MEMORANDUM

To: Stas Margaronis, Santa Maria Shipping, LLC
From: Trinity Consultants, Inc.
Date: January 11, 2018
RE: Trucking Emission Estimates and Comparison to Proposed Shipping Emissions

Executive Summary

This memorandum provides a comparison of emissions associated with goods movement from Los Angeles to Patterson, California via two existing on-road trucking routes and one potential ship-and-truck service utilizing hybrid LNG ship engines and electric trucks as proposed by Santa Maria Shipping, LLC (SMS). This analysis specifically estimates emissions of nitrogen oxide (NOx), particulate matter with an aerodynamic diameter of 10 microns or less (PM_{10}), fine particulate matter with an aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$), and greenhouse gases (GHG) from on-road diesel trucks and compares existing truck route emissions to emissions from the proposed ship-and-truck service. The analysis showed that the proposed ship-and-truck service can potentially reduce statewide NOx emissions by approximately 123 tons/year, PM_{10} by 3 tons/year, $PM_{2.5}$ by 2 tons/year, and GHG by 33,295 tons/year as summarized in Table 1 below.

Table 1: Potential Annual Emission Reductions due to Proposed Ship-and-Truck Service Using Aggregated Model Year Trucks

Pollutant	Emission Reductions Los Angeles -> Patterson
	tons/ year
NOx	123
PM_{10}	3
$PM_{2.5}$	2
GHG	33,295

The proposed ship-and-truck service would transport goods between the Port of Los Angeles (or Long Beach) and the Port of Stockton via the Marine 5 Highway using new hybrid LNG ship engine technology, and then from Stockton to Patterson using electric on-road trucks. The two existing truck routes between Los Angeles and Patterson include one direct route between the two cities, and one indirect route where goods are trans-loaded into larger more efficient containers in Riverside, California. The proposed and existing routes are summarized as follows:

<u>Proposed Ship-and-Truck Service:</u>

- Los Angeles -> Stockton (via hybrid LNG ship)
- Stockton -> Patterson (via electric truck)

<u>Existing Truck Routes:</u>

- Los Angeles -> Patterson (via diesel truck)
- Los Angeles -> Riverside -> Patterson (via diesel truck)

Background Information

The U.S. Maritime Administration (MARAD), a division of the U.S. Department of Transportation, has proposed a series of so-called Marine Highway coastal and inland waterway corridors whereby U.S.-built vessels can transport goods currently trucked via U.S. highways. These vessels can relieve highway truck congestion, reduce emissions, and save shippers money on transportation costs. In the case of the U.S. Pacific Coast I-5 Highway corridor, MARAD has designated the waterborne corridor as the Marine 5 Highway.

A 2017 University of California at Berkeley study, sponsored by the Southern California Association of Governments (SCAG), indicates that in 2015, 4.8% of all containers imported through the Ports of Los Angeles and Long Beach were trucked along the I-5 corridor to Northern California warehouses and distribution centers.[1] This percentage corresponds to approximately 187,000 40-foot containers of imports trucked to Northern California, and a total of up to 374,000 one-way truck trips along the I-5 corridor to account for return trips to the Port of Los Angeles or Long Beach.[2] In many cases, the 40-foot containers are first trucked from the two ports to Southern California warehouses where the goods are reloaded into 53-foot containers for transport to Northern California.

Many of the imported goods are destined for Northern California warehouses located near the Port of Stockton. Patterson, California was chosen as the warehouse delivery point in this study because it is located near the Port of Stockton, but is conservatively positioned further south (i.e. a shorter distance from the Ports of Los Angeles and Long Beach) than many other Northern California warehouses. The Marine 5 Highway ship discussed in this study can carry as many as 505 40-foot containers each voyage, with each container weighing an average of 23.15 short tons (or 21 metric tons). The ship can make 1.5 round trips per week sailing between the Port of Los Angeles (or Long Beach) and the Port of Stockton.

In this analysis, it is assumed that containers are unloaded and trucked by road from the Port of Stockton to Patterson. SMS has proposed to utilize electric-powered trucks to provide road transport between the Port of Stockton and Patterson with negligible on-road emissions. The export containers, leaving the Patterson warehouse (empty or loaded), would be trucked back to the Port of Stockton and transported by the Marine 5 Highway ship to the Port of Los Angeles (or Long Beach). On an annual basis, one proposed Marine 5 Highway ship can transport as many as 78,780 40-foot containers per year. The proposed Marine 5 Highway ship is powered by an 8,000-kilowatt engine (10,728 horsepower) and fueled by LNG so as to minimize emissions when compared to diesel-powered vessels. Details of the vessel's performance characteristics can be found in Attachment 2.

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[1] http://queue.ieor.berkeley.edu/People/Faculty/leachman-pubs/RCL-LA-Basin-Initiatives-Jan_13_2017.pdf
[2] http://santamariashippingllc.com/wp-content/uploads/2017/06/Marine-5-Highway-Fact-Sheet-62117-PDF.pdf

Trucking Emissions Quantification Methodology

On-road diesel truck emission estimates were quantified using the California Air Resources Board (CARB) EMFAC2014 emission factor model. According to SMS, the proposed ship-and-truck service could begin operation in calendar year 2019, and as such annual statewide emission estimates were obtained for analysis year 2019. The following two scenarios in terms of fleet characteristics were analyzed to estimate trucking emissions:

- Scenario 1: Aggregated model year (MY) trucks representing the EMFAC2014 default age distribution in calendar year 2019.
- Scenario 2: MY 2014-2020 trucks representing a 2019 vehicle fleet meeting the highest emission standards and California in-use standards.

Scenario 1 offers a realistic snapshot of emissions from existing on-road trucks in calendar year 2019, while Scenario 2 offers a conservative estimate of the vehicles meeting the highest emission standards and California in-use standards in calendar year 2019. Note that for both scenarios, the emission estimates account for emissions during truck starts, idling, and running operation (exhaust). The emission estimates also include particulate matter emissions from tire wear, break wear, and running operation (exhaust). Since EMFAC2014 assumes that all trucks in the heavy-duty vehicle class (T7 Tractor) operate on diesel fuel, evaporative reactive organic gas (ROG) emissions were modeled as zero. Tables 2 and 3 below present the detailed EMFAC2014 input options for Scenario 1 and 2, respectively.

Table 2: Aggregated MY Trucks (Scenario 1) - EMFAC2014 Model Inputs

EMFAC2014 Parameter	Option Selected
Data Type	Emissions
Region	Statewide
Calendar Year	2019
Season	Annual
Vehicle Category	EMFAC2011 T7 Tractor
Model year	Aggregated
Speed	Aggregated
Fuel	Diesel

Table 3: 2014 to 2020 MY Trucks (Scenario 2) - EMFAC2014 Model Inputs

EMFAC2014 Parameter	Option Selected
Data Type	Emissions
Region	Statewide
Calendar Year	2019
Season	Annual
Vehicle Category	EMFAC2011 T7 Tractor
Model year	2014-2020
Speed	Aggregated
Fuel	Diesel

Total annual emissions were obtained using the EMFAC2014 emission factors in conjunction with route length, estimated container weight, and the number of containers transported per year, as summarized in Table 4. SMS estimates that 78,780 containers will be transported per year at 23.15 short tons each across the ship-and-truck service. Note that along the Los Angeles-Riverside-Patterson route, goods are assumed to be trans-loaded from 23.15 short ton containers to larger 33.07 short ton containers at the Riverside transfer point. As such, the total number of containers transported along the Los Angeles-Riverside-Patterson route is reduced to 55,146 containers per year. It is assumed that one truck carries one container. Note that emissions from the electric trucks along the ship-and-truck service are assumed to be zero and are not quantified for the purposes of this analysis.

Table 4: Truck Emission Route Input Parameters

Route	Distance per Container Transported (miles)[1]	Container Weight (short tons)[2]	Containers Transported Per Year[3]
Los Angeles -> Patterson	324	23.15	78,780
Los Angeles -> Riverside	66	23.15	78,780
Riverside -> Patterson	352	33.07	55,146

Trucking Emissions Results

Trucking emissions are estimated in terms of the net emission rate per ton-mile (g/ton-mile) for each leg of the truck routes, and in terms of annual emissions per route traveled (tons/year) for each of the two EMFAC scenarios discussed above. Detailed emission calculations can be seen in Attachment 1 of this memorandum. Using EMFAC2014 emission rates and the container weight presented in Table 4 above, the net emission rate per ton-mile for each of the trucking routes was calculated and is presented in Tables 5 and 6 for Scenario 1 and Scenario 2, respectively. As shown, the net emission rate on a per ton-mile basis for goods transported along the Riverside-Patterson route is the lowest of all legs because the trucks transporting goods between Riverside and Patterson haul larger containers.

Table 5: Aggregated MY Trucks (Scenario 1) - Trucking Net Emission Rates per Ton Mile (g/ton-mile)

Pollutant	Los Angeles -> Patterson	Los Angeles -> Riverside	Riverside -> Patterson
NOx	0.248	0.248	0.174
PM_{10}	0.005	0.005	0.004
$PM_{2.5}$	0.003	0.003	0.002
GHG	71.2	71.2	49.9

Table 6: 2014 to 2020 MY Trucks (Scenario 2) - Trucking Net Emission Rates per Ton Mile (g/ton-mile)

Pollutant	Los Angeles -> Patterson	Los Angeles -> Riverside	Riverside -> Patterson
NOx	0.053	0.053	0.037
PM_{10}	0.004	0.004	0.003
$PM_{2.5}$	0.002	0.002	0.001
GHG	62.8	62.8	44.0

[1] All distances are determined using Google Maps 2017. Locations of the starting and ending points for each route can be seen in Attachment 1.
[2] The 23.15 short ton container represents a 40-foot shipping container per SMS industry knowledge. Per SMS industry knowledge, it is assumed that a 40-foot shipping container can transport 70% of the total weight of a 53-foot shipping container. As such, the 33.07 short ton container represents a 53-foot shipping container.
[3] Per conversations between Stas Margaronis (SMS) and Elizabeth Geller (Trinity) on December 7, 2017, SMS plans to transport approximately 78,780 23.15 short ton containers via ship per year. Note that between Riverside and Patterson, the larger 53-foot, 33.07 short ton shipping containers are used which reduces the annual containers shipped as follows: 78,780 * 70% = 55,146.

Total annual emissions are shown in Tables 7 and 8 for Scenario 1 and Scenario 2, respectively. As noted above, annual emissions are estimated using the net emission rates per ton-mile, the round-trip mileage of each trucking route, the container weight, and number of containers transported per year.

Table 7: Aggregated MY Trucks (Scenario 1) - Trucking Emissions Summary (tons/year)

Pollutant	Los Angeles -> Patterson	Los Angeles -> Riverside -> Patterson
NOx	162	156
PM_{10}	3.48	3.35
$PM_{2.5}$	1.69	1.63
GHG	46,408	44,732

Table 8: 2014 to 2020 MY Trucks (Scenario 2) - Trucking Emissions Summary (tons/year)

Pollutant	Los Angeles -> Patterson	Los Angeles -> Riverside -> Patterson
NOx	35	34
PM_{10}	2.86	2.76
$PM_{2.5}$	1.11	1.07
GHG	40,935	39,457

Emissions Comparison

The trucking emission estimates presented above were compared to the shipping emission results calculated and evaluated by SMB - Naval Architects and Consultants. Shipping emission estimates were conducted by SMB for one hybrid LNG ship transporting 78,780 containers at 23.15 short tons each per year between the Port of Los Angeles (or Long Beach) and the Port of Stockton.[4] A detailed report outlining the assumptions and methods supporting the shipping emission estimates is included in Attachment 2.

The net emission rate per ton mile is compared for each leg of the two existing truck routes to the net emission rate per ton mile for the proposed shipping route in Tables 9 and 10 below for Scenario 1 and 2 as described above. As shown, the net emission rate per ton-mile is lower for goods transported via ship than transported via truck, regardless of the truck route or truck model year scenario.

[4] Per Case 7 of the SMB report titled "NOx and PM Emissions of Container Transport via Marine 5 Highway" provided via email from Stas Margaronis (SMS) to Trinity Consultants on December 4, 2017.

Table 9: Aggregated MY Trucks (Scenario 1) Compared to Ship Net Emission Rates per Ton Mile (g/ton-mile)

Pollutant	Trucking Net Emission Rate			Shipping Net Emission Rate[5]
	Los Angeles -> Patterson	Los Angeles -> Riverside	Riverside -> Patterson	Los Angeles -> Stockton
NOx	0.248	0.248	0.174	0.032
PM_{10}	0.005	0.005	0.004	0
$PM_{2.5}$	0.003	0.003	0.002	0
GHG	71.2	71.2	49.9	11.1

Table 10: MY 2014-2020 Trucks (Scenario 2) Compared to Ship Net Emission Rates per Ton Mile (g/ton-mile)

Pollutant	Trucking Net Emission Rate			Shipping Net Emission Rate[6]
	Los Angeles -> Patterson	Los Angeles -> Riverside	Riverside -> Patterson	Los Angeles -> Stockton
NOx	0.053	0.053	0.037	0.032
PM_{10}	0.004	0.004	0.003	0
$PM_{2.5}$	0.002	0.002	0.001	0
GHG	62.8	62.8	44.0	11.1

Finally, annual emissions for the two existing truck routes were compared to the proposed ship-and-truck service, as shown in Table 11 and 12 below. Note that the annual emissions for the ship-and-truck service represent the shipping emissions from Los Angeles to Stockton and that emissions from Stockton to Patterson are assumed to be zero due to the use of electric trucks. The annual emission results suggest that the ship-and-truck service results in fewer annual emissions for the transport of an equal amount of goods via diesel truck, even in the 2014-2020 MY truck scenario representing the most stringent fleet standards. This comparison suggests that SMS could displace 78,780 containers (23.15 short tons each) transported via diesel truck per year resulting in reduced emissions in the South Coast and San Joaquin Valley air basins. Tables 13 and 14 present the total potential emission reductions, which could be realized when SMS implements the proposed hybrid LNG ship and electric truck operations.

Table 11: Aggregated MY Trucks (Scenario 1) Compared to Ship-and-Truck Annual Emissions (tons/year)

Pollutant	Trucking Emissions		Ship-and-Truck Emissions
	Los Angeles -> Patterson	Los Angeles -> Riverside -> Patterson	Los Angeles -> Stockton -> Patterson
NOx	162	156	33
PM_{10}	3.48	3.35	0
$PM_{2.5}$	1.69	1.63	0
GHG	46,408	44,732	11,437

[5] Shipping emission estimates provided by SMB – Naval Architects and Consultants. See Attachment 2 for further details.
[6] Ibid.

Table 12: 2014-2020 MY Trucks (Scenario 2) Compared to Ship-and-Truck Annual Emissions (tons/year)

Pollutant	Trucking Emissions		Ship-and-Truck Emissions
	Los Angeles -> Patterson	Los Angeles -> Riverside -> Patterson	Los Angeles -> Stockton -> Patterson
NOx	35	34	33
PM_{10}	2.86	2.76	0
$PM_{2.5}$	1.11	1.07	0
GHG	40,935	39,457	11,437

Table 13: Potential Annual Emission Reductions due to Proposed Ship-and-Truck Service Using Aggregated MY Trucks (Scenario 1)[7]

Pollutant	Emission Reductions Los Angeles -> Patterson
	tons/ year
NOx	123
PM_{10}	3
$PM_{2.5}$	2
GHG	33,295

Table 14: Potential Annual Emission Reductions due to Proposed Ship-and-Truck Service Using 2014-2020 MY Trucks (Scenario 2)[8]

Pollutant	Emission Reductions Los Angeles -> Patterson
	tons/ year
NOx	0.7
PM_{10}	2.8
$PM_{2.5}$	1.1
GHG	28,020

In conclusion, when emission estimates for existing on-road truck routes are compared to emission estimates for a proposed ship-and-truck service utilizing hybrid LNG ship engine technology and electric trucks, the ship-and-truck service results in a lower net emission rate per ton mile and lower annual emissions for the same amount of goods transported between Los Angeles and Patterson, California using diesel trucks. The ship-and-truck service proposed by SMS has the potential to displace nearly 80 thousand of on-road diesel trucks per year, which would provide significant emission benefits for the South Coast and San Joaquin Valley air basins.

[7] Potential annual emission reductions are the difference between the annual ship-and-truck emission estimates (tons/year) presented in Table 10 and the annual trucking emission estimates (tons/year) for Los Angeles -> Riverside -> Patterson presented in Table 10.

[8] Potential annual emission reductions are the difference between the annual ship-and-truck emission estimates (tons/year) presented in Table 11 and the annual trucking emission estimates (tons/year) for Los Angeles -> Riverside -> Patterson presented in Table 11.

ATTACHMENT 1

Detailed Trucking Emission Calculations

Table 1-1. Los Angeles to Patterson Input Parameters (Scenario 1)

Parameter	**Value**
Starting Location	Port of Los Angeles, CA
Ending Location	Amazon Distribution Center, 255 Park Center Drive, Patterson, CA
Container Length (feet)	40
Container Weight (short tons)	23
Containers/year	78,780
Miles/Container:	324

Table 1-2. Los Angeles to Patterson Emission Calculations (Scenario 1) [1]

	ROG	**NOx**	**CO**	**SOx**	**PM10**[6]	**PM2.5**[6]	**CO2**	**CH4**[7]	**N2O**[7]	**Total CO2e**[8]
Emission Factor (g/mile)[2]	0.16	5.74	0.64	0.02	0.12	0.06	1,648	5.10E-03	4.80E-03	1,649
Net Emission Rate per Ton-Mile (g/ton-mile)[3]	7.03E-03	2.48E-01	2.76E-02	6.79E-04	5.34E-03	2.60E-03	71.2	2.20E-04	2.07E-04	71.2
Emissions per Container (g/container)[4]	52.7	1,861	207	5.09	40.0	19.5	533,906	1.65	1.56	534,410
Annual Emissions (tons/year)[5]	4.58	162	18.0	0.44	3.48	1.69	46,364	0.14	0.14	46,408

1. ROG = Reactive Organic Gas; NOx = Nitrogen Oxide; CO = Carbon Monoxide; SOx = Sulfur Oxide; PM10 = Particulate Matter with an aerodynamic diameter of 10 microns or less; PM2.5 = Particulate Matter with an aerodynamic diameter of 2.5 microns or less; CO2 = Carbon Dioxide; CH4 = Methane; N2O = Nitrous Oxide; CO2e = Carbon Dioxide Equivalents.

2. Emission factors per California Air Resources Board EMFAC2014 Database using the following input parameters:
    Data Type: Emissions
    Region: Statewide
    Calendar Year: 2019
    Season: Annual
    Vehicle Category: EMFAC 2011 T7 Tractor
    Model Year: Aggregated
    Speed: Aggregated
    Fuel: Diesel

3. Net Emission Rate per Ton-Mile (g/ton-mile) = Emission Factor (g/mile) / Container Weight (short tons)

4. Emissions per Container (g/container) = Emission Factor (g/mile) * Miles/Container

5. Annual Emissions (tons/year) = Emission Factor (g/mile) * Miles/Container * Containers Transported/year / Conversion Factor (g/ton)

6. PM emission factors account for PM from exhaust, tire wear, and break wear.

7. California Climate Action Registry General Reporting Protocol Version 3.1 January 2009. Table C4 Diesel Heavy -Duty Vehicles, All Model Years

8. Global Warming Potentials obtained from 40 CFR 98, Subpart A, Table A-1 as follows: GWP_CH4 = 25, GWP_N2O = 298.

Table 2-1. Los Angeles to Riverside Input Parameters (Scenario 1)

Parameter	Value
Starting Location	Port of Los Angeles, CA
Ending Location	Walmart Distribution Center, 1001 Columbia Ave, Riverside CA 92507
Container Length (feet)	40
Container Weight (short tons)	23.15
Containers Transported/year	78,780
Miles/Container:	66

Table 2-2. Los Angeles to Riverside Emission Calculations (Scenario 1)

	ROG	NOx	CO	SOx	PM10[5]	PM2.5[5]	CO2	CH4[6]	N2O[6]	Total CO2e[7]
Emission Factor (g/mile)[1]	0.16	5.74	0.64	0.02	0.12	0.06	1,648	5.10E-03	4.80E-03	1,649
Net Emission Rate per Ton-Mile (g/ton-mile)[2]	7.03E-03	2.48E-01	2.76E-02	6.79E-04	5.34E-03	2.60E-03	71.2	2.20E-04	2.07E-04	71.2
Emissions per Container (g/container)[3]	10.7	379	42.2	1.04	8.14	3.96	108,594	0.34	0.32	108,696
Annual Emissions (tons/year)[4]	0.93	32.9	3.66	0.09	0.71	0.34	9,430	0.03	0.03	9,439

1. Emission factors per California Air Resources Board EMFAC2014 Database using the following input parameters:
   Data Type: Emissions
   Region: Statewide
   Calendar Year: 2019
   Season: Annual
   Vehicle Category: EMFAC 2011 T7 Tractor
   Model Year: Aggregated
   Speed: Aggregated
   Fuel: Diesel
2. Net Emission Rate per Ton-Mile (g/ton-mile) = Emission Factor (g/mile) / Container Weight (short tons)
3. Emissions per Container (g/container) = Emission Factor (g/mile) * Miles/Container
4. Annual Emissions (tons/year) = Emission Factor (g/mile) * Miles/Container * Containers Transported/year / Conversion Factor (g/ton)
5. PM emission factors account for PM from exhaust, tire wear, and break wear.
6. California Climate Action Registry General Reporting Protocol Version 3.1 January 2009. Table C4 Diesel Heavy -Duty Vehicles, All Model Years
7. Global Warming Potentials obtained from 40 CFR 98, Subpart A, Table A-1 as follows: GWP_CH4 = 25, GWP_N2O = 298.

Table 3-1. Riverside to Patterson Input Parameters (Scenario 1)

Parameter	Value
Starting Location	Walmart Distribution Center, 1001 Columbia Ave, Riverside CA 92507
Ending Location	Amazon Distribution Center, 255 Park Center Drive, Patterson, CA
Container Length (feet)	53
Container Weight (short tons)	33
Containers/year	55,146
Miles/Container:	352

Table 3-2. Riverside to Patterson Emission Calculations (Scenario 1)

	ROG	NOx	CO	SOx	PM10[5]	PM2.5[5]	CO2	CH4[6]	N2O[6]	Total CO2e[7]
Emission Factor (g/mile)[1]	0.16	5.74	0.64	0.02	0.12	0.06	1,648	5.10E-03	4.80E-03	1,649
Net Emission Rate per Ton-Mile (g/ton-mile)[2]	4.92E-03	1.74E-01	1.94E-02	4.75E-04	3.74E-03	1.82E-03	49.8	1.54E-04	1.45E-04	49.9
Emissions per Container (g/container)[3]	57.3	2,022	225	5.53	43.5	21.2	580,046	1.80	1.69	580,594
Annual Emissions (tons/year)[4]	3.48	123	13.7	0.34	2.64	1.29	35,260	0.11	0.10	35,293

1. Emission factors per California Air Resources Board EMFAC2014 Database using the following input parameters:
   - Data Type: Emissions
   - Region: Statewide
   - Calendar Year: 2019
   - Season: Annual
   - Vehicle Category: EMFAC 2011 T7 Tractor
   - Model Year: Aggregated
   - Speed: Aggregated
   - Fuel: Diesel
2. Net Emission Rate per Ton-Mile (g/ton-mile) = Emission Factor (g/mile) / Container Weight (short tons)
3. Emissions per Container (g/container) = Emission Factor (g/mile) * Miles/Container
4. Annual Emissions (tons/year) = Emission Factor (g/mile) * Miles/Container * Containers Transported/year / Conversion Factor (g/ton)
5. PM emission factors account for PM from exhaust, tire wear, and break wear.
6. California Climate Action Registry General Reporting Protocol Version 3.1 January 2009. Table C4 Diesel Heavy -Duty Vehicles, All Model Years
7. Global Warming Potentials obtained from 40 CFR 98, Subpart A, Table A-1 as follows: GWP_CH4 = 25, GWP_N2O = 298.

Table 4-1. Los Angeles to Patterson Input Parameters (Scenario 2)

Parameter	Value
Starting Location	Port of Los Angeles, CA
Ending Location	Amazon Distribution Center, 255 Park Center Drive, Patterson, CA
Container Length (feet)	40
Container Weight (short tons)	23
Containers/year	78,780
Miles/Container:	324

Table 4-2. Los Angeles to Patterson Emission Calculations (Scenario 2)

	ROG	NOx	CO	SOx	PM10[5]	PM2.5[5]	CO2	CH4[6]	N2O[6]	Total CO2e[7]
Emission Factor (g/mile)[1]	0.06	1.24	0.35	0.01	0.10	0.04	1,453	5.10E-03	4.80E-03	1,455
Net Emission Rate per Ton-Mile (g/ton-mile)[2]	2.63E-03	5.34E-02	1.53E-02	5.99E-04	4.40E-03	1.70E-03	62.8	2.20E-04	2.07E-04	62.8
Emissions per Container (g/container)[3]	20	401	115	4	33	13	470,882	2	2	471,386
Annual Emissions (tons/year)[4]	1.71	35	10.0	0.39	2.86	1.11	40,891	0.14	0.14	40,935

1. Emission factors per California Air Resources Board EMFAC2014 Database using the following input parameters:
   - Data Type: Emissions
   - Region: Statewide
   - Calendar Year: 2019
   - Season: Annual
   - Vehicle Category: EMFAC 2011 T7 Tractor
   - Model Year: 2014-2020
   - Speed: Aggregated
   - Fuel: Diesel
2. Net Emission Rate per Ton-Mile (g/ton-mile) = Emission Factor (g/mile) / Container Weight (short tons)
3. Emissions per Container (g/container) = Emission Factor (g/mile) * Miles/Container
4. Annual Emissions (tons/year) = Emission Factor (g/mile) * Miles/Container * Containers Transported/year / Conversion Factor (g/ton)
5. PM emission factors account for PM from exhaust, tire wear, and break wear.
6. California Climate Action Registry General Reporting Protocol Version 3.1 January 2009. Table C4 Diesel Heavy -Duty Vehicles, All Model Years
7. Global Warming Potentials obtained from 40 CFR 98, Subpart A, Table A-1 as follows: GWP_CH4 = 25, GWP_N2O = 298.

Table 5-1. Los Angeles to Riverside Input Parameters (Scenario 2)

Parameter	Value
Starting Location	Port of Los Angeles, CA
Ending Location	Walmart Distribution Center, 1001 Columbia Ave, Riverside CA 92507
Container Length (feet)	40
Container Weight (short tons)	23.15
Containers/year	78,780
Miles/Container:	66

Table 5-2. Los Angeles to Riverside Emission Calculations (Scenario 2)

	ROG	NOx	CO	SOx	PM10[5]	PM2.5[5]	CO2	CH4[6]	N2O[6]	Total CO2e[7]
Emission Factor (g/mile)[1]	0.06	1.24	0.35	0.01	0.10	0.04	1,453	5.10E-03	4.80E-03	1,455
Net Emission Rate per Ton-Mile (g/ton-mile)[2]	2.63E-03	5.34E-02	1.53E-02	5.99E-04	4.40E-03	1.70E-03	62.8	2.20E-04	2.07E-04	62.8
Emissions per Container (g/container)[3]	4.0	81.5	23.4	0.91	6.71	2.59	95,775	0.34	0.32	95,878
Annual Emissions (tons/year)[4]	0.35	7.1	2.03	0.08	0.58	0.23	8,317	0.03	0.03	8,326

1. Emission factors per California Air Resources Board EMFAC2014 Database using the following input parameters:
   Data Type: Emissions
   Region: Statewide
   Calendar Year: 2019
   Season: Annual
   Vehicle Category: EMFAC 2011 T7 Tractor
   Model Year: 2014-2020
   Speed: Aggregated
   Fuel: Diesel
2. Net Emission Rate per Ton-Mile (g/ton-mile) = Emission Factor (g/mile) / Container Weight (short tons)
3. Emissions per Container (g/container) = Emission Factor (g/mile) * Miles/Container
4. Annual Emissions (tons/year) = Emission Factor (g/mile) * Miles/Container * Containers Transported/year / Conversion Factor (g/ton)
5. PM emission factors account for PM from exhaust, tire wear, and break wear.
6. California Climate Action Registry General Reporting Protocol Version 3.1 January 2009. Table C4 Diesel Heavy -Duty Vehicles, All Model Years
7. Global Warming Potentials obtained from 40 CFR 98, Subpart A, Table A-1 as follows: GWP_CH4 = 25, GWP_N2O = 298.

Table 6-1. Riverside to Patterson Input Parameters (Scenario 2)

Parameter	Value
Starting Location	Walmart Distribution Center, 1001 Columbia Ave, Riverside CA 92507
Ending Location	Amazon Distribution Center, 255 Park Center Drive, Patterson, CA
Container Length (feet)	53
Container Weight (short tons)	33
Containers/year	55,146
Miles/Container:	352

Table 6-2. Riverside to Patterson Emission Calculations (Scenario 2)

	ROG	NOx	CO	SOx	PM10[5]	PM2.5[5]	CO2	CH4[6]	N2O[6]	Total CO2e[7]
Emission Factor (g/mile)[1]	0.06	1.24	0.35	0.01	0.10	0.04	1,453	5.10E-03	4.80E-03	1,455
Net Emission Rate per Ton-Mile (g/ton-mile)[2]	1.84E-03	3.74E-02	1.07E-02	4.19E-04	3.08E-03	1.19E-03	43.9	1.54E-04	1.45E-04	44.0
Emissions per Container (g/container)[3]	21.4	435	125	4.88	35.8	13.8	511,575	1.80	1.69	512,123
Annual Emissions (tons/year)[4]	1.30	26	7.6	0.30	2.18	0.84	31,098	0.11	0.10	31,131

1. Emission factors per California Air Resources Board EMFAC2014 Database using the following input parameters:
   Data Type: Emissions
   Region: Statewide
   Calendar Year: 2019
   Season: Annual
   Vehicle Category: EMFAC 2011 T7 Tractor
   Model Year: 2014-2020
   Speed: Aggregated
   Fuel: Diesel
2. Net Emission Rate per Ton-Mile (g/ton-mile) = Emission Factor (g/mile) / Container Weight (short tons)
3. Emissions per Container (g/container) = Emission Factor (g/mile) * Miles/Container
4. Annual Emissions (tons/year) = Emission Factor (g/mile) * Miles/Container * Containers Transported/year / Conversion Factor (g/ton)
5. PM emission factors account for PM from exhaust, tire wear, and break wear.
6. California Climate Action Registry General Reporting Protocol Version 3.1 January 2009. Table C4 Diesel Heavy -Duty Vehicles, All Model Years
7. Global Warming Potentials obtained from 40 CFR 98, Subpart A, Table A-1 as follows: GWP_CH4 = 25, GWP_N2O = 298.

Table 7-1: Aggregated MY Trucks (Scenario 1) - Trucking Emission Summary (tons/year)

			Ship-and-Truck Emissions (tons/year)	Emission Savings (tons/year)
Pollutant	**Los Angeles -> Patterson**	**Los Angeles -> Riverside -> Patterson**	**Los Angeles -> Stockton -> Patterson**	**Ship-and-Truck minus Trucking**
NOx	162	156	33	123
PM10	3.48	3.35	0	3
PM2.5	1.69	1.63	0	2
CO2e (GHG)	46,408	44,732	11,437	33,295

Table 7-2: 2014 to 2020 MY Trucks (Scenario 2) - Trucking Emission Summary (tons/year)

			Ship-and-Truck Emissions (tons/year)	Emission Savings (tons/year)
Pollutant	**Los Angeles -> Patterson**	**Los Angeles -> Riverside -> Patterson**	**Los Angeles -> Stockton -> Patterson**	**Ship-and-Truck minus Trucking**
NOx	35	34	33	0.7
PM10	2.86	2.76	0	2.8
PM2.5	1.11	1.07	0	1.1
CO2e (GHG)	40,935	39,457	11,437	28,020

ATTACHMENT 2

Shipping Emission Estimates

SMB - Naval Architects & Consultants
Stam, Marttin, Balt & Partner bv

USA Feeder Project

NOx, PM and GHG Emissions of Container Transport via Marine 5 Highway

Contract No. : SMB11.024
Doc. No. : SMB11.024-380-080
Revision : J
Date : 18.12.2017
Originator : HSt

Contents

Coverpage photo: Artist's impression of the proposed container feeder vessel

Executive Summary

SMB - Naval Architects & Consultants has performed a study to investigate the emissions produced during the transport of containers between the Port of Stockton and the Port of LA/Long Beach. This study forms part of a broader study by Santa Maria Shipping LLC, a California-based corporation, to compare emissions produced by transporting containers on truck via road and on a vessel via river/sea.

This report only deals with the emissions produced during seaborne transport of the containers. Another consultancy firm, Trinity Consultants based in Oakland, California, will prepare the emissions study of land-based transport and any emissions that will be produced during intermodal transfer of containers (e.g. from ship to shore or from quayside onto truck) and will make the final comparison between transport via road and transport via ship.

In this report the main focus is on the nitrogen oxide (NOx), particulate matter (PM) and Green House Gas emissions (GHG), as produced by the ship during sailing. It is assumed that the vessel will use shore power when moored at the container terminals.

As a result of data from a recent study and data provided by two engines makers, MAN and Wärtsilä, we were able to determine that an LNG, dual fuel engine would generate 1.4 grams per kilowatt/hour as an average for engine emissions.

The calculations show the following emissions, depending on the actual loading of the vessel and actual weight of the containers:

- NOx: 0.0187 - 0.0235 g/(t·km) or 0.0272 - 0.0343 g/(short ton·mile)
- PM: 0.0000 - 0.0000 g/(t·km) or 0.0000 - 0.0000 g/(short ton·mile)
- GHG: 6.48 - 8.16 g/(t·km) or 9.46 - 11.92 g/(short ton·mile)

Compared to diesel engines, the LNG results showed that NOx emissions dropped by over 50% and Particulate Matter was found to be negligible. Both MAN and Wärtsilä confirmed this as well a recent study by Stenersen and Thonstad **[8]**. As a result, the decision was to adopt a dual fuel LNG engine.

The CO_2 emissions for the engine are undermined by what is called methane slip. This emission of unburnt methane has been found to decline in newer engines and a catalyst technology has been proposed to reduce this type of emission further, but such technology is not yet available based on the same study by Stenersen and Thonstad **[8]**. In this report, methane slip is accounted for in the emission factor for GHG and corrected for its global warming potential (GWP).

A battery-powered system is also planned to support zero emission entry and exits from the ports, so emissions will be reduced further. Anecdotal information from Scandlines, which operates a fleet of ferries sailing between Denmark and Germany suggest that fuel savings from batteries could reach as high as 10%, but there are no third party studies to validate this claim.

The proposed vessel is a typical feeder vessel, designed to carry approximately one thousand two hundred twenty foot equivalent type of containers (1200 TEU, TEU being a standard size in the (marine) transportation industry).

1. Introduction

SMB - Naval Architects & Consultants has been commissioned by California-based Santa Maria Shipping LLC to assess the emissions and NOx emissions in particular of ship borne transportation of containers along the Stockton - Los Angeles route, also known as the Marine 5 Highway initiative. The assessment of the emissions will be specifically done for the ship as proposed by Santa Maria Shipping for this trade, a vessel to be designed to have a hybrid propulsion system and the main fuel for the generators/engines to be Liquified Natural Gas (LNG). This hybrid technology will enable Santa Maria Shipping to further reduce the emissions of environmental harmful gases even further than the current and proposed measures, such as the Tier III regulations as proposed by the International Maritime Organisation (IMO).

2. General

2.1. Methodology

No universal proposed methodology to calculate and/or assess emissions from marine diesel engines exists. However, numerous publications and proposals on the subject can be found. Without trying to be exhaustive, a number of these are supplied in the reference list as attached hereto. As far as emissions go, this report will use a limited number of reports and studies that have become available recently on the emissions of LNG fuelled ships.

2.2. History of emission control in the marine environment

Prevention of pollution of the marine environment is regulated worldwide by the International Maritime Organisation. More specifically, the MARPOL (MARitime POLlution) protocol has been instituted to this effect. Regulations of air pollution and control of air pollutant emissions were discussed and put into force from the late nineteen seventies onward.

In this last decade, the IMO and a number of its member states have been actively instating and enforcing Emission Control Areas (ECAs) or Sulphur Emission Control Areas (SECAs) which are meant to control and minimise emissions of a number of air pollutants, those being sulphur oxide (SOx), nitric and nitrogen oxide (NOx), Ozone Depleting Substances (ODS) and Volatile Organic Compounds (VOC).

Currently ECAs include the US and Canadian coast, the US Caribbean, including Puerto Rico and the US Virgin Islands, the Baltic Sea and the North Sea.

From 2006 and onwards, the sulphur content in marine fuel has been reduced and is now restricted to 0.1% in the SECAs. Globally, a sulphur cap of 0.5% will be instated from January 1st 2020. The graph in figure 2.2.1 shows the progressive limits on sulphur content in marine fuel oil.

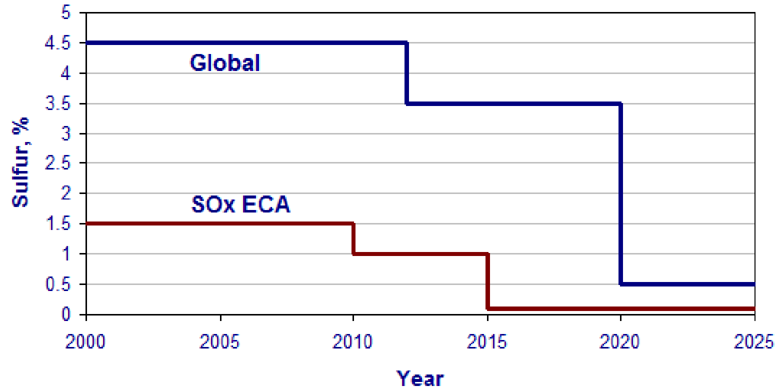

Fig. ***2.2.1:*** *Restriction of sulphur content in marine fuel oil*

As of January 1st, 2000 marine diesel engines had to comply with Tier I regulations for NOx emissions, Tier II has come into force on January 1st, 2011, restricting the emissions of NOx further. Tier III is to come in force on January 1st, 2020 as a further reduction. Figure 2.2.2 gives the various NOx restriction of Tiers I-III.

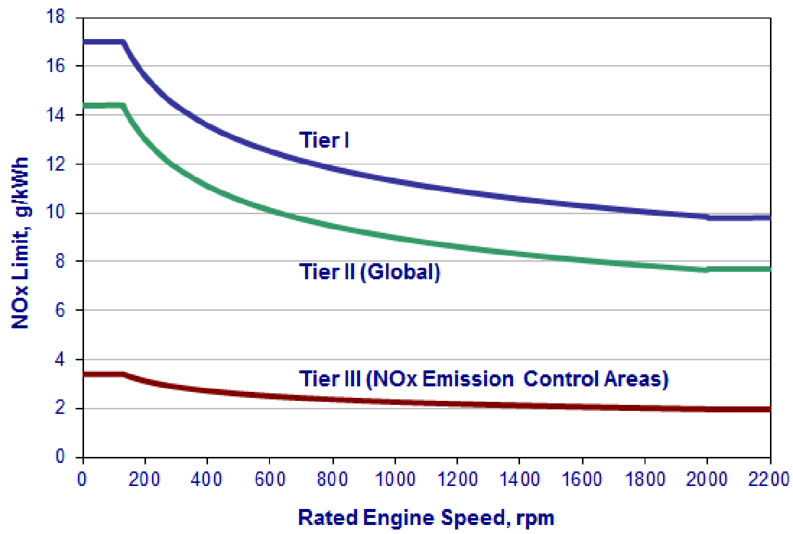

Fig. ***2.2.2:*** *NOx limits in exhaust gases*

2.3. The vessel

The following table describes the main characteristics of the 1200 TEU vessel as proposed for the feeder services between Stockton and Los Angeles (tab. 2.3.1):

Description	Value	Unit
Length over all	171,35	[m]
Length between perpendiculars	164,00	[m]
Breadth moulded	24,50	[m]
Depth to upper deck	11,95	[m]
Depth to main deck	9,50	[m]
Draught design	8,60	[m]
Draught scantling	9,50	[m]
Deadweight at scantling draught (approx.)	15.600	[mt]
Speed at design draught (approx) at 85% MCR	18	[kts]
Installed main engine power (approx.)	10.000	[kW]
Containers 20 ft nominal total	1173	[TEU]
of which loaded at 14 mt. Homogeneous (approx.)	880	[TEU]
Containers 40/45ft nominal total	577	[FEU/FFEU]
of which loaded at 28 mt. Homogeneous (approx.)	440	[FEU/FFEU]

*Tab. **2.3.1:** Main characteristics of vessel*

A side view of the general arrangement of the vessel is presented in fig. **2.3.1.**

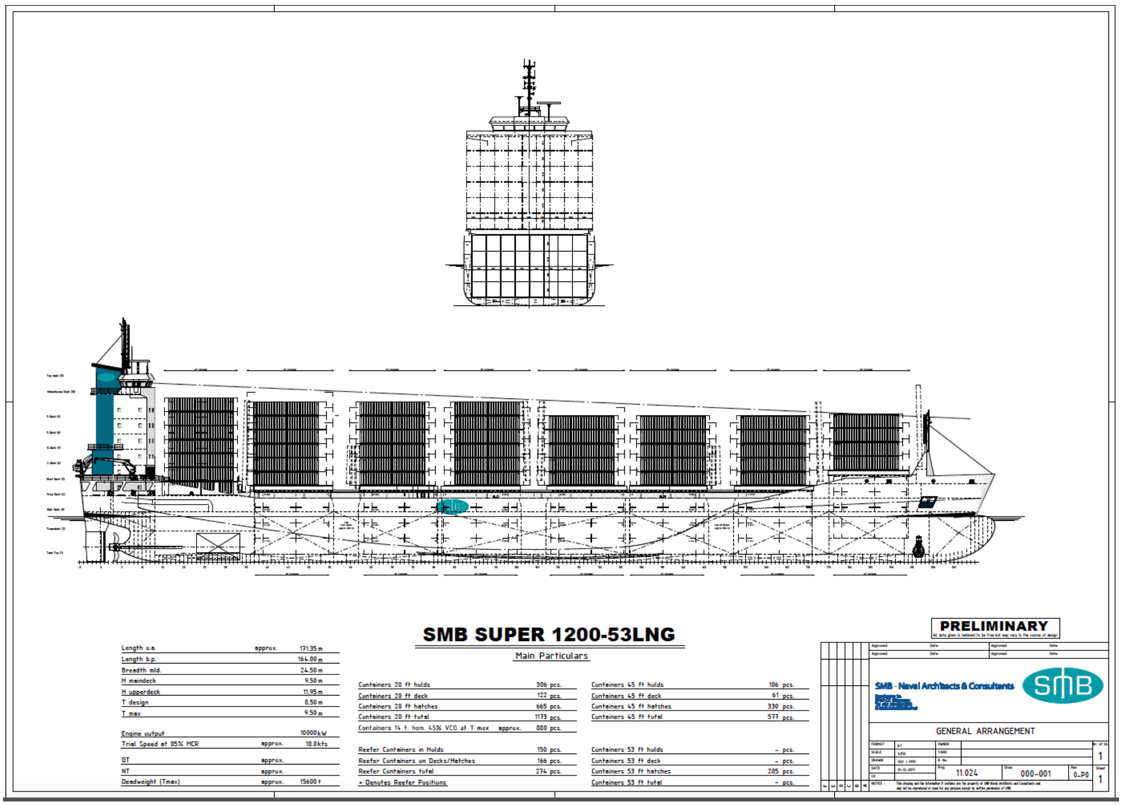

*Fig. **2.3.1:** Side view of vessel*

The vessel is to carry approximate 1173 TEU (Twenty-foot Equivalent Unit) containers nominal, meaning empty containers, out of which approximately 880 TEU could be loaded to a maximum of 14 metric tonnes (the 14 metric tonnes being the typical average loaded weight for a TEU container). The amount of homogeneously loaded FEU is estimated to be approximately 440 containers. As the vessel is designed to take as many FFEU (Forty-Five foot Equivalent Unit) as it will take FEU's, the amount of loaded FFEU's will be the same as the amount of loaded FEU' carried.

2.4. Propulsion and on-board power generation system

Typically the type of vessel as described in paragraph 2.3 will be fitted with a diesel direct propulsion system running on LNG (Liquified Natural Gas) fuel and consisting of either a two stroke marine diesel engine directly coupled to the propulsion shaft or a four stroke marine diesel engine coupled to the propulsion shaft via a single stage gear box.

Electricity for on-board purposes will be generated via a shaft generator coupled to the propulsion shaft via a PTO (Power Take Off) - which can be used both in case of two and four stroke installations - or by mounting a shaft generator directly onto the propulsion shaft - used most commonly with two stroke installations. The latter installation typically would also require a frequency converter in order to deal with the varying engine revolutions also in plain sailing modes. A PTO Shaft Generator installation with a four stroke engine is typically not provided with a frequency generator and will therefore only function at constant rated speed of the main engine (although a frequency converter obviously could be used as well).

As an independent source of electrical power, diesel driven generators would be installed in order to provide electricity when electricity from the shaft generator is available, for instance in adverse weather or under manoeuvring conditions.

Both the shaft generator and the diesel driven generators will be directly connected after being synchronised to the on-board electrical system's main bus bar.

For such a system the typical voltage will be 440 V with a 60 Hz frequency.

2.5. The hybrid propulsion system

For the proposed vessel the propulsion system as described in 2.4 will be augmented with additional electrical power storage batteries and further components modified so as to form a hybrid system.

In such a system the main propulsion line or shaft can be driven by multiple motors each developing power from a different power source. This is different from so-called dual fuel engines, which can develop power from different fuel sources, e.g. LNG and/or diesel oil, although dual fuel engines can form part of a hybrid system. In a hybrid system these power sources could be diesel driven generators, shaft generators, batteries, fuel cells, solar cells or any other viable source of power.

The aim of a hybrid system is to optimise the energy efficiency of the propulsion system, sometimes in combination with other, auxiliary systems. This can be understood knowing that a diesel engine, although relatively efficient at higher engine loads, tends to run rather inefficiently at low loads.

Optimisation of a propulsion system by means of a hybrid system can be done in two ways:

- Peak shaving - In some cases a certain engine power is required to deal with power demands that may or may not occur or will occur at long intervals. This power requirement can be met by installing a diesel engine of the required power which would then run at a lower, less optimal load for much of its operational time
- Take-over - At low loads, where the main propulsion engine would run inefficiently, propulsion is taken over by a smaller engine or other power source that can run efficiently at those loads. These would typically be electric motors, served either by diesel generators (that can be dimensioned to run optimally at those lower power demands) or batteries. In some cases "Father and Son" installations are used in which a large and smaller diesel engine are coupled via a gear box to the same propulsion shaft. The latter tend to be fairly complex and expensive solutions and require more maintenance, which is why they are not widely used anymore but diesel-electric hybrid versions are used instead.

With a hybrid system both methods can be employed and optimised via on-board power management, either automatically or manually.

Examples of situations where these methods can be used are:

- Manoeuvring - In this situation power demand is characterised by sudden rapid requirement of power which can be easily met by an electrical system or, to a somewhat lesser extent, with a four stroke diesel engine set-up. A two stroke engine cannot be ramped up as quickly as manoeuvring often requires and a hybrid system can provide a quick reacting source of additional power

- Slow-steaming - A hybrid system can provide "silent" slow steaming capabilities for low speeds for certain limited periods of time, whereby electric power is provided from more efficient or alternative sources, e.g. batteries, solar panels, fuel cells, etc.

- Service speed - Ships are usually designed with a certain service speed in mind. In order to guarantee this service speed under most weather conditions a reserve is designed into the required engine power. This necessitates an engine larger than usually required. With a hybrid system the main propulsion diesel engine can be designed to always operate around its optimum with the electric motor and associated power sources providing additional power when required, typically for shorter periods.

A hybrid system will typically operate on higher voltages, up to 6.6 kV, than a conventional ship's auxiliary power system and will strive to integrate all power sources and consumers via a so called DC (direct current) bus. For connection to this DC bus AC/DC and DC/AC converters will be used. A typical setup of a hybrid system is shown in fig. **2.5.1** with a proposed schematic layout in fig. **2.5.2**.

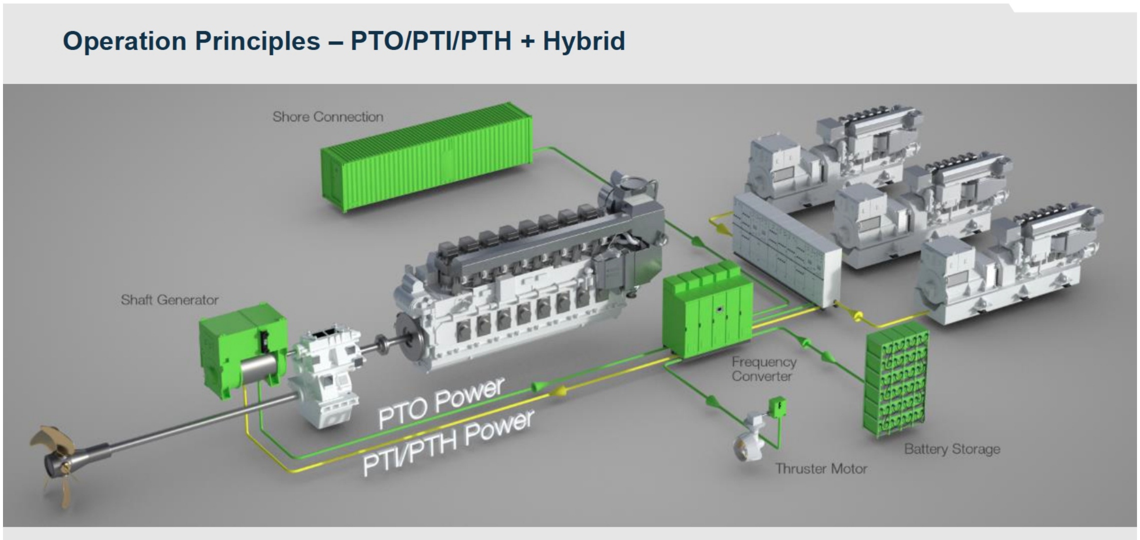

*Fig. **2.5.1:** Typical hybrid propulsion system (Source: Wärtsilä)*

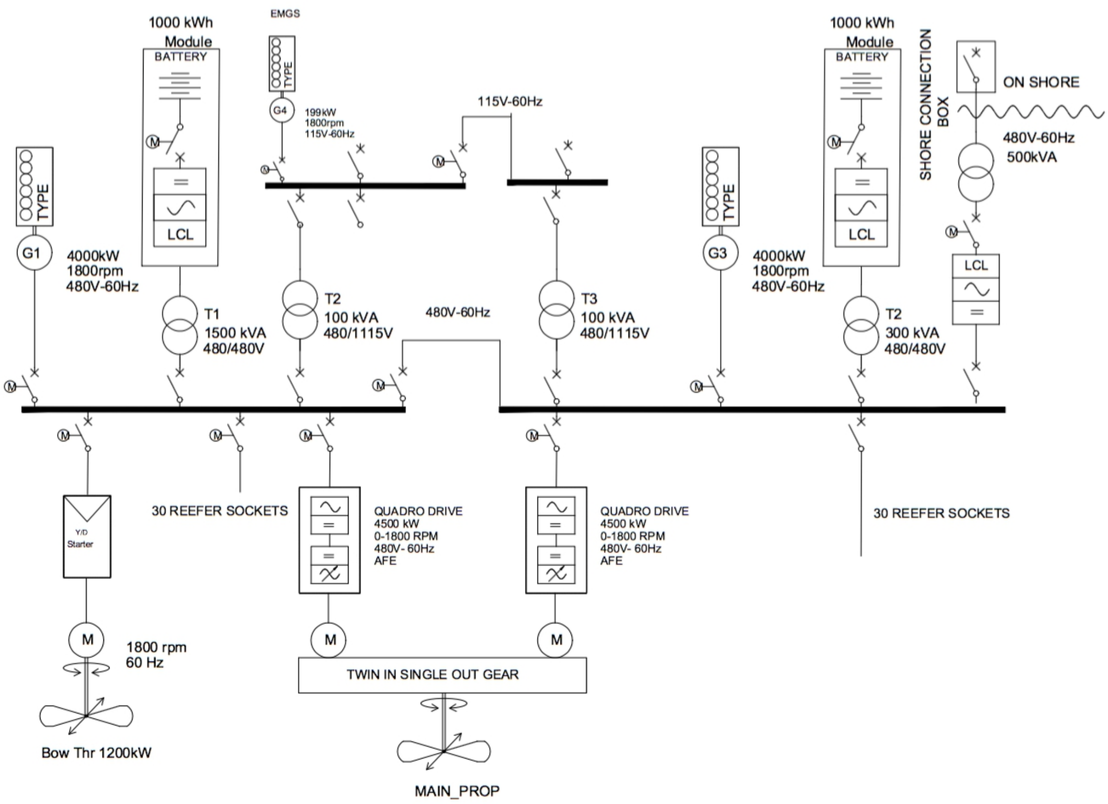

Fig. ***2.5.2*** *Schematic layout hybrid propulsion system* *(Source: Norwegian Electric Systems)*

2.6. Description of typical marine diesel engines

Main Propulsion - Two Stroke

Two main players are active in supplying two stroke dual fuel (i.e. capable of burning LNG) marine diesel engines: MAN-B&W and WinGD. Considering the required power and taking into account certain derating and sea-margin factors an engine within the 500 mm. bore range typically would be chosen. Considering full application of the benefits of hybrid propulsion, it also might be investigated if a smaller 400 mm. bore engine could be employed (although a smaller bore engine tends to use more fuel), however for the purpose of this report the more conservative, larger engine has been chosen.

MAN-B&W uses a high pressure (approx. 300 bar) fuel feed system for its dual fuel engines. This has the advantage that the engine performs in much the same way as a diesel engine would. The performance of the engine thus is much less susceptible to the quality of the fuel gas provided (this is often indicated by the “Methane Number” of the gas) and produes very low methane slip (according to MAN approx. 0.2 g/kWh). The installation does require high pressure gas compressors and other parts that can handle the high pressures, such as piping, valves, etc. It should also be noted that this compression of gas does produces boil-off gas that cannot be used anymore and should be considered as methane slip as well.

WinGD employs a low pressure system, which has the advantage of being a relatively simple system to design and build. However this has the disadvantage of the engine operating on the Otto-process rather than the Diesel process (thus comparable to a petrol engine) and makes the engine susceptible to the quality of the methane gas (a low methane number can cause knocking of the engine, which in turn will invoke an automatic power reduction of the engine).

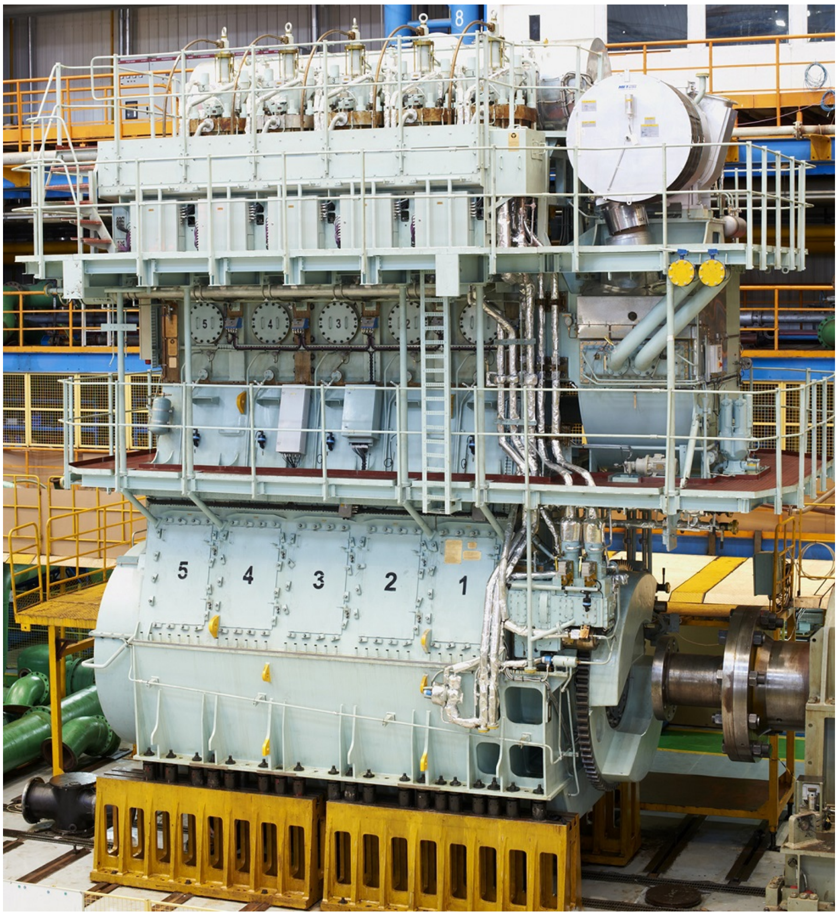

*Fig. **2.6.1**: Two stroke engine (WinGD RT-Flex50, picture: WinGD)*

Main Propulsion - Four Stroke

Quite a few makers can supply four stroke dual fuel marine diesel engines, although within the required power range the number does become limited. Without being exhaustive, engine producers such as Wärtsilä, Caterpillar/Mak and MAN are named.

Similar bore size as for the two stroke engine would be chosen, however with more cylinders since four stroke engine tend to produce less power per cylinder when compared to two stroke engines. All engines comply with the IMO Tier III (EPA Tier 4) regulations without the need for further NOx abatement systems when running on LNG. Figure **2.6.2** depicts such an engine and further details are presented in Appendix II.

Diesel engines for auxiliary duties

Many suppliers are available for marine diesel generator sets. For Tier III compliance, abatement systems will be required as with the larger engines. An example of a Tier III compliant engine and setup is given in Appendix III. It is to be expected that more alternatives in the required power range will become available in the near future.

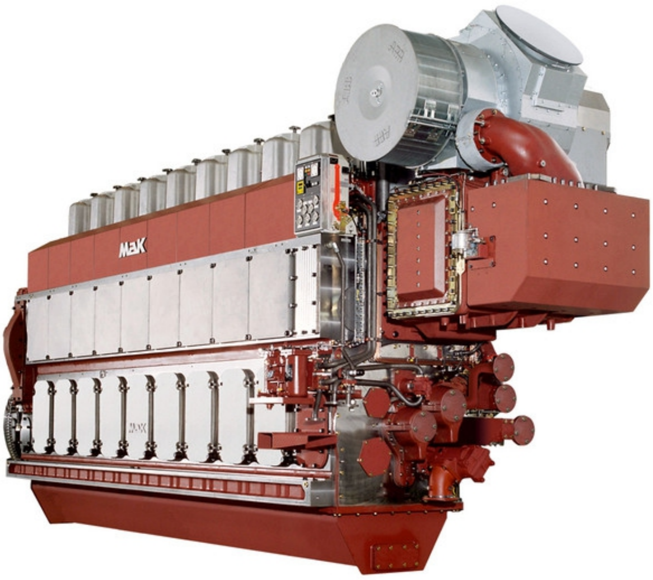

*Fig. **2.6.2**: Four stroke engine (Caterpillar-MaK M 46, picture: Caterpillar-MaK)*

Although some dual fuelled diesel engines do exist in the size and range typically associated with generators on board of the vessel as described, there is not much choice yet. It is therefore to be assumed that the diesel generators will be of the diesel fuelled type and will have some sort of NOx abatement system as is typical for such an engine (these would be similar to systems as also found on large truck engines).

2.7. Intended sailing route and sailing profile

The intended sailing route forms part of the I-5 Marine Highway Corridor and will be from Stockton, CA via Pittsburg, CA to the Golden Gate. From there the vessel will sail along the coast to the Breakwater Gate at Long Beach. From the Breakwater Gate it is a short distance to one of the container terminals.

The total distance sailed will be 446 nautical miles one way. The following table gives the intended sailing profile.

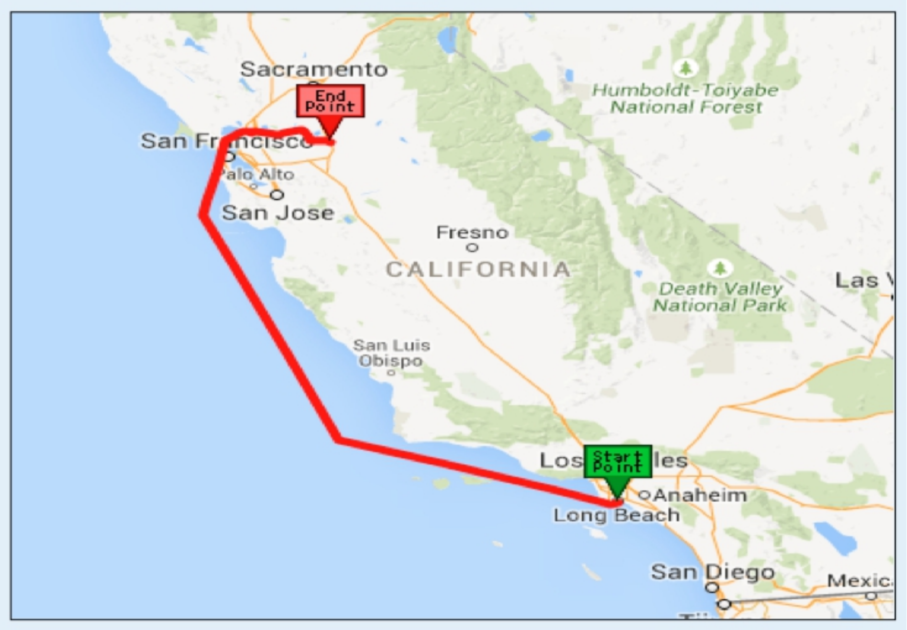

*Fig. **2.8.1**: Proposed sailing route*

Leg	Distance	Speed
	[nm]	[kts]
Stockton Inner Port	0,25	3
Stockton - Pittsburg CA	38	7
Pittsburg CA - Golden Gate	39	8
Golden Gate - Los Angeles Breakwater	366,30	16
Breakwater Gate to Port of Long Beach	2,3	7
Port of Long Beach - Inner Harbour	0,9	3
Total distance (one way)	445,85	

*Tab. **2.8.1**: Sailing profile*

2.8. Units

In this report, units generally according to the SI (International System of Units or Système International) system will be used. For certain nautical measurements such as speed and distance non-SI units such as respectively Knots (kts) and Nautical Miles (nm) will be used.

In all calculations a comma is used as decimal separator.

3. Conclusions

The calculations show the following emissions, depending on various loading of the vessel:

- NOx: 0.0186 - 0.0202 g/(t·km) (base cases, 440 FEU carried)
  0.0216 - 0.0235 g/(t·km) (alternative cases, 505 FEU carried)
- GHG: 6.48 - 7.03 g/(t·km) (base cases, 440 FEU carried)
  7.53 - 8.16 g/(t·km) (alternative cases, 505 FEU carried)

The calculations have been based on the emissions of NOx and GHG as reported in the study by Stenersen and Thonstad **[8]** and, where possible, the values reported in this study have been cross-checked with main engine manufacturers.

PM is taken as nil, based on various studies that have shown this emission to be not measurable. (source: website of World Ports Climate Initiative)

Optimisation of the use of the battery and on board power systems will yield additional reductions of fuel consumption and thus emissions. These reductions can only be estimated by doing full simulations or measurements when the vessel has actually been built. Comparable vessels with similar propulsion and power setup show possible reductions of fuel consumption between 10% and 20%, depending on the variance in the ship's load and weather conditions.

A complete estimation of GHG methane slip also is taken into account in conjunction with its greenhouse warming potential factor. A recent study **[8]** shows that methane slip for gas-fuelled engines is much lower than anticipated and new technologies are being developed to further minimise the methane slip.

4. Calculations

4.1. Description of the calculation model

The calculation model as developed here takes the specific route into account as per paragraph 2.7. An average journey time is calculated per leg by the distance and average speed sailed.

The power requirements for propulsion are derived from the speed-power curve of a comparable vessel. This vessel has been tank tested and the experimental data has been verified by sea trials. It is assumed the vessel will be able to sail using a combinator curve for its propeller pitch and propeller shaft revolutions combination settings, therefore minimising/mitigating the losses due to high propeller rpm in low power requirements.

The ship's own power requirement is derived from the electrical load balance, which provides all permanent and temporary users, such as pumps, ventilator motors, lighting, control and automation, electronics etc. A cross survey has been made of vessels of similar size[1], function and outfitting to derive a typical value of the ship's own power requirements. This study has shown that such vessels require on average 600 kW for permanent users (i.e. always on) and 200 kW for temporary users (i.e. not always on, for example lighting would only be used at night). For the temporary users a load factor of 0.5 (e.g. lighting is only turned on at night) is used, thus giving a total of 700 kW for the ship's own power requirements.

Calculations will be made for the carriage of 440 FEU/FFEU's of 28 mt. An earlier project, the M580 Stockton to Oakland Tug-Barge service has shown that the average weight of containers ranges between 20 and 22 mt. In some cases export containers are heavier (up to 24 mt). Calculations will therefore also be provided for a vessel loaded with average mean containers at 21 mt. Based on the stability data of the vessel it is expected that 505 FEU of 21 mt can be carried.

Reefer containers are addressed in separate calculation cases, in order to highlight the influence of this special cargo on the emissions. It is assumed, in this case, that out of the 440 loaded FEU, 60 units will be reefer containers. Although the nominal rating of such containers is 12.5 kW, a typical required power value of 5.3 kW is used in the calculations. This value has been derived from long term surveys and is being applied by eminent reefer container companies such as Hapag-Süd.

The proposed hybrid propulsion system assumes that a 2000 kWh battery will be installed with a 3C power factor. This means that the battery can be (dis)charged at 3 times its nominal (1C0 rating. Since the full effects of the application of such a battery in e.g. peak shaving would involve a full dynamic simulation, which falls beyond the scope of this report, it has been chosen to use the battery as a means for “silent running” only, meaning that the vessel will sail from and into port on batteries as long as possible. After the battery is depleted it needs to be charged by the on board generators or via shore power.

[1]Data taken from SMB - Naval Architects' own database, comprising data of vessels designed and/or built between 2005 - 2017

Emission data for dual fuel engines is still considered as proprietary by many of the engine makers. For the emission values the following data will be used:

- NOx - the value of 1.4 g/kWh as provided by the report by Stenersen and Thonstad [8] is taken. This value is consistent and on the conservative side as confirmed by both Wärtsilä and MAN.[2] Actual emissions may be as low as 0.9 g/kWh but cannot be confirmed at this stage and are therefore not used.
- PM - for Particulate Matter, the value PM will be used, meaning the particulate matter 10 micrometers in diameter or less. This value includes both the PM_{10} and $PM_{2.5}$ particulate matter as per EPA's guidelines (ICF International 2009). These guidelines give a further breakdown of the PM values as consisting of 97% $PM_{2.5}$ matter and the remainder being PM_{10} matter. General consensus is that because of its nature, LNG will produce no PM as a result of the combustion process, since the production of PM is associated with ash and sulphur content in the fuel, which for LNG is non-existent. However, small amounts of pilot oil are injected, which may generate PM. Considering the small amount and the fact that this will be clean, low sulphur (<0.1%) MGO, the amount of PM produced will be negligible. Stenersen and Thonstad do not mention it and López-Aparicio and Tønnesen **[9]** mention 0.00036 g/kWh. López-Aparicia and Tønnesen do refer to a study by Verbeek et al and their findings of 0.02 - 0.21 g/kWh but this should be seen in the light that these values have not been obtained by measurement or actual data and are based on higher sulphur diesel oil. In this report it will be assumed that no PM of significance is produced.
- GHG - Green House Gases are mainly associated with CO_2. For CO_2 emissions the value as suggested by Stenersen and Thonstad is used and set to 2.66 kg of CO_2 produced per kilogram of fuel gas burned. This is slightly lower than the value used in the EEDI calculation methodology as per IMO regulations but found to be realistic as the lower value is obtained from actual measurements.

  Since LNG is being used as the main fuel source, the methane slip has to be considered as well, since it is known that methane is more potent as a greenhouse gas than CO_2.[3] The amount of methane slip is assumed to be 2.5 g/kWh, as per engine makers' supplied data and has been found to be 5.3 g/kWh or 31 g/kg fuel burnt as per the study by Stenersen and Thonstad. Since this methane is actually unburned fuel gas, it is deducted from the fuel consumption, as cited by the engine makers, as this value is used to calculate

[2] E-mail from Wärtsilä sales representative Mark Keneford names 1.5 g/kWh as maximum and 1 g/kWh as weighted average and in a telephone conversation with MAN this was confirmed by their representative

[3] The EPA website mentions that the GWP of methane is 25, meaning that 1 kg of methane has the global warming potential equivalent to 25 kg of CO_2

the amount of CO_2 emitted. In this report we will use the higher value as a conservative assumption of 31 g/kg fuel burnt. This equals to 31 times 25 = 775 g additional "CO_2" per kg fuel burnt because of the higher GWP. The total amount of GHG thus becomes 3.435 kg of GHG produced per kg of fuel used.

The emission calculations are achieved by applying the following equation (Eq. 4.1.1.):

$$E = kW \cdot Act \cdot LF \cdot EF \qquad \text{Eq. 4.1.1}$$

Where:

E = emissions in grams per defined time unit
kW = kilowatts
Act = activity in hours
LF = engine load factor (for the activity)
ef = emission factor in grams per kilowatt per hour

In the calculation sheets LF is accounted for in the actual engine power (in kW) required to sail at the required speed. LF will therefore always be 1.

4.2. Calculations

The following cases are calculated and the results presented in Appendix IV:

1. 440 FEU, no reefers on board, battery partly loaded via a shore connection
2. 440 FEU, of which 60 reefers, battery partly loaded via a shore connection
3. 440 FEU, no reefers on board, battery fully loaded via on board generators
4. 440 FEU, of which 60 reefers on board, battery fully loaded via on board generators
5. 505 FEU, no reefers on board, battery partly loaded via a shore connection
6. 505 FEU, of which 60 reefers, battery partly loaded via a shore connection
7. 505 FEU, no reefers on board, battery fully loaded via on board generators
8. 505 FEU, of which 60 reefers on board, battery fully loaded via on board generators

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[7] University of California, Determination of Emissions from a Very Large Crude Carrier Using Two Different Fuels, Prepared for the California Air Resources Board, ARB Contract #12-425, April 2015

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[9] Susane López-Aparicia and Dag Tønnesen, Pollutant emissions from LNG fuelled ships, Norwegian Institute for Air Research, June 2015

Company background

SMB - Naval Architects & Consultants is a firm established in 2008 and has been providing design and consultancy services to shipowners and shipyards worldwide, mainly in the field of the design and operation of container (feeder) vessels. Apart from design and consultancy services in the shipping business, SMB - Naval Architects & Consultants also provides design and consultancy services for the building and installation of offshore windfarm installations such as transformer and rectifying platforms.

Hans Karel Stam has studied Naval Architecture at the Polytechnic University in Delft and has been working in the design and shipbuidling industry for over 25 years. He is the initiator and co-founder of SMB - Naval Architects & Consultants.

APPENDICES

I. Typical specification for a two stroke dual fuel engine - approx. 8000 kW

II. Typical specification for a four stroke dual fuel engine - approx. 8000 kW

III. Typical specification for a high speed marine diesel engine intended for a generator

IV. Test Cycles and Weighting Factors (Regulation 13 MARPOL Annex VI)

V. Calculations for the various cases

APPENDIX I. Typical specification for a two stroke dual fuel engine - approx. 8000 kW

WinGD RT-flex50DF

IMO Tier III in gas mode

Cylinder bore	500 mm
Piston stroke	2050 mm
Speed	99–124rpm
Mean effective pressure at R1	17.3 bar
Stroke/bore	4.10

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Length A' mm	Weight tonnes
	124 rpm	124 rpm	99 rpm	99 rpm			
	R1	R2	R3	R4			
5	7 200	6 000	5 750	4 775	5 576	6 793	200
6	8 640	7 200	6 900	5 730	6 456	7 670	225
7	10 080	8 400	8 050	6 685	7 336		255
8	11 520	9 600	9 200	7 640	8 216		280

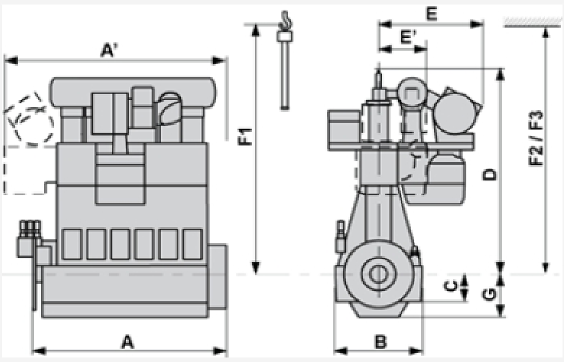
Dimensions (mm)					
	B	C	D	E	E*
	3 150	1 088	7 646	3 570	1 900
	F1	F2	F3	G	
	9 270	9 270	8 800	1 636	

Brake specific consumptions in gas mode

Rating point		R1	R2	R3	R4
BSEC (energy)	kJ/kWh	7 200	7 158	7 200	7 158
BSGC (gas)	g/kWh	142.7	141.6	142.7	141.6
BSPC (pilot fuel)	g/kWh	1.5	1.8	1.5	1.8

Brake specific fuel consumption in diesel mode

Rating point		R1	R2	R3	R4
BSFC (diesel)	g/kWh	182.1	182.1	182.1	182.1



APPENDIX II. Typical specification for a four stroke dual fuel engine - approx. 8000 kW

OVERVIEW

The low emission footprint paired with high efficiency and reliability make the M 46 DF an ideal propulsion engine for operation inside and outside of environmental protected areas as well as waters with HFO limitations. Upcoming IMO III emission regulations, selected operation profiles and low diesel fuel costs make the M 46 DF a preferred engine regarding cost of operation.

POWER RATING UNITS: US METRIC

Power Range	5400 - 8685 kW

ENGINE SPECIFICATIONS

Speed Range	500 / 514 rpm
Emissions	IMO II in diesel mode / IMO III in gas mode
Aspiration	Turbocharged
Bore	460.0 mm
Stroke	610.0 mm
Rotation (from flywheel end)	Counterclockwise / Clockwise
Configuration	6,7,8,9 Cylinder
Swept Volume	101.3 l/cyl

DIMENSIONS & WEIGHTS

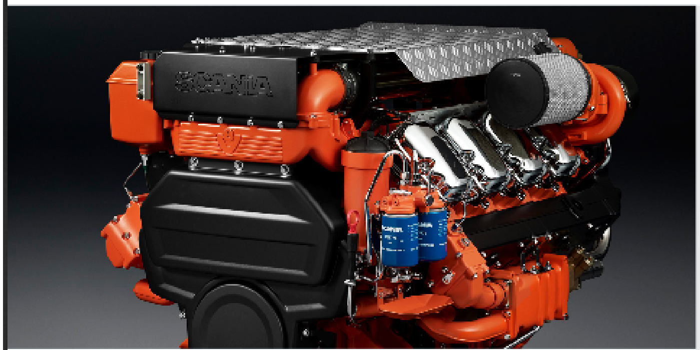
Minimum Dry Weight	94.0 t
Minimum Length	8330.0 mm
Maximum Length	10768.0 mm
Minimum Height	5130.0 mm
Maximum Height	5501.0 mm
Minimum Width	2961.0 mm
Maximum Width	2961.0 mm

APPENDIX III. Typical specification for a high speed marine diesel engine intended for a generator

SCANIA MARINE ENGINES

DI16 091M. 480-596 kW

IMO Tier III, IMO Tier II



The marine engines from Scania are based on a robust design with a strength optimised cylinder block containing wet cylinder liners that can easily be exchanged. Individual cylinder heads with 4 valves per cylinder promotes repairability and fuel economy.

The engine is equipped with a Scania developed Engine Management System, EMS, in order to ensure the control of all aspects related to engine performance. The injection system is based on electronically controlled unit injectors that in combination with SCR (Selective catalytic Reduction) gives low exhaust emissions with good fuel economy and a high torque already at low revs.
The engine can be fitted with many accessories such as air cleaners, PTOs and cast iron flywheel housing with dual positions for starter in order to suit a variety of installations.

	Rating	Engine speed (rpm)	
		1500	1800
Gross power, full load (kW)	PRP	480	596
Gross torque (Nm)		3056	3162
Spec fuel consumption. Full load (g/kWh)		203	210
Spec fuel consumption. 3/4 load (g/kWh)		199	203
Spec fuel consumption. 1/2 load (g/kWh)		201	206
Optimum fuel consumption (g/kWh)		199	
Reductant consumption. Full load (g/kWh)		16	15
Heat rejection to coolant* (kW)		359	457

*Including charge air

PRP - Prime power: For continuous operation and unlimited yearly operation at varying load. Max. mean load factor of 70% of rated power over 24 h of operation.
1 hour/12 hours period of accumulated peak overload to 110%.

Standard equipment
- Scania Engine Management System, EMS
- Unit injectors, PDE
- Twin turbochargers, heat insulated
- Fuel pre-filter with water separator
- Fuel filter
- Oil filter, full flow
- Centrifugal oil cleaner
- Oil cooler, integrated in block
- Oil filler, in valve cover
- Deep front oil sump
- Oil dipstick, front
- Starter, 2-pole 7.0 kW
- Alternator, 2-pole 100A
- Flywheel SAE 14
- Silumin flywheel housing, SAE 1 flange
- Front-mounted engine brackets
- SCR-system
- Catwalk and cover for belt transmission
- Closed crankcase ventilation
- Operator's manual

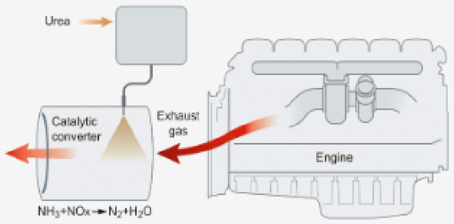
Engines with heat exchanger:
- Sea water charge air cooler
- Impeller sea water pump
- Dual heat exchangers with expansion tanks

Optional equipment
- Hydraulic pump
- Side-mounted PTO
- Front-mounted PTO
- Exhaust connections
- Engine heater
- Engine brackets with different heights
- Stiff rubber suspension
- Air cleaner
- Cast iron flywheel housing, SAE 1 flange
- Reversible fuel filter
- Low coolant level sensor
- Variable idle speed setting
- Low oil sump
- Reversible oil filters
- Oil draining with pump
- Oil level sensor
- Reductant feed pump
- Bilge pump

Appendix III. (cont'd) Typical specification for a high speed marine diesel engine intended for a generator

SCANIA MARINE ENGINES

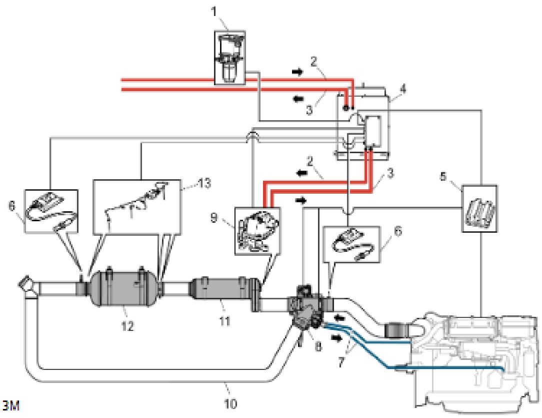
SCR system



The principle for Scania SCR system

SCR (Selective Catalytic Reduction) technology is used on Scania's engines for IMO Tier III to reduce the NO_x content in the exhaust gases. A chemical process is started by injecting reductant, an urea and water mixture, into the exhaust gas stream. During injection the water evaporates and the urea breaks down to form ammonia. The ammonia then reacts with the nitrogen gases in the catalytic converter and forms harmless products such as nitrogen gas and water. Through the use of SCR the exhaust gases are purged of poisonous levels of NO_x in the best possible way. Scania is making use of a system that is carefully developed and tested in our own laboratory.

The Scania SCR system contains an exhaust routing valve that enables to by-pass the SCR system in order to meet the class requirements for marine installations. The system is delivered with an urea unit in stainless steel, prepared for connection to a main tank supported by customer. To ensure the flow of reductant between the main tank and the urea unit a reductant feed pump controlled by Scania can be included. The system can be offered with all mechanical and electrical parts needed except from the exhaust piping which is to be adapted according to the customers installation.



System overview DI13M

		Standard	Optional
1	Reductant feed pump	-	✓
2	Reductant fluid pressure line	-	-
3	Reductant fluid return line	-	-
4	Urea unit (including reductant tank, -pump, -pick up unit and control unit EEC)	✓	-
5	Control unit EMS	✓	-
6	NO_x sensors	✓	-
7	Coolant pipes	-	-

		Standard	Optional
8	Exhaust routing valve	✓	-
9	Reductant doser	✓	-
10	Branch pipe	-	-
11	Evaporator module	✓	-
12	SCR catalyst	✓	-
13	Exhaust temperature sensors	✓	-

APPENDIX IV. NOx Emission Test Cycles and Weighting Factors

(MARPOL Annex VI, Regulation 13)

Annex VI- Regulations for the Prevention of Air Pollution from Ships

Appendices to Annex VI

Appendix II - Test cycles and weighting factors (Regulation 13)

The following test cycles and weighting factors should be applied for verification of compliance of marine diesel engines with the NOx limits in accordance with regulation 13 of this Annex using the test procedure and calculation method as specified in the NOx Technical Code.

.1 For constant-speed marine engines for ship main propulsion, including diesel-electric drive, test cycle E2 should be applied.

.2 For variable-pitch propeller sets test cycle E2 should be applied.

.3 For propeller-law-operated main and propeller-law-operated auxiliary engines the test cycle E3 should be applied.

.4 For constant-speed auxiliary engines test cycle D2 should be applied.

.5 For variable-speed, variable-load auxiliary engines, not included above, test cycle C1 should be applied.

Test cycle for *constant-speed main propulsion application* (including diesel-electric drive or variable-pitch propeller installations)

Test cycle type E2	Speed	100%	100%	100%	100%
	Power	100%	75%	50%	25%
	Weighting factor	0.2	0.5	0.15	0.15

Test cycle for *propeller-law-operated main and propeller-law-operated auxiliary engine* application

Test cycle type E3	Speed	100%	91%	80%	63%
	Power	100%	75%	50%	25%
	Weighting factor	0.2	0.5	0.15	0.15

Test cycle for *constant-speed auxiliary engine* application

Test cycle type D2	Speed	100%	100%	100%	100%	100%
	Power	100%	75%	50%	25%	10%
	Weighting factor	0.05	0.25	0.3	0.3	0.1

Test cycle for *variable-speed and -load auxiliary engine* application

Test cycle type C1	Speed	Rated				Intermediate			Idle
	Torque	100%	75%	50%	10%	100%	75%	50%	0%
	Weighting factor	0.15	0.15	0.15	0.1	0.1	0.1	0.1	0.15

ANNEX V. Emission Calculations

SMB - Naval Architects & Consultants

Stam, Marttin, Balt & Partner bv

380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 1 440 FEU No Reefers LNG Battery charging via shore power

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	440	FEU/FFEU
No of reefers		FEU/FFEU
Average weight of container	28	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: LNG fuel consumption for two stroke engine in low load as per manufacturer's data

Note: LNG fuel consumption for two stroke engine in normal load as per manufacturer's data

Note: Electrical load is provided by the shaft generator in all parts of the journey

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	0	29	58	0	88	88		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	0	4886	3800	0	8686	1913		6773
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	0	5363	3413	0	8775			15548
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	0	103022	16026	0	119048		841	135436
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	0	296	230	0	526	526		135436
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	0	105	210	0	315	315		135436
Totals	446,75		33,91							137436	2841	841	135436

Calculation of NOx and PM emissions production		
Total NOx production:	189611	g/trip
NOx production (SI units):	0,0186	g/(t·km)
NOx production (US units):	0,0272	g/(st·USm)
NOx/FEU-FFEU:	0,4309	kg/cont/trip
Total PM production:	0,0000	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production				
Leg				
			Total GHG production per trip:	
Stockton - Inner Port	0,0000	mt/leg	66,077 [mt] or	72,839 [st]
Stockton - Pittsburg CA	3,4899	mt/leg	equals	0,166 [st/FEU]
Pittsburg CA - SF Golden Gate	4,5213	mt/leg	equals	6,48 [g/t·km]
SF Golden Gate - LA Breakwater Gate	58,0661	mt/leg	equals	9,46 [g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,0000	mt/leg		
Port of Long Beach - Inner Habour	0,0000	mt/leg		

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380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 2 | 440 FEU | 60 Reefers | LNG | Battery charging via shore power

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	440	FEU/FFEU
No of reefers	60	FEU/FFEU
Average weight of container	28	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	60	29	58	27	114	114		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	60	4886	3800	1726	10412	1886		8526
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	60	5363	3413	1550	10325			18851
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	60	103022	16026	7280	126328		1041	146220
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	60	296	230	104	630	630		146220
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	60	105	210	95	410	410		146220
Totals	446,75		33,91							148220	3041	1041	146220

Calculation of emissions production		
Total NOx production:	204707	g/trip
NOx production (SI units):	0,0201	g/(t·km)
NOx production (US units):	0,0293	g/(st·USm)
NOx/FEU-FFEU:	0,4652	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production						
Leg						
			Total GHG production per trip:			
Stockton - Inner Port	0,0000	mt/leg	71,083	[mt] or	78,356	[st]
Stockton - Pittsburg CA	4,3930	mt/leg		equals	0,178	[st/FEU]
Pittsburg CA - SF Golden Gate	5,0009	mt/leg		equals	6,97	[g/t·km]
SF Golden Gate - LA Breakwater Gate	61,6889	mt/leg		equals	10,18	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,0000	mt/leg				
Port of Long Beach - Inner Habour	0,0000	mt/leg				

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380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 3 440 FEU No Reefers LNG Battery charging via onboard shaft generator

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	440	FEU/FFEU
No of reefers		FEU/FFEU
Average weight of container	28	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

(Note: the charging of the battery of power consumption in LA legs will actually take place on the return trip)

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	0	29	58	0	88	88		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	0	4886	3800	0	8686	1913		6773
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	0	5363	3413	0	8775			15548
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	0	103022	16026	0	119048		841	135436
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	0	296	230	0	526	526	526	135962
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	0	105	210	0	315	315	315	136277
Totals	446,75		33,91							137436	2841	1681	136277

Calculation of emissions production		
Total NOx production:	190788	g/trip
NOx production (SI units):	0,0187	g/(t·km)
NOx production (US units):	0,0273	g/(st·USm)
NOx/FEU-FFEU:	0,4336	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production					
Leg					
			Total GHG production per trip:		
Stockton - Inner Port	0,0000	mt/leg	66,510 [mt] or	73,316	[st]
Stockton - Pittsburg CA	3,4899	mt/leg	equals	0,167	[st/FEU]
Pittsburg CA - SF Golden Gate	4,5213	mt/leg	equals	6,52	[g/t·km]
SF Golden Gate - LA Breakwater Gate	58,0661	mt/leg	equals	9,53	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,2709	mt/leg			
Port of Long Beach - Inner Habour	0,1623	mt/leg			

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380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 4   440 FEU   60 Reefers   LNG   Battery charging via onboard shaft generator

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	440	FEU/FFEU
No of reefers	60	FEU/FFEU
Average weight of container	28	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

(Note: the charging of the battery of power consumption in LA legs will actually take place on the return trip)

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	60	29	58	27	114	114		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	60	4886	3800	1726	10412	1886		8526
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	60	5363	3413	1550	10325			18851
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	60	103022	16026	7280	126328		1041	146220
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	60	296	230	104	630	630	630	146850
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	60	105	210	95	410	410	410	147260
Totals	446,75		33,91							148220	3041	2081	147260

Calculation of emissions production		
Total NOx production:	206164	g/trip
NOx production (SI units):	0,0202	g/(t·km)
NOx production (US units):	0,0295	g/(st·USm)
NOx/FEU-FFEU:	0,4686	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production					
Leg					
			Total GHG production per trip:		
Stockton - Inner Port	0,0000	mt/leg	71,619 [mt] or	78,947	[st]
Stockton - Pittsburg CA	4,3930	mt/leg	equals	0,179	[st/FEU]
Pittsburg CA - SF Golden Gate	5,0009	mt/leg	equals	7,03	[g/t·km]
SF Golden Gate - LA Breakwater Gate	61,6889	mt/leg	equals	10,26	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,3247	mt/leg			
Port of Long Beach - Inner Habour	0,2115	mt/leg			

380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 5 505 FEU No Reefers LNG Battery charging via shore power

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	505	FEU/FFEU
No of reefers		FEU/FFEU
Average weight of container	21	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	0	29	58	0	88	88		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	0	4886	3800	0	8686	1913		6773
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	0	5363	3413	0	8775			15548
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	0	103022	16026	0	119048		841	135436
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	0	296	230	0	526	526		135436
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	0	105	210	0	315	315		135436
Totals	446,75		33,91							137436	2841	841	135436

Calculation of emissions production		
Total NOx production:	189611	g/trip
NOx production (SI units):	0,0216	g/(t·km)
NOx production (US units):	0,0315	g/(st·USm)
NOx/FEU-FFEU:	0,3755	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production					
Leg					
			Total GHG production per trip:		
Stockton - Inner Port	0,0000	mt/leg	66,077 [mt] or	72,839	[st]
Stockton - Pittsburg CA	3,4899	mt/leg	equals	0,144	[st/FEU]
Pittsburg CA - SF Golden Gate	4,5213	mt/leg	equals	7,53	[g/t·km]
SF Golden Gate - LA Breakwater Gate	58,0661	mt/leg	equals	10,99	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,0000	mt/leg			
Port of Long Beach - Inner Habour	0,0000	mt/leg			

SMB - Naval Architects & Consultants

Stam, Marttin, Balt & Partner bv

380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 6 505 FEU 60 Reefers LNG Battery charging via shore power

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	505	FEU/FFEU
No of reefers	60	FEU/FFEU
Average weight of container	21	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	60	29	58	27	114	114		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	60	4886	3800	1726	10412	1886		8526
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	60	5363	3413	1550	10325			18851
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	60	103022	16026	7280	126328		1041	146220
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	60	296	230	104	630	630		146220
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	60	105	210	95	410	410		146220
Totals	446,75		33,91							148220	3041	1041	146220

Calculation of emissions production		
Total NOx production:	204707	g/trip
NOx production (SI units):	0,0233	g/(t·km)
NOx production (US units):	0,0341	g/(st·USm)
NOx/FEU-FFEU:	0,4054	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production						
Leg						
			Total GHG production per trip:			
Stockton - Inner Port	0,0000	mt/leg	71,083	[mt] or	78,356	[st]
Stockton - Pittsburg CA	4,3930	mt/leg		equals	0,155	[st/FEU]
Pittsburg CA - SF Golden Gate	5,0009	mt/leg		equals	8,10	[g/t·km]
SF Golden Gate - LA Breakwater Gate	61,6889	mt/leg		equals	11,83	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,0000	mt/leg				
Port of Long Beach - Inner Habour	0,0000	mt/leg				

380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 7 505 FEU No Reefers LNG Battery charging via onboard shaft generator

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	505	FEU/FFEU
No of reefers		FEU/FFEU
Average weight of container	21	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

(Note: the charging of the battery of power consumption in LA legs will actually take place on the return trip)

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	0	29	58	0	88	88		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	0	4886	3800	0	8686	1913		6773
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	0	5363	3413	0	8775			15548
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	0	103022	16026	0	119048		841	135436
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	0	296	230	0	526	526	526	135962
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	0	105	210	0	315	315	315	136277
Totals	446,75		33,91							137436	2841	1681	136277

Calculation of emissions production		
Total NOx production:	190788	g/trip
NOx production (SI units):	0,0217	g/(t·km)
NOx production (US units):	0,0317	g/(st·USm)
NOx/FEU-FFEU:	0,3778	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production					
Leg					
			Total GHG production per trip:		
Stockton - Inner Port	0,0000	mt/leg	66,510 [mt] or	73,316	[st]
Stockton - Pittsburg CA	3,4899	mt/leg	equals	0,145	[st/FEU]
Pittsburg CA - SF Golden Gate	4,5213	mt/leg	equals	7,58	[g/t·km]
SF Golden Gate - LA Breakwater Gate	58,0661	mt/leg	equals	11,07	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,2709	mt/leg			
Port of Long Beach - Inner Habour	0,1623	mt/leg			

380-091 EMISSION CALCULATIONS

Order No.:	SMB11.024	Originator:	SMB/HSt	Date:	17-12-17
Client:	Santa Maria Shipping LLC			Revision:	J
Description:	Calculation of NOx and PM emissions for the Stockton to Los Angeles Sea Route			Check:	

Case 8 505 FEU 60 Reefers LNG Battery charging via onboard shaft generator

Assumptions		
Battery power	2000	kWh battery/Energy Type 3C
No of containers carried	505	FEU/FFEU
No of reefers	60	FEU/FFEU
Average weight of container	21	[mt] homogeneous loaded
Nominal power for reefer	5,3	[kW]
NOx production ME	1,4	[g/kWh]
PM production ME	0	[g/kWh]
GHG production ME	3,435	[kg CO2/kg fuel]
LNG consumption<2000 kW	150	[g/kWh]
LNG consumption>2000 kW	141	[g/kWh]
Units		
Nautical Mile [nm]	1852,000	[m]
US Survey Mile [USm]	1609,347	[m]
short ton [st]	0,907	[mt]
Pound [lb]	453,59	[g]

Note: Electrical load is provided by the shaft generator in all parts of the journey

(Note: the charging of the battery of power consumption in LA legs will actually take place on the return trip)

Leg	Distance	Speed	Time	Power Required									Nett Power
				Propulsion	Ship	Reefer	Propulsion	Ship	Reefer	Total	Battery ->	-> Battery	requirement
	[nm]	[kts]	[h]	[kW]	[kW]	[pcs]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kW]
Stockton - Inner Port	0,3	3,0	0,08	350	700	60	29	58	27	114	114		0
Stockton - Pittsburg CA	38,0	7,0	5,43	900	700	60	4886	3800	1726	10412	1886		8526
Pittsburg CA - SF Golden Gate	39,0	8,0	4,88	1100	700	60	5363	3413	1550	10325			18851
SF Golden Gate - LA Breakwater Gate	366,3	16,0	22,89	4500	700	60	103022	16026	7280	126328		1041	146220
LA Breakwater Gate - Port Of Long Beach	2,3	7,0	0,33	900	700	60	296	230	104	630	630	630	146850
Port of Long Beach - Inner Habour	0,9	3,0	0,30	350	700	60	105	210	95	410	410	410	147260
Totals	446,75		33,91							148220	3041	2081	147260

Calculation of emissions production		
Total NOx production:	206164	g/trip
NOx production (SI units):	0,0235	g/(t·km)
NOx production (US units):	0,0343	g/(st·USm)
NOx/FEU-FFEU:	0,4082	kg/cont/trip
Total PM production:	0	g/trip
PM production (SI units):	0,0000	g/(t·km)
PM production (US units):	0,0000	g/(st·USm)
PM/FEU-FFEU:	0,0000	kg/cont/trip

Calculation of GHG emissions production						
Leg						
			Total GHG production per trip:			
Stockton - Inner Port	0,0000	mt/leg	71,619	[mt] or	78,947	[st]
Stockton - Pittsburg CA	4,3930	mt/leg		equals	0,156	[st/FEU]
Pittsburg CA - SF Golden Gate	5,0009	mt/leg		equals	8,16	[g/t·km]
SF Golden Gate - LA Breakwater Gate	61,6889	mt/leg		equals	11,92	[g/st·USm]
LA Breakwater Gate - Port Of Long Be	0,3247	mt/leg				
Port of Long Beach - Inner Habour	0,2115	mt/leg				