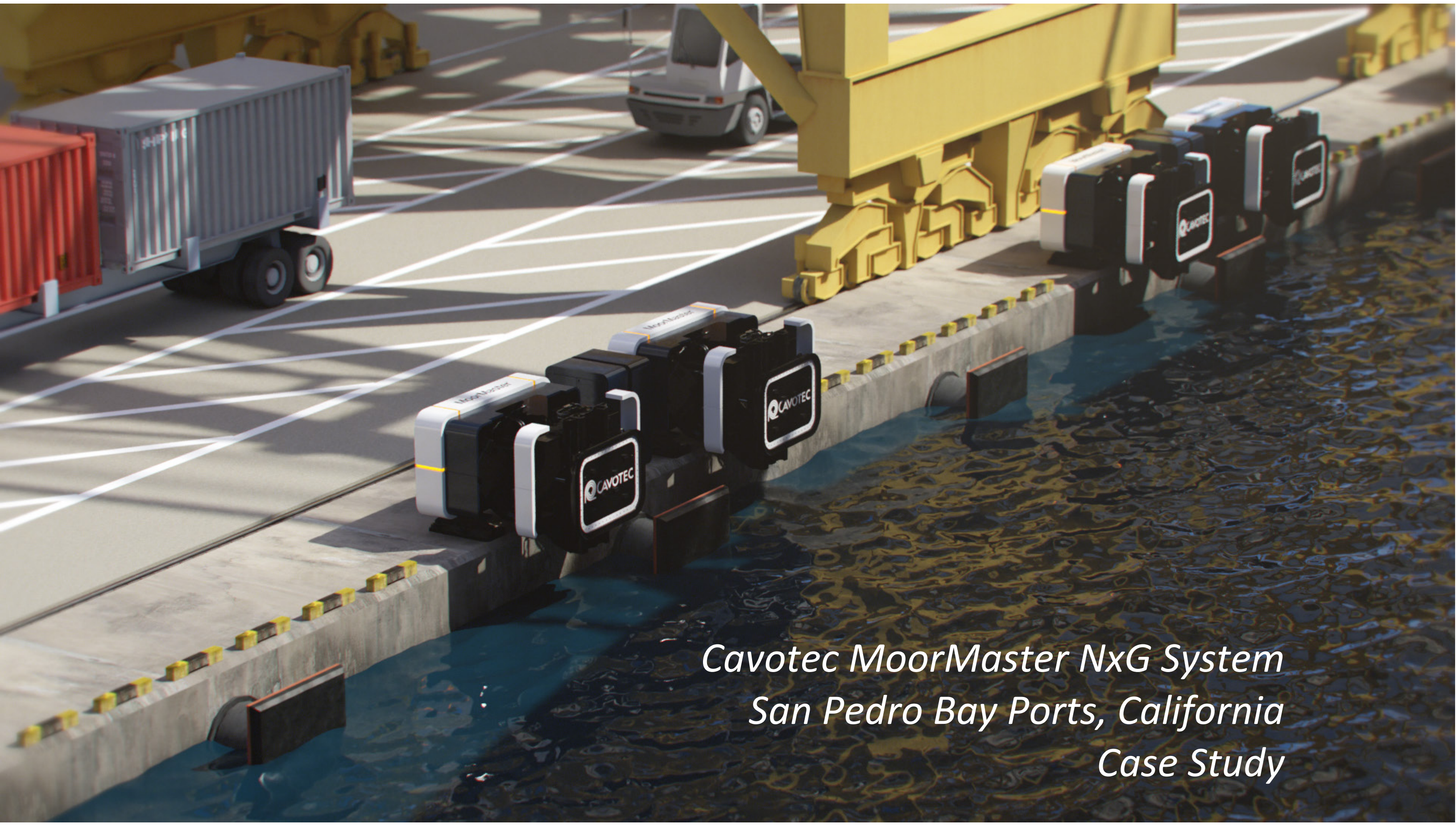
CAVOTEC

We connect the future.



Cavotec MoorMaster NxG System
San Pedro Bay Ports, California
Case Study

June 2021

Prepared by:

STARCREST CONSULTING GROUP, LLC

ENVIRONMENTAL MANAGEMENT • AIR QUALITY • CLIMATE • SUSTAINABILITY

Established 1997

Table of Contents

Table of Tables

1.0 Introduction

Cavotec commissioned Starcrest Consulting Group, LLC (Starcrest) to analyze and evaluate the potential fuel and emissions saving from its MoorMaster™ next generation system (MoorMaster NxG System or NxG System), which improves mooring operational efficiency by reducing the time it takes to moor a ship to and from a dock. This report presents several case study scenarios of a typical container terminal at the San Pedro Bay Ports (SPBP or Ports) complex to determine the potential fuel, costs, and emission reductions of the MoorMaster NxG System compared to conventional mooring operations. The SPBP complex is comprised of the Port of Long Beach (POLB) and Port of Los Angeles (POLA) and is the largest port complex in the Western Hemisphere. Both Ports' staff were briefed on the study with regards to the technology and case study.

The scenarios evaluated an average SPBP container terminal equipped with the NxG System compared to a container terminal with conventional mooring operations. The two scenarios evaluated are as follows:

1. Scenario 1 – Systemwide Reduction Scenario: This scenario estimates potential fuel, cost, and emissions reductions from the NxG System using a systemwide perspective that considers all pieces of equipment involved in the mooring process as well as secondary benefits of greater operational efficiencies. Specifically, this scenario includes ships and assist tugs in port (at-berth), and it presumes slower ship transit speeds resulting from the time saved during mooring. This scenario results in maximum reductions, but it is a complicated model that requires data and cooperation from multiple actors. As such, this scenario is most suitable for ports or organizations interested in understanding and quantifying system-level benefits of the NxG System for policy or programmatic purposes.

2. Scenario 2 – Simple Near Berth (Simple) Scenario: This scenario minimizes the complexity and uncertainty of Scenario 1 by estimating reductions only from ships during the actual mooring process; it does not include assist tugs nor secondary transit benefits. This scenario is more conservative than Scenario 1 and results in fewer emissions reductions; however, this scenario is a good fit for grant-funding programs because it is simple and easy to demonstrate the reductions. In this scenario, there are fewer actors involved, less uncertainty, and fewer data required for grant applications and ongoing tracking and reporting.

This analysis was conducted independently by Starcrest aligned with methods used by the Ports in their annual emissions inventories. Starcrest also developed a dynamic model to allow users to conduct similar scenario analyses for their specific terminals and operations. The model uses aggregated data from the Ports' inventories to represent actual container ship and assist tug operations in SPBP. The model can be used for other ports in California as an indicator for the potential benefits related to efficiency improvements in mooring operations and speed adjustments for ships in California waters outside of vessel speed reduction (VSR) zones.

2.0 Technical Approach

This section describes the technical approach used to determine the potential fuel and emissions benefits for ship mooring operations in California. The study considered benefits from two operational modes/geographic areas:

1. Port area at-berth, in which the NxG System reduces fuel usage and associated emissions alongside the dock (in the port area) from mooring operations, and

2. Transit, which assumes ships using the NxG system would use the time saved during mooring to slow down slightly on their journey to the next port. Theoretically there is potential for this to occur when reduced speeds are applied at the ship's fastest transit speeds, similar to Vessel Speed Reduction Programs operated by both Ports. Emission estimates were made for this scenario to identify the potential magnitude of the savings. From a practical air quality/carbon planning perspective, these reductions are highly uncertain and highly complex to try to quantify, so it is strongly recommended not incorporating these reductions in regulatory agency discussions like federal or state grant applications.

The following sections describe the assumptions, methods, and limitations of this study. The detailed emission estimated methodology used for this case study is provided in Appendix A.

2.1 Emissions Estimates

The approaches used to model emissions for both modes were consistent with the 2019 emission inventories for both Ports.[1][2] Emission benefits estimated in this study include the following:

Greenhouse Gases (GHGs) in metric tons or tonnes
- carbon dioxide equivalents (CO_2e)
- carbon dioxide (CO_2)

Air quality pollutants in short tons
- oxides of sulfur (SOx)
- oxides of nitrogen (NOx)
- diesel particulate matter (DPM)

The following global warming potentials were used to calculate CO_2e:

nitrous oxide (N_2O)	298
methane (CH_4)	25
CO_2	1

[1] POLA, *Inventory of Air Emissions – 2019*, Starcrest, 2020, *https://kentico.portoflosangeles.org/getmedia/4696ff1a-a441-4ee8-95ad-abe1d4cddf5e/2019_Air_Emissions_Inventory,* accessed April 2021 [POLA 2019]

[2] POLB, *Air Emissions Inventory – 2019*, Starcrest, 2020, *https://polb.com/download/14/emissions-inventory/10596/2019-air-emissions-inventory.pdf*, accessed April 2021 [POLB 2019]

2.2 Benefits of NxG System

Cavotec states that the NxG System would reduce the typical mooring time of 30 minutes and vessel release time of 15 minutes to under a minute, so the net reduction in mooring operational time would be 44 minutes or 0.7 hours per call. This estimate is based on data Cavotec has collected from its deployed MoorMaster systems around the world. These values were used in the case study; however, these data were ***not*** independently confirmed by Starcrest although they are a fundamental assumption of this case study.

Additionally, Cavotec states that the NxG System would substantially reduce vessel motion. At berths which suffer from reduced loading productivity due to excessive vessel motion, this could significantly shorten the vessel turn-around time. This benefit had not been quantified in this case study, however Cavotec believes this could significantly increase the potential savings in transits with the additional saved time at berth.

2.3 Ships and Assist Tugs

For this case study, only container ships were considered. Container ships are typically configured with a large main or propulsion engine, several smaller auxiliary engines (not all of them operating at once), and auxiliary boilers. During docking/mooring operations, the main engine is operated intermittently at various loads as needed during positioning, while auxiliary engines and boilers operate continuously. Due to the high level of main engine loading variability between calls, potential emission reductions from the main engine were not quantified. In addition, due to their relatively small contribution to emissions during maneuvring/mooring operations, boiler emission benefits were not quantified. These omissions make the estimates for the case study conservatively low.

Tugs that assist container ships during berthing operations could also benefit from reduced time on station which in turn reduces both fuel consumption and emission generation. The potential quantification of tug-related benefits is limited by the nature of tug operations. The number of tugs assisting and their engine loads during assisting operations are highly variable, and there are three tug assist companies servicing the two ports with differently configured tugs. For this case study, the emissions benefit analysis for tugs was limited to the shortened duration of mooring operations.

2.4 Terminal Characteristics

There are 13 container terminals in operation across both Ports. With permission from both Ports, terminal call data were evaluated by container ship size category for 2019 for each terminal. Container ships are grouped by 1,000 twenty-foot equivalent units or teus in the two Ports' emissions inventories. An 'average size' terminal related to the number of ship size categories and annual calls was selected for the case study, 161 calls for 2019. The following call frequency and ship size distributions were used:

- 53 Container2000
- 12 Container4000
- 3 Container5000
- 16 Container6000
- 31 Container8000
- 24 Container9000
- 22 Container10000

With the continued evolution in the container ship size call distribution that the two Ports have been experiencing since the mid-2000s, the actual number of available berths at each terminal is highly dynamic. As the ships get larger, they encroach into multiple berths and depending on the number and size of ships at a terminal, the ship call capacity can change nearly continuously. The constant measure for a terminal is the length of its wharves (unless the terminal gets reconfigured). The average length of wharf for the average container terminal at both ports is 4,600', with the shortest being 1,800' and the longest being 7,300'.

2.5 Case Study Calculator: Analysis Model

A case study calculator model was developed by Starcrest to conduct the operational efficiency analysis, to input terminal characteristics, to estimate potential fuel, emissions, and cost savings benefits. The calculator model was designed such that it can be used for any case study in California and have results consistent with emission estimates used by the two Ports and State Implementation Plans.

The case study calculator was developed using Microsoft Excel for ease of access to the broadest audience. They consist of the following pages:

- Cover & Instructions
- Scenario Summary
- Ship Information
- Tug Information
- Ship Parameters
- Assist Tug Parameters

The case study calculator sheets are further described in Appendix B.

2.6 Study Limitations

This study has limitations. For one, the results are not generalizable beyond California because California requires 0.1% sulfur MGO/MDO for all ship within 24-nautical miles of the California coast and leeward islands while the rest of North America is under the Sulfur Emission Control Area (SECA) that only requires 0.1% sulfur fuels, which includes heavy fuel oil with scrubbers and blended fuels to 0.1%.

Second, as stated earlier, Starcrest did not independently verify Cavotec's claims that the NxG System reduces mooring time by .7 hours.

Lastly, Starcrest assumed the NxG System could be installed on every SPBP container berth. In reality, the terminal or Port would need to conduct an engineering assessment to determine the wharf's suitability for this system.

3.0 Scenario Analysis

This section describes the scenario analyses and findings for an average SPBP container terminal equipped with the NxG System compared to conventional mooring operations. Again, the two scenarios evaluated are as follows:

1. Scenario 1 – Systemwide Reduction Scenario: This scenario estimates potential fuel, cost, and emissions reductions from the NxG System using a systemwide perspective that considers all pieces of equipment involved in the mooring process as well as secondary benefits of greater operational efficiencies. Specifically, this scenario includes ships and assist tugs in port (at-berth), and it presumes slower ship transit speeds resulting from the time saved during mooring. This scenario results in maximum reductions, but it is a complicated model that requires data and cooperation from multiple actors. As such, this scenario is most suitable for ports or organizations interested in understanding and quantifying system-level benefits of the NxG System for policy or programmatic purposes.
2. Scenario 2 – Simple Near Berth (Simple) Scenario: This scenario minimizes the complexity and uncertainty of Scenario 1 by estimating reductions only from ships during the actual mooring process; it does not include assist tugs nor secondary transit benefits. This scenario is more conservative than Scenario 1 and results in fewer emissions reductions; however, this scenario is a good fit for grant-funding programs because it is simple and easy to demonstrate the reductions. In this scenario, there are fewer actors involved, less uncertainty, and fewer data required for grant applications and ongoing tracking and reporting.

Both case studies use the call numbers by container ship size category for the average SPBP container terminal based on 2019 calls. Note that for both scenarios, the Ship and Assist Tug Parameters pages remained the same. Both scenarios also assumed that 100% of the calls were serviced by the NxG System. The individual scenario inputs are described in the following subsections.

3.1 Scenario 1 – Systemwide Reduction Scenario

Inputs for Scenario 1 include the following three sets of calculator inputs:

Table 3.1: Scenario 1 Summary Page Inputs

Select ship size, TEU's	Container 2000	Container 4000	Container 5000	Container 6000	Container 8000	Container 9000	Container 10000
Number of calls per year per ship size	53	12	3	16	31	24	22
Current mooring time, min	30	30	30	30	30	30	30
Current release time, min	15	15	15	15	15	15	15
Typical average open water speed, knots	14.7	14.7	15.7	15.7	16.3	16.3	16.3
Average open water transit distance to next port, nm	360	360	360	360	360	360	360
Number of assist tugs used	1	1	1	1	1	2	2
Ship fuel cost, USD per tonne	$335						
Tug fuel cost, USD per tonne	$1,000						

Note that the average open water speed was taken from IMO 2020 and assumes that the ships, reduce speed after the SPBP Vessel Speed Reduction zone. This assumes the ships are not participating in the VSR programs to the north along the California Coast.

Table 3.2: Scenario 1 Ship Information Page Inputs

	Container 2000	Container 4000	Container 5000	Container 6000	Container 8000	Container 9000	Container 10000
Ship propulsion SFOC default, g fuel/kWh	175	175	175	175	175	175	175
Ship auxiliary SFOC default, g fuel/kWh	227	227	227	227	227	227	227

Table 3.3: Scenario 1 Assist Tug Information Page Inputs

Tug propulsion engine rating, kW	3,000
Number of tug propulsion engines	2
Tug auxiliary engine load, kW	137
Number of tug auxiliary engines used	1

The findings from the analysis for Scenario 1, which represent the maximum potential for an average SPBP container terminal, indicate that there is the annual potential to save over 560 tonnes of fuel and over $360,000 in fuel expenses, to reduce NOx emissions by 50 tons, and to have slight reductions in GHGs. Of the potential 50 tons of NOx reductions, just over 6 tons come from the port area related to mooring operations and include both ship and tug reductions. The fuel cost savings potential for the ships are just over $300,000 of which $37,000 related to mooring operations.

The total annual scenario summary results are presented below.

Table 3.4: Scenario 1 Total Annual Savings

Total annual savings		
	Potential fuel savings for ship, tonnes	**508.2**
	… of which in port	**62.3**
	Potential fuel savings for tug, tonnes	**60.0**
	Potential total fuel savings, tonnes	**568.2**
	Potential fuel savings for ship, USD	**$304,897**
	… of which in port	**$37,392**
	Potential fuel savings for tug, USD	**$60,030**
	Potential total fuel savings, USD	**$364,927**
	Potential total emission reductions (ship + tug)	
	CO_2e, tonnes/year	**1,913**
	CO_2, tonnes/year	**1,887**
	SOx, tons/year	**1.243**
	NOx, tons/year	**51.11**
	DPM, tons/year	**0.891**
	Potential at-berth emission reductions (ship + tug)	
	CO_2e, tonnes/year	**378**
	CO_2, tonnes/year	**375**
	SOx, tons/year	**0.142**
	NOx, tons/year	**6.11**
	DPM, tons/year	**0.162**

For ships only, the potential annual fuel savings is over 500 tonnes, with 12% resulting from mooring operational improvements and 88% resulting from ships optimizing their open water voyages outside of VSR zones. Scenario 1 indicates that ship mooring operational efficiency improvements make up nearly 60% of the total at-berth NOx emission reductions due to improved mooring operational efficiencies.

The scenario summary results for the ships are presented below.

Table 3.5: Scenario 1 Annual Ship Savings

Total annual ship savings		
	Potential fuel savings for ship, tonnes	**508.2**
	… of which in port	**62.3**
	Potential fuel savings for ship, USD	**$304,897**
	… of which in port	**$37,392**
	Potential port emission reductions, transit	
	CO_2e, tonnes/year	**1,535**
	CO_2, tonnes/year	**1,512**
	SOx, tons/year	**1.10**
	NOx, tons/year	**45.0**
	DPM, tons/year	**0.73**
	Potential total emission reductions, at-berth	
	CO_2e, tonnes/year	**196.4**
	CO_2, tonnes/year	**193.9**
	SOx, tons/year	**0.14**
	NOx, tons/year	**3.6**
	DPM, tons/year	**0.08**

For assist tugs, the potential annual fuel savings is 60 tonnes from improved mooring operational efficiencies and a NOx reduction of 2.5 tons.

Table 3.6: Scenario 1 Annual Assist Tug Savings

Total annual tug savings		
	Potential net fuel savings, tonnes/year	**60.0**
	Potential net fuel savings, $/year	**$60,030**
	Potential tug-related at-berth emission reductions	
	CO_2e, tonnes/year	**181**
	CO_2, tonnes/year	**181**
	SOx, tons/year	**0.002**
	NOx, tons/year	**2.50**
	DPM, tons/year	**0.085**

If the MoorMaster NxG System were to be deployed across all 14 SPBP container terminals the maximum potential reductions for fuel, costs, and emissions could increase to over 7,100 tonnes of fuel reduced, over $5,10,000 fuel costs saved, and over 700 tons of NOx reduced annually.

3.2 Scenario 2 – Simple Scenario

Since Scenario 2 is only evaluating ship efficiency improvements associated with mooring operations and does not include assist tugs nor potential transiting improvements, only two sets of data inputs were required, as presented below.

Table 3.7: Scenario 2 Ship Information Page Inputs

Select ship size, TEU's	Container 2000	Container 4000	Container 5000	Container 6000	Container 8000	Container 9000	Container 10000
Number of calls per year per ship size	53	12	3	16	31	24	22
Current mooring time, min	30	30	30	30	30	30	30
Current release time, min	15	15	15	15	15	15	15
Typical average open water speed, knots	-	-	-	-	-	-	-
Average open water transit distance to next port, nm	-	-	-	-	-	-	-
Ship fuel cost, USD per tonne	$335						
Tug fuel cost, USD per tonne	$1,000						

Table 3.8: Scenario 2 Ship Information Page Inputs

	Container 2000	Container 4000	Container 5000	Container 6000	Container 8000	Container 9000	Container 10000
Ship propulsion SFOC default, g fuel/kWh	-	-	-	-	-	-	-
Ship auxiliary SFOC default, g fuel/kWh	227	227	227	227	227	227	227

The findings from the analysis for Scenario 2, which minimizes uncertainty associated with ship operations at-sea and highly dynamic load conditions for assist tugs during mooring operations, indicate that there is the potential to save over 60 tonnes of fuel and over $37,000 in fuel expenses, to reduce NOx emissions by 3.6 tons, and to have a slight reduction in GHGs.

The total annual scenario summary results for an average SPBP container terminal are presented below.

Table 3.9: Scenario 2 Total Annual Ship Savings

Total annual ship savings		
	Potential fuel savings for ship, tonnes	**62.3**
	... of which in port	**62.3**
	Potential fuel savings for ship, USD	**$37,392**
	... of which in port	**$37,392**
	Potential port emission reductions, transit	
	CO_2e, tonnes/year	**0**
	CO_2, tonnes/year	**0**
	SOx, tons/year	**0.00**
	NOx, tons/year	**0.0**
	DPM, tons/year	**0.00**
	Potential total emission reductions, at-berth	
	CO_2e, tonnes/year	**196.4**
	CO_2, tonnes/year	**193.9**
	SOx, tons/year	**0.14**
	NOx, tons/year	**3.6**
	DPM, tons/year	**0.08**

4.0 Conclusions and Recommendations

Starcrest's analysis demonstrates that there is potential for fuel, costs, and emissions savings across multiple actors if the MoorMaster NxG System improves mooring operational efficiencies to the levels stated by Cavotec.

There is heightened interest globally, but particularly in California and the Southern California region, in reducing NOx and greenhouse gas emissions associated with port operations, and the MoorMaster NxG System could play a role in helping to secure these reductions. For example, California recently amended its At-Berth Emissions Regulation to include roll-on/roll-off (RoRo) ships, which have traditionally been poor candidates for at-berth emission reduction technologies such as shore power. This study found that if the NxG System were deployed across all 14 of the SPBP container terminals, the potential NOx reduction could range from 42 to 56 tons NOx annually – 60% to 79% of the at-berth reductions needed from SPBP RoRo ships under the state regulation.

In fact, this study could understate the fuel savings and emission reductions from improved mooring efficiencies. This study only looked at ships and assist tugs; however, terminal operators could also benefit from the efficiency improvements and the associated reduced time of mooring operations. These efficiencies would allow shore-side work to start sooner and reduced berth times would allow the turnover of ships more quickly. The associated fuel, costs, and emissions savings for terminal operators were not part of this analysis.

Given the potential for emission reductions, the NxG System could be a good candidate for grant funding to support acquisition and deployment, although operational efficiency systems face a steeper hurdle than traditional technologies in this regard. Emission reductions from operational efficiencies are more difficult to measure and quantify, and there is no standard certification process. Looking at an efficiency improvement strategy from an emissions reduction perspective, it is critical to document conditions before and after the strategy is employed. In the case of the NxG System, the grant applicant would need to baseline mooring operations for a terminal by ship size before system installation and then would need to validate the total number of minutes reduced per call related to mooring operations after installation. It is recommended that if such baselining is conducted that it be precoordinated with the appropriate regulatory bodies or funding agencies so that all parties agree on the outcome.

Appendix A – Emissions Estimation Methodology

This appendix describes the technical approached used to determine the potential benefits for ship mooring operations in California. The difference from the rest of North America being that California requires 0.1% sulfur MGO/MDO for all ship within 24-nautical miles of the California coast and leeward islands while the rest of North America is under the Sulfur Emission Control Area (SECA) that only requires 0.1% sulfur fuels, which includes heavy fuel oil with scrubbers and blended fuels to 0.1%.

Port Area Efficiencies

Port area efficiencies were evaluated on a conservative basis as to not overestimate the potential savings and reductions from the MoorMaster System, therefore the potential findings from the analysis should not overstate the potential benefits.

The port area analysis focused on the operational efficiency improvements associated with only the auxiliary engines of the ships. During mooring and vessel release operations the main engine will be operated in a dynamic fashion and will highly dependent on berth configuration, weather, and other parameters. The reduction in main engine operational time during these operations would be expected, but again the main engine is typically not on the full time of these operations. Auxiliary boilers were not included in the analysis either. While, auxiliary boilers are typically on during the full mooring and vessel release operations, their fuel consumption is significantly lower than the auxiliary engines. Again, we would expect to see operational efficiencies and associated reductions from both the main engine and auxiliary boilers, however those have been left out to ensure that the analysis does not overstated the potential benefits.

$$\textbf{Auxiliary engine fuel savings, tonnes} = (AL_m \times T_s \times SFOC_{aux}) \,/\, 10^6$$

Where,

AL_m	-	auxiliary load maneuvring, kilowatts (kW)
T_s	-	time saved due to use of MoorMaster system (hour)
$SFOC_{aux}$	-	specific fuel oil consumption, grams/kW-hour (g fuel/kWh)
10^6	-	conversion from g to metric tons (tonnes)

For the California analysis, the auxiliary loads for container ship maneuvring were averaged for each capacity size class from the 2019 POLA and POLB annual emission inventories. The $SFOC_{aux}$ for this analysis was set based on the Fourth IMO GHG Study 2020.

Potential auxiliary engine emission reductions were estimated based on the fuel saved and the same approached described for auxiliary engines in the next section.

Transit Efficiencies

For the potential transit efficiency improvements, both main engine and auxiliary engines were analyzed. In the transit mode, the main engines are the dominant emission source. Again, auxiliary boiler operations were not included to be conservative as boiler operations during transit are dependent if a container ship has waste heat recovery systems, which is quite common across the fleet. When these systems are in operation during the transit mode, the auxiliary boilers are turned off.

Potential transit efficiencies are related to the ship's captain using the 0.7 hours saved to potentially slow down the transit to the next port to arrive at the scheduled time. The baseline transit speed is estimated using the following equation:

$$\textbf{Transit time}_{\textbf{baseline}}\textbf{, hours} = D_t \ / \ S_{baseline}$$

Where,

D_t - transit distance, nautical miles (nm)
$S_{baseline}$ - transit speed baseline (knots per hour)

The baseline speeds for each container ship class were taken from IMO 2020.

To determine the adjusted speed to take into account the time savings related to mooring and vessel release operations, the following equation was used:

$$\textbf{Transit speed}_{\textbf{adjusted}}\textbf{, knots} = D_t \ / \ (\textbf{Transit time}_{\textbf{baseline}} + 0.7 \textbf{ hours})$$

Fuel estimates for the main engine are developed for both the baseline and adjusted transits conditions the same way, using the following equation:

$$\textbf{Main engine fuel consumption}_x\textbf{, tonnes} = (MCR \times \textbf{Transit time}_x \ LF_x \times SFOC_{me} \times SFOCAF_x) \ / \ 10^6$$

Where,

MCR - maximum continuous rating (kW)
LF_x - load factor for speed x for either baseline or adjusted speeds
$SFOC_{me}$ - specific fuel oil consumption for main engine (g fuel/kWh)
$SFOCAF_x$ - speed based SFOC adjustment factor for speed x either baseline or adjusted speeds

MCR for the California analysis is an average per container ship class based on POLA 2019 and POLB 2019 and for the North American analysis it's based on IHS Markit data[3] for the world fleet. $SFOC_{me}$ and $SFOCAF_x$ are from IMO 2020. $SFOCAF_x$ adjusts $SFOC_{me}$ for the baseline and adjusted speeds based on engine load which accounts for varying fuel consumption rates.

[3] [IHS 2020]

The main engine load factor is based on Propeller Law cubic equation which is as follows:

$$\mathbf{LF_x,\ dimensionless = (Transit\ speed_x\ /\ Rated\ speed)^3}$$

Where,

Transit Speed_x - transit speed x for either baseline or adjusted speed (knots)
Rated speed - rated speed as listed in IHS 2020

Potential main engine transit fuel savings is derived using the following equation:

$$\mathbf{Main\ engine\ fuel\ savings,\ tonnes\ =}$$
$$\mathbf{Main\ engine\ fuel\ consumption_{baseline}\ -\ Main\ engine\ fuel\ consumption_{adjusted}}$$

Emissions associated with the potential fuel consumption savings from the main engine is estimated by the use of emission factors. The conversion from fuel to emissions savings used the following equation:

$$\mathbf{Main\ engine\ emission\ reductions,\ tonnes\ =}$$
$$\mathbf{[(Main\ engine\ EF_{GHG}\ /\ SFOC_{me})\ x\ (Main\ engine\ fuel\ savings\ x\ 10^6)]\ /\ 10^6}$$

or

$$\mathbf{[(Main\ engine\ EF_{AQ}\ /\ SFOC_{me})\ x\ (Main\ engine\ fuel\ savings\ x\ 10^6)]\ /\ 907{,}180}$$

Where,

Main engine EF_{GHG} - greenhouse gas emission factor or EF (g GHG/kWh)
Main engine EF_{AQ} - air quality pollutant EF (g pollutant/kWh)
907,180 - conversion of grams to short tons

For the California analysis, average emission factors were developed from POLA 2019 and POLB 2019 were used.

Note that slower speeds result in an increase in fuel consumption for the auxiliary engines as they have to operate longer during the slower transit. Fuel estimates for the auxiliary engines are developed for both the baseline and adjusted transits conditions the same way, using the following equation:

$$\mathbf{Auxiliary\ engine\ fuel\ consumption_x,\ tonnes\ =\ (AL_t\ x\ TT_x\ x\ SFOC_{aux})\ /\ 10^6}$$

Where,

AL_t - auxiliary load during transit (kW)
TT_x - transit time x either baseline or adjusted speeds
$SFOC_{aux}$ - specific fuel oil consumption for auxiliary engine (g fuel/kWh)

The sources for AL_t are same as for the port area analysis in the previous section.

Potential auxiliary engine transit fuel consumption change is derived using the following equation:

Auxiliary engine fuel savings, tonnes =
Auxiliary engine fuel consumption$_{baseline}$ - Auxiliary engine fuel consumption$_{adjusted}$

Note that the auxiliary engine fuel savings will be a negative number representing an increase in fuel consumption.

Emissions associated with the potential fuel consumption increases are estimated by the use of emission factors. The conversion from fuel to emissions savings used the following equations:

Auxiliary engine emission reductions, tonnes =
$$[(\text{Auxiliary engine } EF_{GHG} \ / \ SFOC_{aux}) \times (\text{Auxiliary engine fuel savings} \times 10^6)] \ / \ 10^6$$

or

$$[(\text{Auxiliary engine } EF_{AQ} \ / \ SFOC_{aux}) \times (\text{Auxiliary engine fuel savings} \times 10^6)] \ / \ 907{,}180$$

Where,

Aux engine EF_{GHG}	-	greenhouse gas EF (g GHG/kWh)
Aux engine EF_{AQ}	-	air quality pollutant EF (g pollutant/kWh)
$SFOC_{aux}$	-	specific fuel oil consumption for main engine (g fuel/kWh)

Again, note that the auxiliary engine emission reductions will be negative numbers as the emissions will actually increase. For the California analysis, average emission factors were developed from POLA 2019 and POLB 2019 were used. $SFOC_{aux}$ was based on IMO 2020.

The potential total transit fuel savings is calculated using the following equation:

Transit fuel savings, tonnes = Main engine fuel savings + Auxiliary engine fuel savings

The potential total transit emission reductions are calculated using the following equation for each GHG and air quality pollutant:

Transit emission reductions, tonnes =
Main engine emission reductions + Auxiliary engine reductions

Tug Operational Efficiency

Tug operational efficiency improvements are realized due to time saved by not using the tug during mooring and vessel release operations of vessel assisted by MoorMaster system. The reduction in two main engines and one auxiliary engine of a tug during these operations would be expected. The potential benefits for tug's main and auxiliary engines are estimated as follows.

$$\textbf{Fuel savings, tonnes} = (L \times T_s \times SFOC) / 10^6$$

Where,

- L - main /auxiliary engine load for tug , kilowatts (kW)
- T_s - time saved due to use of MoorMaster system (hour)
- SFOC - specific fuel oil consumption for main/ auxiliary engine, grams/kW-hour
- 10^6 - conversion from g to metric tons (tonnes)

Main and Auxiliary engine load (L) is calculated as follows:

$$L = Power \times LF$$

Where,

- Power - main /auxiliary engine rated power, kilowatts (kW)
- LF - ratio of average power of the engine used during average operation and average maximum rated power of the engine

For this analysis, the main and auxiliary maximum rated power and load factors were based on information used for 2019 POLA and POLB and emissions inventories developed for ports in North America. The SFOC for this analysis was based on USEPA[4] and is applicable to California as well as North American analysis.

[4] U.S. Environmental Protection Agency, Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder, EPA-420-R-08-001a, May 2008. Available at https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P10024CN.TXT

Potential emissions reduction associated with the potential fuel consumption savings from the main and auxiliary engines is estimated by the use of emission factors. The conversion from fuel to emissions savings used the following equation:

$$\textbf{Emission reductions (Green House Gases), tonnes} = [(EF / SFOC) \times (\text{Fuel savings} \times 10^6)] / 10^6$$

or

$$\textbf{Emission reductions (Air Quality Pollutants), tons} = [(EF / SFOC) \times (\text{Fuel savings} \times 10^6)] / 907{,}180$$

Where,

EF - greenhouse gas or Air Quality pollutant factor in grams/kWh)
907,180 - conversion of grams to short tons

For the California analysis, average emission rates for maneuvring and transit, by ship size, from POLA 2019 and POLB 2019 were used.

The potential total tug emission reductions are calculated using the following equation for each GHG and air quality pollutant:

Emission reductions, tonnes or tons =
Main engine emission reductions (tonnes or tons) +
Auxiliary engine reductions (tonnes or tons)

Appendix B – Scenario Model Overview

This appendix provides an overview of the structure and elements for the case study calculator model developed as part of this study. The model was designed such that it can be used for any case study in California and have results consistent with emission estimates used by the two Ports and State Implementation Plans.

The case study model was developed using Microsoft Excel for ease of access to the broadest audience. They consist of the following pages:

- Cover & Instructions
- Scenario Summary
- Ship Information
- Tug Information
- Ship Parameters
- Assist Tug Parameters

Instruction Page

This is the first page provides instructions on how to use the calculator to simulate case study or scenario for California. Specific scenario inputs in the other pages are highlighted in orange and the use inputs the data for their analysis.

Scenario Summary Page

This page is divided into scenario input parameters and output summaries. The scenario inputs are included in the first block of the page and the input fields are highlighted in orange. The scenario inputs include:

1. Container ship size groups in teus. The user can input up to 7 different container ship sizes utilizing drop down menus that range from Container 1000 to Container 23000.
2. Number of calls for each of the selected container ship size groups.
3. Current (existing) mooring and release times for each container ship size group selected.
4. Typical average open water speeds for each container ship size group selected.
5. Average open water transit distance to the next port for each container ship size group selected.
6. Number of assist tugs per container ship size selected.
7. Ship fuel costs.
8. Tug fuel costs.

The scenario output results are provided in the blocks below the input block and are divided into the following summaries:

1. Total annual savings for the entire scenario.
2. Annual savings for each container ship size group selected.
3. Per call savings for each container ship size group selected.

For each of the three output summaries, the following parameters are provided:

1. Potential scenario annual mass emissions, fuel, and cost savings for both ships and tugs in terms of total scenario, at-berth, and total.
2. Potential scenario annual mass emissions, fuel, and cost savings for ships and tugs in terms of total, at-berth, and total for each container ship size group selected.
3. Potential total mass and cost related fuel savings for each container ship size group selected.
4. Potential mass emission reductions for ship & tug at-berth and total for each container ship size group selected

Ship Information Page

Similar to the summary page, this page is divided into ship input parameters and output summaries. The scenario inputs are included in the first block of the page and the input fields are highlighted in orange. The inputs include:

1. Average ship propulsion engine specific fuel oil consumption (SFOC) values for each container ship size group selected.
2. Average ship auxiliary engine SFOC values for each container ship size group selected.

Similar to the summary page, the ship specific scenario output results are provided in the blocks below the input block and are divided into the following summaries:

1. Potential total annual ship savings in fuel, costs, and emissions savings in terms of the total scenario.
2. Potential operational details summary in terms of ship transit speeds, main engine load reduction for transit, and auxiliary engine loads for maneuvering and open water transits, by container ship size category for each ships size group selected.
3. Potential annual fuel changes from auxiliary and propulsion engine(s) power and net fuel changes for the ship at-berth and transit, for each ships size group selected.
4. Potential per call fuel changes from auxiliary and propulsion engine(s) power and net fuel changes for the ship at-berth and transit, for each ships size group selected.
5. Potential annual mass emission reductions for ships at-berth and transits for each ship size group selected.
6. Potential per call mass emission reductions for ships at-berth and transits for each ship size group selected.

Assist Tug Information

Similar to the ship information page, this page is divided into tug input parameters and output summaries. The scenario inputs are included in the first block of the page and the input fields are highlighted in orange. The inputs include:

1. Tug propulsion power rating.
2. Number of tug propulsion engines.
3. Tug auxiliary engine load.
4. Number of tug engines used.

Similar to the summary page, the ship specific scenario output results are provided in the blocks below the input block and are divided into the following summaries:

1. Potential total annual tug savings in fuel, costs, and emissions savings in terms of the total scenario.
2. Potential operational details summary in terms of mooring times and total time reduced per call, by container ship size category for each ships size group selected.
3. Potential annual fuel reductions from auxiliary and propulsion engine(s) power at-berth, for each ships size group selected.
4. Potential per call fuel reductions from auxiliary and propulsion engine(s) power at-berth, for each ships size group selected.
5. Potential annual mass emission reductions for tugs at-berth for each ship size group selected.
6. Potential per call mass emission reductions for tugs at-berth for each ship size group selected.

Ship Parameters Page

The ship parameters page includes data need to estimate power and fuel consumption and emissions for selected container ship sizes. The data is averaged from POLA 2019 and POLB 2019 emissions inventories, the IMO Fourth Greenhouse Gas Study 2020[5], Bunkerworld,[6] and Cavotec. Ship related data is divided into the following categories:

1. Ship details including size, propulsion engine rating, and maximum rated speeds.
2. Ship engine operational details including auxiliary engine loads for maneuvring and transits modes.
3. Ship mooring operational details including current and new mooring and release times, and total mooring time saved per call.
4. Ship transit details including distance to next port, typical speeds, average transit times, and adjusted transit speed taken into account of slowing down with the additional mooring time saved.
5. Ship-related transit fuel consumption parameters and estimates for propulsion engines, auxiliary engines, and net savings.
6. Ship-related at-berth fuel consumption and associated costs during mooring activities for the auxiliary engines.
7. Total ship-related emission benefits per call.
8. At-berth emission reductions per call.
9. Total transit emission reductions per call.
10. Propulsion emission factors.
11. Auxiliary emission factors.

Assist Tug Parameters Page

The assist tug parameters page includes data need to estimate power and fuel consumption and emissions for tugs during mooring operations. The data is averaged from the 2019 emissions inventories for both ports. Assist tug related data is divided into the following categories:

1. Assist tug details including propulsion and auxiliary engines ratings, number operated, load factors, and unit fuel costs (user provided).
2. Ship mooring operational details similar to the ship parameters page.
3. Assist tug benefits including propulsion and auxiliary engines power and fuel savings, and SFOC rate.
4. Total tug fuel benefits including fuel and cost savings per call.
5. Tug emission reductions per call.
6. Assist tug auxiliary emission rates per engine in SPBP.
7. Assist tug propulsion emission rates per engine in SPBP.
8. Global warming potentials.

---

[5] IMO, *Fourth IMO GHG Study*, Consortium led by CE Delft, July 2020, *https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx*, accessed June 2020 [IMO 2020]

[6] Bunkerworld, Fuel Prices, *https://www.bunkerworld.com/prices/index/bwi*, accessed June 2020