filters, whereas propulsion engines do not, and thus, PM intensity is different for the two engine types.
2. Regulatory category C2 applies to engines with displacements of 5 to 30 litres per cylinder and the duty cycle is intended to be representative of an auxiliary power engine on a large vessel. Regulatory category C3 applies to large marine engines with displacements over 30 litres per cylinder and the duty cycle is intended to be representative of vessel propulsion engines.
3. BSFC is brake-specific fuel consumption.

Source: RTG analysis of carrier data inputs for Environment Canada's 2010 Marine Emissions Inventory Tool and 2016 regulatory requirements (EPA and EC).

The derived fleet-average emissions intensities on a g/CTK (g/CTM) basis are summarized in Table B-40 for the Seaway-size Fleet (top half) and for the U.S. Fleet (lower half).

Sulfur regulations are imposed on the fuel being used rather than the engines. The main propulsion engines will be required to use fuel with a maximum sulfur content of 0.1%, while the auxiliary engines that are used at port will be required to use fuel with a sulfur content of 0.0015%. The two separate requirements translate into reductions in the order of 94% of the 2010-level emissions from each engine type. Marine diesel oil (MDO) is presently used in auxiliary engines, while many vessels use an intermediate fuel oil (IFO) for propulsion — a blend of heavy residual oil and diesel oil. Canadian carriers will be phasing in the use of MDO until the blend is 100% MDO. While the regulation allows a fuel of 0.1% sulfur content, the suppliers of MDO are not expected to create a separate type of MDO for propulsion engines — the sulfur content of MDO supplied in 2010 was already below the 0.1% requirement for propulsion fuels post-regulation. Thus, we assume that once 100% MDO is attained, the sulfur content of that fuel will be 0.0015%, regardless of the application. In Table B-40, MDO-P1 indicates results at the regulatory limit; MDO-P2 indicates the 2010 value (which is lower than the regulatory limit); and MDO-P3 is our base-case assumption of one fuel with the same sulfur content as is required for auxiliary engines.

PM emissions are not being directly regulated for marine propulsion engines; however, due to the high correlation of PM emissions to sulfur content, the sulfur content regulations will lead to reduced PM emissions. The auxiliary engines that are used at port will be required to meet an emissions level of 0.04 g/kWh, representing an 82% reduction from the 2010 emissions levels.

Table B-40. Derived Fleet Average Emissions Intensities by Fleet

Year	Scenario	CO_2-e		NO_X		CO		HC		SO_X		PM	
		(g/ CTK)	*(lb/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*	*(mg/ CTK)*	*(mg/ CTM)*
Seaway-size Fleet													
2010	Unadjusted	11.5	37.0	250.3	365.2	23.0	33.5	9.5	13.9	105.3	153.6	17.0	24.8
	Adjusted	12.5	40.2	270.9	395.2	24.8	36.2	10.2	14.9	110.4	161.0	20.8	30.3
Post-Renewal	MDO-P1	7.7	24.9	30.9	45.1	15.0	21.9	6.1	8.9	3.7	5.4	2.6	3.8
	MDO-P2	7.7	24.9	30.9	45.1	15.0	21.9	6.1	8.9	1.1	1.5	2.2	3.2
	MDO-P3	7.7	24.9	30.9	45.1	15.0	21.9	6.1	8.9	0.07	0.10	2.0	2.9
U.S. Fleet													
2010	Unadjusted	15.3	49.0	266.1	388.3	24.6	35.9	9.0	13.2	69.4	101.3	19.8	28.9
	Adjusted	12.4	39.6	215.2	313.9	20.0	29.1	7.4	10.8	58.9	85.9	10.1	14.7
Post-Renewal	MDO-P1	8.5	27.3	33.8	49.3	16.4	23.9	6.6	9.7	4.0	5.8	2.8	4.1
	MDO-P2	8.5	27.3	33.8	49.3	16.4	23.9	6.6	9.7	1.1	1.7	2.4	3.4
	MDO-P3	8.5	27.3	33.8	49.3	16.4	23.9	6.6	9.7	0.08	0.11	2.2	3.2

Notes: The values reflect average intensities of the Seaway-size Fleet carrying cargo typical of the Seaway-size Fleet and the U.S. Fleet carrying cargo typical of the U.S. Fleet.

The unadjusted values use the 2010 ballast ratio and all auxiliary fuel, while the adjusted values use 2008 ballast ratios, exclude self-unloading auxiliary power and 10% of hotel power at port, in order to get a like-for-like comparison.

The post-renewal SO_X and PM emissions for MDO-1 are based on propulsion fuel sulfur content being 0.1% as called for in the regulation, while in MDO-2, the sulfur content remains the same as it was in 2010 even though the regulation allows a higher level, and in MDO-3, the sulfur content of propulsion fuel MDO is the same as the auxiliary fuel MDO. MDO-3 is our base-case scenario.

The EPA regulatory limits for CO emissions were increased in concert with tighter NO_X regulations. The CO emissions in test data for other modes were well below the regulatory standard. Thus, we based the marine level on the 2010 CO emissions performance being maintained. If adjusted to the new regulatory limit, the marine emissions intensity for CO would be about 4.5 times higher than the values shown.

Source: RTG calculations.

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