Table 1. Emission Estimates for an Ocean Going Vessel Travelling from Los Angeles to Shanghai
Southern California Gas Company
Los Angeles, California

Propulsion Engine	Operating Year	Mass Emissions[1] (tons/trip)			
		PM_{10}	NO_X	SO_X	Black Carbon
IMO Tier III Slow Speed Engine	2016 to 2019	21.9	211.2	152.9	0.29
	2020 and beyond	5.7	211.2	27.8	0.34
LNG Engine	2016 and beyond	1.7	32.4	0.008	0.18

Operating Year	Emission Benefits of Using an LNG Engine[2] (% Reduction)			
	PM_{10}	NO_X	SO_X	Black Carbon
2016 to 2019	92%	85%	99.99%	39%
2020 and beyond	69%	85%	99.97%	49%

Notes:

[1] Mass emissions are estimated using the maximum continuous rating of a 8,000 TEU ocean going vessel (OGV) operating at 25 knots, the transit time for a one-way trip from Los Angeles to Shanghai, and the emission factors shown in Table 3.

[2] Emission benefits are estimated as a percentage difference between the LNG engine mass emissions and the IMO Tier III slow speed engine mass emissions.

[3] Maximum continuous rating of a 8,000 TEU ocean going vessel (OGV) operating at 25 knots was obtained from the document titled "Propulsion of 8,000-10,000 teu Container Vessel" published by MAN Diesel & Turbo. Available at: http://marine.man.eu/docs/librariesprovider6/technical-papers/propulsion-of-8-000-10-000-teu-container-vessel.pdf?sfvrsn=10. Accessed: May 2016.

[4] Transit distance estimates were obtained from http://www.sea-distances.org/. Accessed: May 2016.

[5] Transit time was estimated using transit distance and OGV travel speed.

Constants:

Maximum Continuous Rating at 25 knots[3]	59,880	kW
OGV Travel Speed	25	knots
Transit Distance[4]	5,708	nm
Within North American ECA	200	nm
Outside North American ECA	5,508	nm
Transit Time[5]	228.32	hr
Within North American ECA	8	hr
Outside North American ECA	220.32	hr

Conversion Factor:

907184.7 g/ton

Abbreviations:

% - percentage
ECA - Emission Control Areas
g - grams
hr - hour
IMO - International Maritime Organization
knot - nautical miles per hour
kW - kilowatt
LNG - liquefied natural gas
nm - nautical miles
NO_X - oxides of nitrogen
OGV - ocean going vessels
PM_{10} - particulate matter less than 10 microns in diameter
SO_X - oxides of sulfur
TEU - twenty foot equivalent

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Table 2. Emission Estimates for a Train Traveling from Los Angeles to Chicago
Southern California Gas Company
Los Angeles, California

Engine	Mass Emissions[1] (tons/trip)		
	PM_{10}	NO_X	Black Carbon
Tier 4 Diesel Locomotive	0.0096	0.48	0.008
LNG Locomotive	0.0096	0.58	0.001

Emission Benefits of Using an LNG Engine[2] (% Reduction)		
PM_{10}	NO_X	Black Carbon
0%	-20%	87%

Notes:

[1] Mass emissions are estimated using energy consumption for a one-way trip (shown under sub-heading "constants" below) from Los Angeles to Chicago and emission factors shown in Table 4.

[2] Emission benefits are estimated as a percentage difference between the LNG locomotive engines mass emissions and diesel Tier 4 locomotive engines mass emissions.

[3] Train gross weight is estimated for a 100 stack car train carrying double-stacked forty foot equivalent containers on each stack car, powered by three locomotives.

[4] The weight for a locomotive was obtained from the product specification sheet for the GE Evolution Series Tier 4 Locomotive. Available at: http://media.getransportation.com/sites/default/files/3%20EvoSeries%20Tier%204_locomotives.pdf . Accessed: May 2016.

[5] Mass of a stack car was obtained from the BNSF Glossary of Railroad Terminology and Jargon. Available at: https://www.bnsf.com/customers/pdf/glossary.pdf. Accessed: May, 2016.

[6] Average weight for a forty foot equivalent container (empty and full) was estimated based on the 2015 container statistics from Port of Oakland. Available at: http://www.portofoakland.com/port/seaport/facts-and-figures/. Accessed: May 2016

[7] Diesel fuel productivity factor for California was obtained from ARB's Locomotive Inventory Update dated November 7, 2014. Available at: http://www.arb.ca.gov/msei/goods_movement_emission_inventory_line_haul_octworkshop_v3.pdf. Accessed: May 2016.

[8] Track mileage was estimated based on the track mileage along the BNSF route from Los Angeles to Chicago using BNSF's Division Maps with detailed mile posts. Available at: http://www.bnsf.com/customers/where-can-i-ship/maps/. Accessed: May 2016.

[9] Diesel fuel consumption was estimated using the gross weight of the train, fuel productivity factor, and track mileage.

[10] Energy consumption for a one-way trip from Los Angeles to Chicago was estimated by converting the diesel fuel consumption with the USEPA's conversion factor of 20.8 bhp-hr/gal diesel for large line-haul locomotives. USEPA's conversion factor is available at: https://www3.epa.gov/nonroad/locomotv/420f09025.pdf. Accessed: May 2016.

Train Gross Weight Estimate[3]:

Train Component	Number of Components	Mass of Each Component (ton)
Locomotive[4]	3	213
Train Car[5]	100	27.2
Forty Foot Equivalent Containers[6]	200	13.1
Gross Weight of the Train		**5,979**

Constants:

Diesel Fuel Productivity Factor[7]	640	gross ton-miles/diesel gal
Track Mileage[8]	2247.5	miles
Diesel Fuel Consumption[9]	20,997	diesel gal
Energy Consumption[10]	436,729	bhp-hr

Conversion Factors:

907184.7	g/ton
20.8	bhp-hr/diesel gal

Abbreviations:

% - percentage
bhp - brake horse power
g - grams
gal - gallon
hp - horsepower
hr - hour
LNG - liquefied natural gas
NO_X - oxides of nitrogen
PM_{10} - particulate matter less than 10 microns in diameter
USEPA - United States Environmental Protection Agency

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Table 3. Ocean Going Vessel Emission Factors
Southern California Gas Company
Los Angeles, California

Propulsion Engine Type	Operating Details	Fuel Type	Emission Factors (g/kW-hr)			
			PM_{10} [1,2]	NO_X [3,2]	SO_X [1,2]	Black Carbon [4,5]
IMO Tier III Slow Speed Engine	Within North American Emission Control Area (ECA)	Marine Distillate 0.1% Sulfur[6]	0.25	3.4	0.36	0.013
	Outside ECA before January 1, 2020	Heavy Fuel Oil 2.5% Sulfur[7]	1.50	14.4	10.50	0.020
	Outside ECA after January 1, 2020	Marine Distillate 0.5% Sulfur[8]	0.38	14.4	1.90	0.023
LNG Engine	All operation	LNG	0.115	2.15	0.00051	0.012

Notes:

[1] PM_{10} and SO_X emission factors for the IMO Tier III Slow Speed Engine were obtained from California Air Resources Board's May 2011 reference document titled "Emissions Estimation Methodology for Ocean-Going Vessels." Available at: http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf. Accessed: May 2016.

[2] PM_{10}, NO_X, and SO_X emission factors for the LNG engine were obtained from the scientific report, "Pollutant emissions from LNG fuelled ships" published by the Norwegian Institute of Air Research. Available at: https://brage.bibsys.no/xmlui//bitstream/id/378709/17-2015-sla-Deliverable_Emission_Factors_LNGships_v2.pdf. Accessed: May 2016.

[3] NO_x emission factors for the IMO Tier III Slow Speed Engine are assumed to be equal to the IMO Regulation 13 Tier III standard of 3.4 g/kW-hr while operating within the North American ECA and IMO Regulation 13 Tier II standard of 14.4 g/kW-hr while operating outside ECA. Note, ocean going vessels (OGVs) are required to meet the Tier III standard only while operating inside the ECA. For purposes of this analyses Ramboll Environ has assumed that the slow speed engine will have a NO_X control technology like an selective catalytic reduction (SCR) unit that operates only when the OGV is within the ECA.

[4] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. CARB's speciation profiles for PM4251, PM1191, and PM4252 OGVs are used to estimate black carbon emission factors for IMO Tier III slow speed engine operating on 0.1%, 2.5%, and 0.5% sulfur fuel oils respectively. Available at: http://www.arb.ca.gov/ei/speciate/speciate.htm. Accessed: May 2016.

[5] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. EPA's speciation profiles for CNG buses is used to estimate black carbon emission factors for the LNG engine. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

[6] IMO Regulation 14 requires OGVs to use fuel oils with a sulfur content ≤0.10% mass by mass (m/m) while operating within the North American Emission Control Areas (ECA), nominally 200 nautical miles out from the USA and Canadian west coast.

[7] IMO Regulation 14 requires OGVs to operate on fuel oils with a sulfur content ≤3.50% m/m while operating outside ECA. For purposes of this analyses Ramboll Environ has assumed the use of heavy fuel oil with a nominal sulfur content of 2.5% while operating outside ECA.

[8] IMO Regulation 14 requires OGVs to operate on fuel oils with a sulfur content ≤0.50% m/m while operating outside ECA on and after January 1, 2020. Depending on the outcome of a review as to the availability of the required fuel oil, this date could be deferred to 1 January 2025.

Black Carbon Speciation Factors:

Fuel	Speciation Profile	Elemental Carbon/PM_{10}
Marine Distillate 0.1% Sulfur	CARB PM4251[4]	0.052
Heavy Fuel Oil 2.5% Sulfur	CARB PM1191[4]	0.013
Marine Distillate 0.5% Sulfur	CARB PM4252[4]	0.061
LNG	Average of EPA Profiles 95220 and 95219[5]	0.102

Abbreviations:

% - percentage
ECA - Emission Control Areas
g - grams
hr - hour
IMO - International Maritime Organization
kW - kilowatt
LNG - liquefied natural gas
NO_X - oxides of nitrogen
OGV - ocean going vessels
PM_{10} - particulate matter less than 10 microns in diameter
SO_X - oxides of sulfur

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Table 4. Locomotive Emission Factors
Southern California Gas Company
Los Angeles, California

Engine Type	Fuel Type	Emission Factors (g/hp-hr)		
		PM_{10} [1,2]	NO_X [1,2]	Black Carbon [3,4]
Tier 4 Diesel	Diesel	0.02	1	0.016
LNG Engine	LNG	0.02	1.2	0.002

Notes:

[1] PM_{10} and NO_X emission factors for the locomotive were obtained from USEPA engine certification 2015 data for a Tier 4 locomotive (engine family FGETK0958T3A, model ET44AC/C4). Available at: https://www3.epa.gov/otaq/certdata.htm#locomotive. Accessed: May 2016.

[2] PM_{10}, and NO_x emission factors for the LNG engine were obtained from the GE NextFuel™ presentation slides, "NextFuelTM Natural Gas" published by the GE on September 3, 2014.

[3] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. EPA's speciation profiles for diesel heavy-heavy-duty truck without diesel particulate filter is used to estimate black carbon emission factors for the locomotives. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

[4] For purposes of this analyses elemental carbon is used as a surrogate for black carbon. EPA's speciation profiles for CNG buses is used to estimate black carbon emission factors for the LNG engine. Available at: https://www3.epa.gov/otaq/models/moves/documents/420r15022.pdf. Accessed: May 2016.

Black Carbon Speciation Factors:

Fuel	Speciation Profile	Elemental Carbon/PM_{10}
Diesel	EPA Profile 8995	0.7897
LNG	Average of EPA Profiles 95220 and 95219[4]	0.102

Abbreviations:

% - percentage
ECA - Emission Control Areas
g - grams
hr - hour
IMO - International Maritime Organization
kW - kilowatt
LNG - liquefied natural gas
NO_X - oxides of nitrogen
OGV - ocean going vessels
PM_{10} - particulate matter less than 10 microns in diameter
SO_X - oxides of sulfur

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