BRIEFING

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Great Lakes-St. Lawrence Seaway ship emissions inventory, 2019

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The Great Lakes-St. Lawrence Seaway (GL-SLS) of North America extends more than 3,700 kilometers and is an important commercial waterway.[1] There are more than 110 ports within the GL-SLS system, and vessel operators transported over 143.5 million tonnes (Mt) of cargo with a value of US$15.2 billion on the GL-SLS system in 2017.[2] While research has found that ships are a relatively efficient mode of cargo transportation,[3] the sector currently relies on fossil fuels that pollute the air and contribute to climate change.

In 2012, the United States Environmental Protection Agency (EPA) published estimates of ship emissions in the Great Lakes that showed 541,336 tonnes of CO_2 in 2002 and predicted 704,390 tonnes CO_2 by 2020. However, this only accounted for Category 3 vessels operating within the U.S. portion of the Great Lakes, and thus covered only a portion of the GL-SLS area and fleet.[4] For example, Category 3 vessels accounted for 73% of the cargo capacity of bulk carriers, per the EPA report. This briefing paper presents an inventory that is both broader and based on more recent data: It covers all ships operating in the GL-GLS that we could identify for the year 2019. Here we present

1 "Overview of the Great Lakes / St. Lawrence Seaway," The St. Lawrence Seaway Management Corporation, accessed on December 24, 2021, https://greatlakes-seaway.com/wp-content/uploads/2019/10/overview_brochure-1.pdf.

2 "Economic Impacts of Maritime Shipping in the Great Lakes-St. Lawrence Region," Great Lakes St. Lawrence Seaway Development Corporation, accessed on November 30, 2021, https://www.seaway.dot.gov/publications/economic-impact-study. Throughout this paper, tonnes refers to metric tons, which is equal to 1,000 kg.

3 Bryan Comer et al., "Marine Vessels as Substitutes for Heavy-Duty Trucks in Great Lakes Freight Transportation," *Journal of the Air & Waste Management Association* 60, no. 7 (2010): 884–890, https://www.tandfonline.com/doi/abs/10.3155/1047-3289.60.7.884.

4 U.S. EPA Office of Transportation and Air Quality, "Economic Impacts of the Category 3 Marine Rule on Great Lakes Shipping," 2012, https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=OTAQ&dirEntryID=230803. Category 3 vessels are defined as having engines with a per cylinder displacement of at least 30 liters per cylinder and are usually the largest vessels on the lakes. In the report referenced here, EPA estimated that there were 12 U.S.-flagged and 68 Canada-flagged Category 3 vessels operating on the lakes based on 2010 data from Greenwoods Guide to Great Lakes Shipping.

the estimates of CO_2 emissions and fuel consumption. Our estimates of emissions of other air and climate pollutants, including methane (CH_4), nitrous oxide (N_2O), black carbon (BC), sulfur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), and volatile organic compounds (VOCs), are included in a supplemental statistics file on the ICCT website (see Appendix C for the link).

We used the Systematic Assessment of Vessel Emissions (SAVE) model developed by ICCT, and it estimates fuel use and emissions based on satellite and terrestrial Automatic Identification System (AIS) data from exactEarth and ship characteristics from IHS Markit. We intend to periodically update this inventory to cover more recent years, as data and resources permit. The results can be used by governments, ports, community groups, nongovernmental organizations, researchers, and other stakeholders as a baseline inventory to understand the potential benefits of developing policies, action plans, and roadmaps that can improve the environmental performance of maritime transport in the GL-SLS system.

DATA AND METHODS

We used the GL-SLS Geographic Information System (GIS) map layers published by the Great Lakes Commission to define the GL-SLS study region (Figure 1).[5] To analyze the different emissions characteristics between the GL and SLS, we split the Great Lakes from the St. Lawrence Seaway at the location of the Moses-Saunders Power Dam near Cornwall, Ontario, as shown in the right panel of Figure 1. In this paper, the GL-SLS covers the entire area in blue; the GL region is to the west of Cornwall, and the SLS region is to the east of Cornwall, ending between Cap-St-Ignace and L'Anse-à-Gilles, Québec.

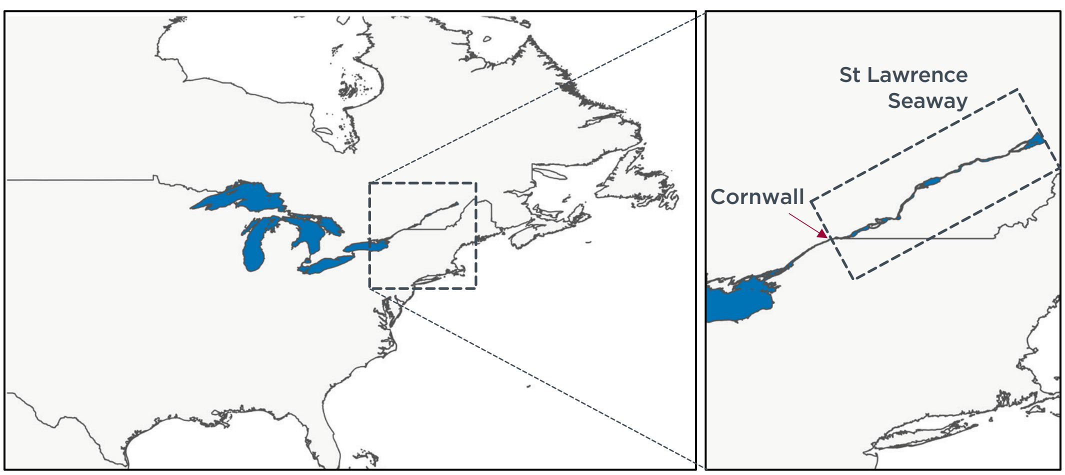

Figure 1. Study region (blue) and boundary between the Great Lakes and St. Lawrence Seaway regions (right panel).

EMISSIONS AND FUEL CONSUMPTION MODEL

We used ICCT's SAVE model, which has assumptions that are consistent with the *Fourth IMO Greenhouse Gas Study*, to identify the vessels operating in the GL-SLS system and

5 Great Lakes Commission, "Great Lakes Boundaries," last modified November 8, 2019, https://www.arcgis.com/home/item.html?id=d87347457bc84e5c985db9e904b66b10.

to estimate their fuel consumption and emissions.[6] The SAVE model was described in detail in a previous ICCT report about global shipping emissions.[7] SAVE uses AIS data from exactEarth, which provides timestamped activity for ships that includes their identification number (Internal Maritime Organization [IMO] number or Maritime Mobile Service Identity number), speed, heading, and draught. With the ships' location and speed at a specific timestamp in the AIS data, we can identify whether the ship operated in the GL-SLS and when this happened. SAVE matches ships in the AIS dataset to a ship characteristics database from IHS Markit based on their identification number.

The IHS dataset includes information about the ship type, size, engine power, maximum speed, flag state, and more. SAVE uses the information from IHS to predict the type of fuel each ship uses and adjusts the fuel type based on where the ship is operating and whether it is outfitted with an exhaust gas cleaning system, also known as a scrubber. For example, if the ship would normally use high-sulfur residual fuel, but it is operating in an Emission Control Area, SAVE assumes it switches to lower-sulfur distillate fuel unless the ship has a scrubber installed. This is an important feature because the GL-SLS is within the North American Emission Control Area. SAVE then estimates fuel consumption and emissions based on the ship's activity and characteristics; these are a function of fuel type, engine power, maximum speed, actual speed over ground, and emission factors. The emission factors are the same as those used in the *Fourth IMO Greenhouse Gas Study*, except for ships that use heavy fuel oil with scrubbers. In the case of ships with scrubbers, we apply emission factors developed by the ICCT that account for how scrubbers affect emissions of air pollutants and greenhouse gases.[8]

RESULTS

We identified 953 vessels operating in the GL-SLS in 2019. Of these, bulk carriers were the most common (40%) and second most common were chemical tankers (22%). This is shown in Table 1, which also shows that in the GL-SLS, ships flagged to Canada, the Marshall Islands, and the United States were the most common, accounting for 19%, 16%, and 10% of the total, respectively.

6 Jasper Faber et al., "Fourth IMO Greenhouse Gas Study," (London: International Maritime Organization, 2021), https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf.

7 Naya Olmer et al., *Greenhouse gas emissions from global shipping, 2013–2015*, (ICCT: Washington, D.C., 2017), https://theicct.org/publications/GHG-emissions-global-shipping-2013-2015.

8 See Table 6 in Bryan Comer, Elise Georgeff, and Liudmila Osipova, *Air emissions and water pollution discharges from ships with scrubbers*, (ICCT: Washington, D.C., 2020) https://theicct.org/publication/air-emissions-and-water-pollution-discharges-from-ships-with-scrubbers/.

Table 1. Number and type of identified vessels operating in GL-SLS region in 2019.

Flag state	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
Canada	50	24	1	20	4	47	38	**184**
Marshall Islands	85	45	2	0	14	1	4	**151**
United States	34	0	0	3	0	45	16	**98**
Panama	46	12	26	0	2	0	3	**89**
Liberia	30	20	8	0	10	0	1	**69**
All others	134	107	26	1	40	3	51	**362**
Total	**379**	**208**	**63**	**24**	**70**	**96**	**113**	**953**

Figure 2 shows the distribution of emissions in the GL-SLS region using a 0.05° x 0.05° grid cell. Starting in the SLS, this relatively narrow sailing channel had higher ship activity intensity compared to the GL, and thus the emissions intensity in the SLS was higher than in the GL. However, later we will show that most of the absolute emissions in the GL-SLS occurred within the GL portion of the system. Unsurprisingly, CO_2 emissions were highest along the main shipping corridors in the GL-SLS. The total CO_2 emissions in the GL-SLS were approximately 1.6 Mt, of which about 1 Mt occurred within U.S. waters.

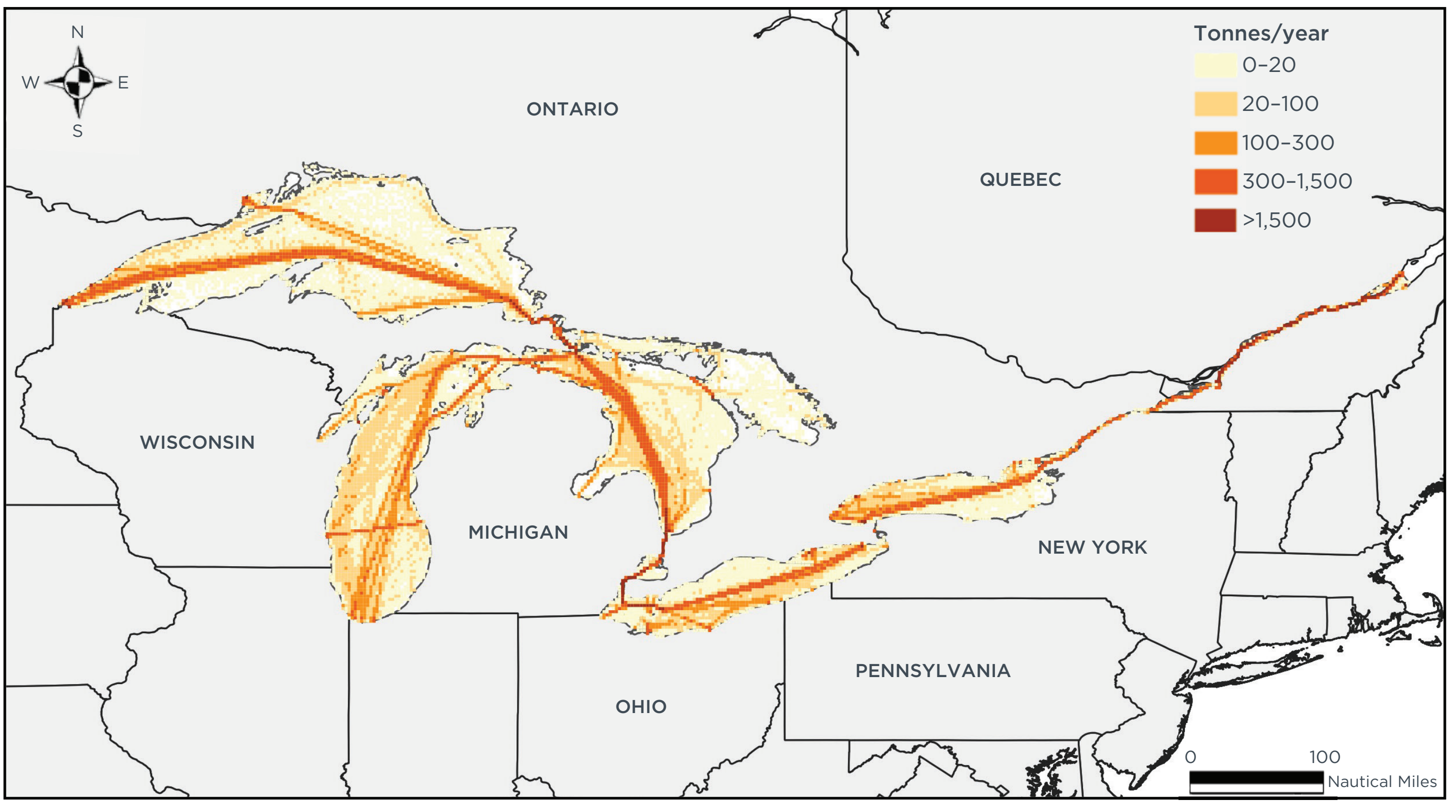

Figure 2. CO_2 emissions from ships in the GL-SLS in 2019, 0.05° grid cell size. Emission map is attached in Appendix D.

SHIP TYPE AND FLAG

Different ship types contributed to CO_2 emissions in different amounts, as shown in both Table 2 and Figure 3. Of the approximately 1.6 Mt of maritime transport CO_2 emissions in GL-SLS in 2019, about 1 Mt (62%) was emitted by bulk carriers; chemical tankers were a distant second with 10% and tugs emitted about 9%.

In terms of flag state, U.S.- and Canada-flagged vessels accounted for nearly 80% of CO_2 emissions in the GL-SLS, each responsible for approximately 40% of total emissions, as shown in Figure 3. Although there were many "salty" (i.e., oceangoing) Marshall Islands-flagged vessels in the GL-SLS, they did not emit much CO_2. This shows the importance of understanding ship activity and not just the number of ships. Marshall Islands-flagged vessels operated for 76,400 hours in the GL-GLS, compared to 642,000 for Canada-flagged vessels and 407,000 hours for U.S.-flagged vessels.

Table 2. Marine CO_2 emissions by flag state and ship type in the GL-SLS in 2019, in thousand tonnes.

Flag state	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
United States	499	0	0	15	0	115	18	**646**
Canada	386	92	4	40	41	31	34	**628**
All others	125	74	88	0	29	0	35	**351**
Total	**1,010**	**166**	**91**	**55**	**70**	**146**	**87**	**1,626**

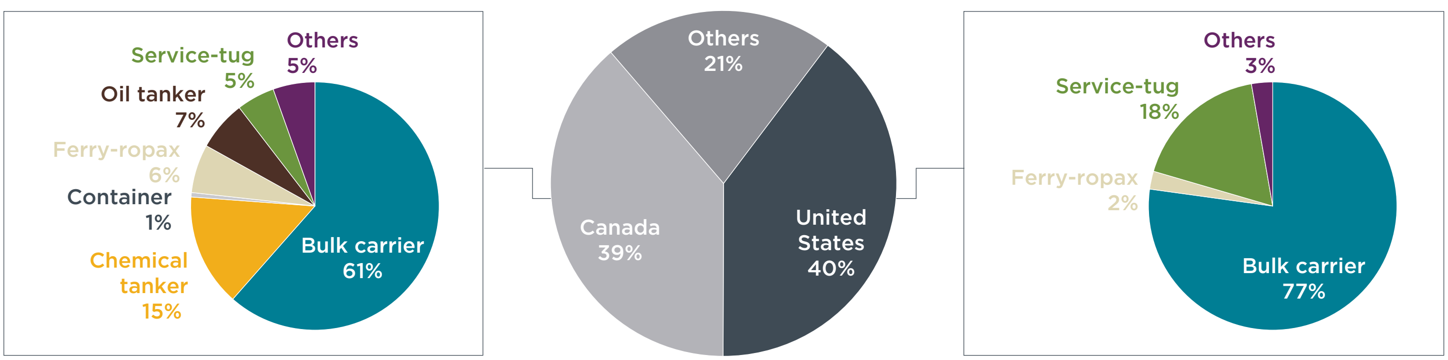

Figure 3. Share of CO_2 emissions from U.S.- and Canada-flagged vessels in the GL-SLS, 2019.

As shown in Figure 3, emissions from U.S.- and Canada-flagged vessels are similar, but the main contributors are different. For the U.S.-flagged vessels, 95% of the emissions were from just two ship types: bulk carriers (77%) and tugs (18%). For Canada-flagged vessels, the top contributors were bulk carriers (61%), chemical tankers (15%), and oil tankers (7%), which combined for 83% of their emissions.

OPERATING PHASE

Table 3 provides CO_2 emissions by ship type in different operating phases. Over 78% of the emissions were emitted by ships sailing at cruising speeds. About 10.5% of emissions occurred when ships were at anchor and about 8.5% occurred when at berth. The maneuvering phase only accounted for around 2% of emissions, and that is expected because ships do not spend much time operating in this phase.

Table 3. Ship CO_2 emissions by operating phase in the GL-SLS in 2019, in thousand tonnes.

Operating phase	Bulk carrier	Chemical tanker	Container	Ferry–ropax	Oil tanker	Service–tug	All other ship types	Total
At-anchor	51	33	38	15	13	8	14	**171**
At-berth	18	57	0	13	34	2	15	**138**
Cruising	922	73	52	24	23	131	54	**1,279**
Maneuvering	19	3	2	3	1	5	4	**37**
Total	**1,010**	**166**	**91**	**55**	**70**	**146**	**87**	**1,626**

Bulk carriers and chemical tankers emitted the most while at anchor and at berth, with bulk carriers accounting for 30% of at-anchor emissions and chemical tankers accounting for 41% of at-berth emissions. Adding at-anchor and at-berth emissions together, chemical tankers accounted for 29% and bulk carriers accounted for 22%. At cruising speeds, bulk carriers accounted for 72% of emissions, the most of any ship type. Appendices A and B contain details of emissions by operating phase within the GL and SLS separately. Within the GL, bulk carriers accounted for 50% of at-berth and 25% of at-anchor CO_2 emissions; chemical tankers accounted for 18% of emissions at berth and 40% of emissions at anchor. Adding at-berth and at-anchor emissions in the GL together, bulk carriers accounted for 39% of CO_2 emissions and chemical tankers were responsible for 27%.

DISTRIBUTION BY REGION

Figure 4 illustrates the contribution to emissions by flag state and ship type, including the CO_2 emissions difference between the GL and SLS. Of the total CO_2 emissions from ships, 75% were emitted in the GL. However, considering the area difference between the GL and SLS, the average CO_2 emissions intensity in the SLS was 36-times higher than the GL. At approximately 2,200 km^2, the SLS represents less than 1% of the geographic area of the roughly 250,000 km^2 GL-SLS, and yet it is home to 25% of GL-SLS CO_2 emissions.[9]

9 ICCT calculated these areas using ArcGIS.

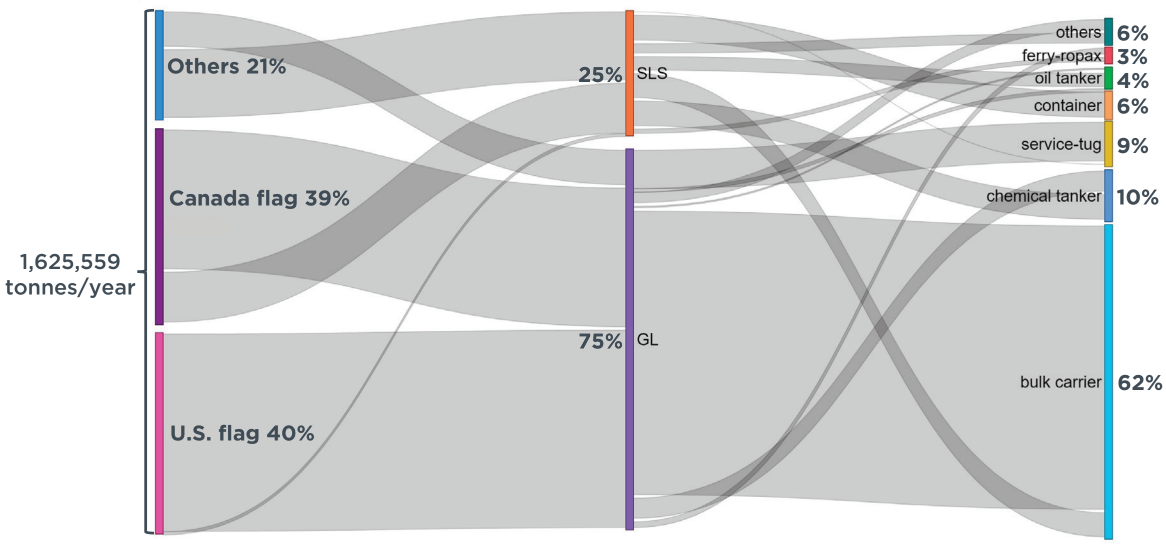

Figure 4. CO_2 emissions in GL and SLS by flag and ship type, 2019.

The CO_2 emissions within each region were distinct. For the GL, over 90% of emissions were from Canada- and U.S.-flagged ships; more than 50% of these were from U.S.-flagged ships. However, for the SLS, U.S.-flagged ships accounted for less than 1% of CO_2 emissions. The contribution of each ship type to CO_2 emissions was also different in the GL and SLS. For the GL, bulk carriers accounted for 75% CO_2 emissions; tugs were a distant second, emitting 11%. For the SLS, emissions were more evenly spread across ship types: bulk carriers accounted for 22% of emissions, container ships emitted 23%, chemical tankers accounted for 22%, and oil tankers were responsible for 14%.

FUEL CONSUMPTION

We estimate that ships in the GL-SLS consumed 510,000 tonnes of fuel in 2019. As shown in Figure 5, 83% of the fuel consumption was distillate fuels. These are fuels that have a sulfur content of less than 0.1% by mass (1,000 parts per million), to comply with the North American Emission Control Area fuel sulfur requirements.[10] Despite the Emission Control Area, high-sulfur residual fuels represented 15% of fuel consumption, mostly by bulk carriers. These bulk carriers are equipped with scrubbers.[11] Lastly, we found that the use of liquefied natural gas (LNG) is not significant in the GL-SLS.[12]

10 "Designation of North American Emission Control Area to Reduce Emissions from Ships," regulatory announcement, United States Environmental Protection Agency, (2010), https://nepis.epa.gov/Exe/ZyPDF.cgi/P100AU0I.PDF?Dockey=P100AU0I.PDF.

11 The ICCT has published research on the growing use of scrubbers to comply with fuel sulfur regulations and the differences in air emissions and water pollution discharges from ships using open-loop, closed-loop, and hybrid scrubbers. Ships on the Great Lakes use closed-loop scrubbers because they do not have access to seawater that is used in open-loop systems. More information on scrubbers is available at the ICCT website: https://theicct.org/search/?_search=scrubbers.

12 The ICCT has researched the life-cycle greenhouse gas consequences of using LNG as a marine fuel and results show that it is usually worse from a climate perspective than conventional fuels: Nikita Pavlenko et al., *The climate implications of using LNG as a marine fuel*, (ICCT: Washington, D.C., 2020), https://theicct.org/publication/the-climate-implications-of-using-lng-as-a-marine-fuel/

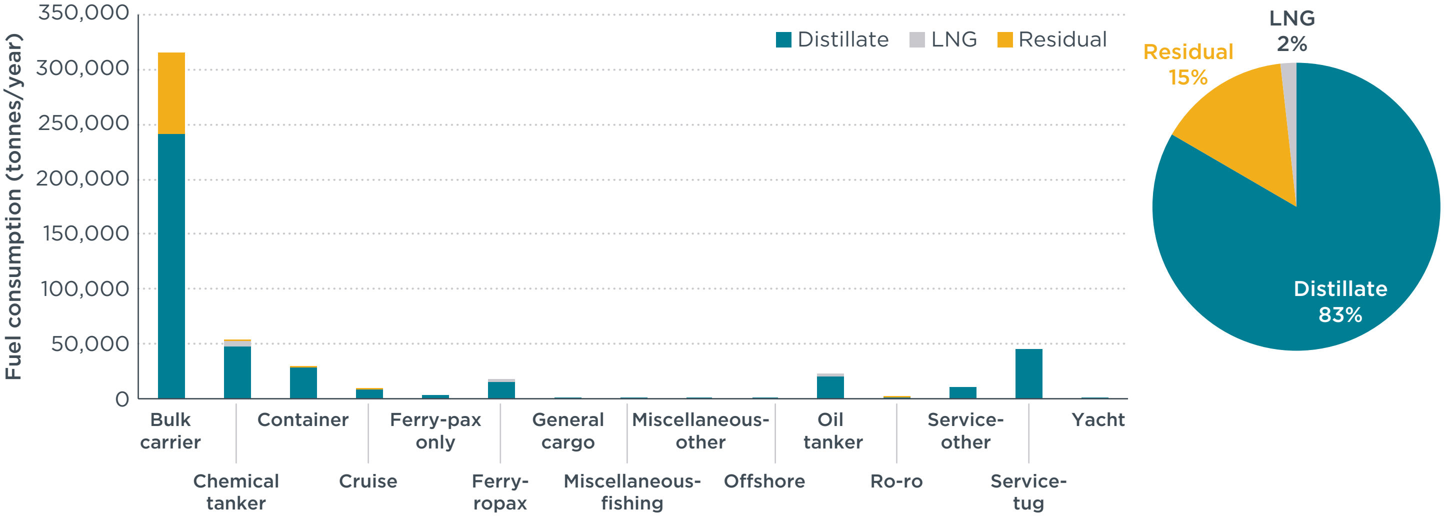

Figure 5. Fuel consumption of vessels in the GL-SLS, 2019.

CONCLUSION

With this inventory of CO_2 emissions and fuel consumption for ships operating in the GL-SLS in 2019, we estimated that ships consumed more than 500,000 tonnes of fuel and it resulted in approximately 1.6 Mt of CO_2 emissions. About two-thirds of these emissions were in U.S. waters. Of the fuel consumed, 83% was low-sulfur distillate fuel, 15% was high sulfur residual fuel used by ships with scrubbers, and 2% was LNG.

By ship type, bulk carriers were the largest contributor to GL-SLS CO_2 emissions, accounting for 62%. By flag state, U.S.- and Canada-flagged vessels emitted 80% of the CO_2 emissions in the GL-SLS region in 2019, split roughly evenly. By operating phase, 19% of emissions were from ships at anchor or at berth, while 78% came from ships sailing at cruising speeds, and only 2% from ships while they were maneuvering. Regarding at-berth and at-anchor emissions, bulk carriers and chemical tankers emitted the most, with bulk carriers accounting for 30% of at-anchor emissions and chemical tankers accounting for 41% of at-berth emissions. Within the GL, bulk carriers accounted for 50% of at-berth and 25% of at-anchor CO_2 emissions; chemical tankers accounted for 18% of emissions at-berth and 40% of emissions at-anchor.

These results can be used by a variety of stakeholders as a baseline to understand the potential benefits of developing policies, action plans, and roadmaps that can improve the environmental performance of the GL-SLS maritime transportation sector. Actions to reduce air pollution and mitigate climate impacts could include promoting the use of shore power, shore-based or barge-based emissions capture bonnets, batteries, fuel cells, low life-cycle emission fuels, wind-assisted propulsion, hull air lubrication, propeller upgrades, energy efficiency retrofits, and other technologies.

We intend to periodically update this analysis with results for other years, as data and resources allow.

APPENDIX A. SUMMARY OF RESULTS FOR THE GREAT LAKES PORTION OF THE GL-SLS

Table A1. Number of identified vessels operating in the GL, 2019.

Flag state	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
Canada	47	21	0	4	2	26	22	**122**
United States	34	0	0	3	0	45	16	**98**
Marshall Islands	44	4	1	0	0	1	2	**52**
Cyprus	21	0	0	0	0	0	0	**21**
Malta	10	6	0	0	0	0	0	**16**
All others	30	35	0	0	1	0	21	**87**
Total	**186**	**66**	**1**	**7**	**3**	**72**	**61**	**396**

Table A2. Maritime CO_2 emissions by flag state and ship type in the GL in tonnes, 2019.

Flag state	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
United States	498,961	0	0	15,141	0	114,114	17,136	**645,352**
Canada	345,049	52,001	0	14,915	9,300	20,859	14,724	**456,848**
All others	77,788	23,898	28	0	6,554	19	13,209	**121,496**
Total	**921,798**	**75,898**	**28**	**30,057**	**15,855**	**134,991**	**45,068**	**1,223,695**

Table A3. Maritime CO_2 emissions by operating phase in the GL in tonnes, 2019.

Operating phase	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
At anchor	31,203	11,356	0	3,835	1,921	5,469	8,343	**62,121**
At berth	11,794	18,776	0	3,272	6,079	1,948	5,615	**47,677**
Cruising	862,371	43,957	26	21,283	7,451	124,123	29,204	**1,088,270**
Maneuvering	16,430	1,809	2	1,666	403	3,451	1,906	**25,627**
Total	**921,798**	**75,898**	**28**	**30,056**	**15,854**	**134,991**	**45,068**	**1,223,695**

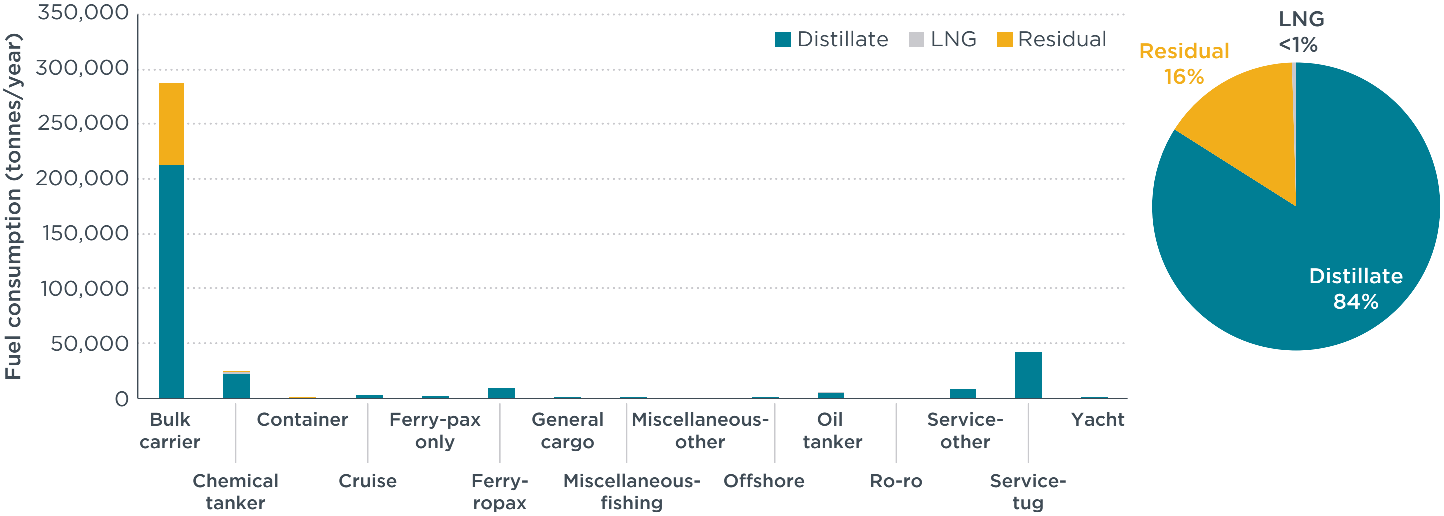

Figure A1. Fuel consumption of vessels in the GL, 2019.

APPENDIX B. SUMMARY OF RESULTS FOR THE ST. LAWRENCE SEAWAY PORTION OF THE GL-SLS

Table B1. Number of identified vessels operating in the SLS, 2019.

Flag state	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
Canada	45	23	1	16	4	37	29	**155**
Marshall Islands	85	44	1	0	14	0	3	**147**
Panama	46	12	26	0	2	0	3	**89**
Liberia	30	20	8	0	10	0	1	**69**
Malta	25	24	0	0	6	1	5	**61**
United States	0	0	0	0	0	8	3	**11**
All others	109	83	26	1	34	2	43	**298**
Total	**340**	**206**	**62**	**17**	**70**	**48**	**87**	**830**

Table B2. Maritime CO_2 emissions by flag state and ship type in SLS in tonnes, 2019.

Flag state	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
United States	0	0	0	0	0	440	621	**1,061**
Canada	41,446	40,216	3,637	24,867	31,552	10,381	19,529	**171,627**
All others	46,869	50,174	87,536	20	22,921	210	21,445	**229,176**
Total	**88,315**	**90,390**	**91,173**	**24,886**	**54,472**	**11,032**	**41,595**	**401,864**

Table B3. Maritime CO_2 emissions by operating phase in the SLS in tonnes, 2019.

Operating phase	Bulk carrier	Chemical tanker	Container	Ferry-ropax	Oil tanker	Service-tug	All other ship types	Total
At anchor	19,973	21,767	37,618	10,856	11,044	2,114	5,375	**108,753**
At berth	6,489	37,910	28	9,764	27,675	212	8,899	**90,784**
Cruising	59,556	29,443	51,797	2,717	15,111	7,088	25,269	**191,127**
Maneuvering	2,297	1,270	1,730	1,550	643	1,619	2,051	**11,200**
Total	**88,315**	**90,390**	**91,173**	**24,886**	**54,472**	**11,032**	**41,595**	**401,864**

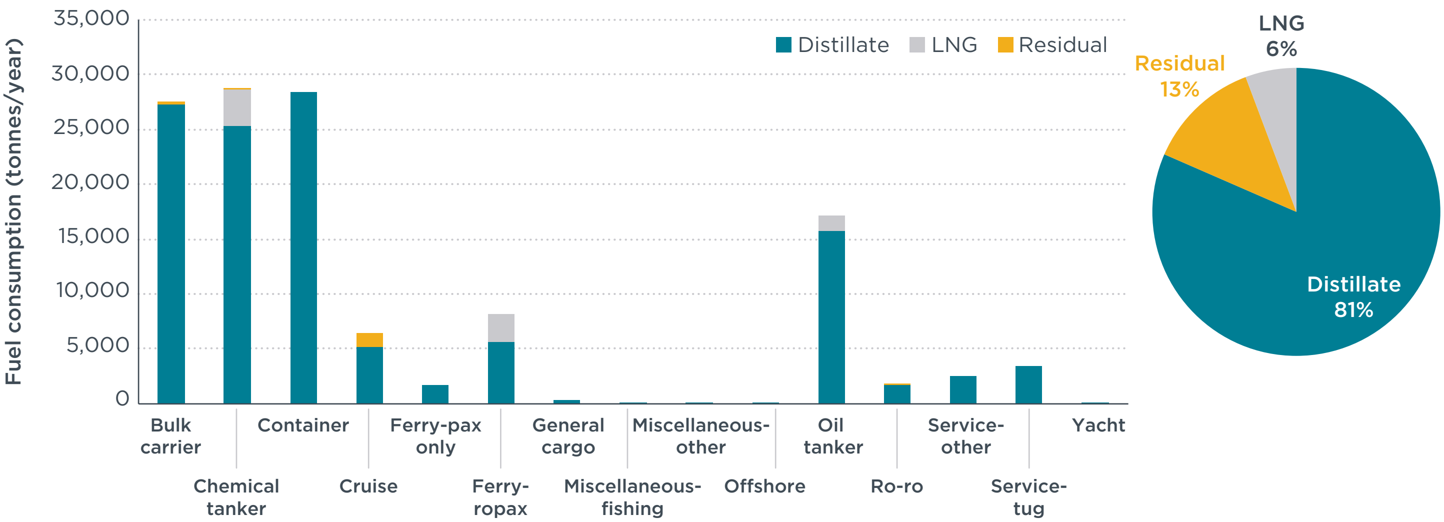

Figure B1. Fuel consumption of vessels in the SLS, 2019.

APPENDIX C. SUPPLEMENTAL STATISTICS

Please see the supplemental statistics file published on the ICCT webpage for this briefing paper, which can be found at https://theicct.org/publication/ships-great-lakes-emissions-mar22. It reports results for non-CO_2 climate and air pollutant emissions.

APPENDIX D. MAP FILES

Please find an ArcGIS shapefile on the ICCT webpage for this briefing paper, which can be found at https://theicct.org/publication/ships-great-lakes-emissions-mar22. This shapefile contains the gridded CO_2 emissions inventory for the GL-SLS at a 0.05° x 0.05° resolution.