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DELTA STEWARDSHIP COUNCIL

SHORE-BASED BALLAST WATER TREATMENT IN CALIFORNIA

TASK 10: COST ANALYSIS

PREPARED FOR

DELTA STEWARDSHIP COUNCIL
SACRAMENTO, CALIFORNIA

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Revision History

Section	Rev	Description	Date	Approved
All	-	Released as final.	20 Feb 2018	KJR

References

1. *Shore-Based Ballast Water Treatment in California, Task 2: Assessment of Retrofitting Vessels,* Glosten, 4 August 2016.
2. *Shore-Based Ballast Water Treatment in California, Task 3: Assessment of Retrofitting Ports and Wharves,* KPFF Consulting Engineers, 4 August 2016.
3. *Shore-Based Ballast Water Treatment in California, Task 4: Assessment of Shore-Based Ballast Water Treatment Facilities,* Kennedy/Jenks Consultants, Rev. P0, 4 August 2016.
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5. National Ballast Information Clearinghouse, Smithsonian Environmental Research Center & United States Coast Guard, http://invasions.si.edu/nbic/, accessed 11 April 2015.
6. *Considering Options for the Management & Funding of an Optimal Response System in the Aleutian Islands,* Nuka Research & Planning Group, LLC, September 2014.
7. *Shore-Based Ballast Water Treatment in California: Memorandum on Scale-up of Land-based and Barge-based Alternatives*, Glosten, 6 April 2017.
8. Panel Comments on *Memorandum on Scale-Up of Land-based and Barge-based Alternatives*, Delta Science Program Independent Review Panel for the Feasibility Study of Shore-Based Ballast Water Reception and Treatment Facilities in California, 4 May 2017.

Executive Summary

The 30-year lifecycle cost of building and operating a network of ballast water treatment barges (treatment barges) capable of treating all ballast water discharged into California waters is estimated at $3.63 billion. This overall lifecycle cost includes a one-time capital investment of $552 million to build the barges and an estimated $55.3 million in annual operating costs. A separate ongoing investment of $127 million will be required every year to outfit marine vessels that are newly entering the California market with the ballast transfer stations that are required to use the barge network. Each year, marine vessels will also incur an estimated $7.6 million in operating costs.

Costs could be shared and passed along to ship operators and shippers in many different ways. Table 1 provides a perspective about which sectors will incur costs initially and how they may be reflected in cargo shipment costs.

Table 1 Comparative costs

Perspective	Metrics
Shipping Industry	$2.17 billion 30 year lifecycle cost $127 million annual investment in outfitting marine vessels $7.6 million annual operating costs on marine vessels themselves *Excludes fees from treatment barge operator
Treatment Barge Operators	$1.45 billion 30 year lifecycle cost $552 million to invest in treatment barges $55.3 million annual operating costs for treatment barges, including tugs *Excludes treatment barge profit
Ship Operator, Single Marine Vessel	$152,633 to $308,893 one-time cost to outfit ballast transfer station $36,751 to $118,321 cost for barge per ballast water discharge event 10 to 20 hours of personnel time per ballast water discharge event *Excludes treatment barge profit
Cargo Shipment	$2.18 cost per metric ton of bulk cargo, such as grain or petroleum $18.68 per shipping container TEU $11.30 per automobile $46.38 per passenger *Excludes shipping industry costs *Excludes treatment barge profit

Section 1 Introduction

This report is part of an overall coordinated study evaluating the feasibility of using shore-based mobile or permanently positioned ballast water treatment facilities to meet California's Interim Ballast Water Discharge Performance Standards (CA Interim Standards). This report is presented to the Delta Stewardship Council to meet the objectives of Task 10 – Cost analysis. Description of the overall study can be found in Appendix A, along with definitions for terms used in this study.

This report (Task 10) is a cost analysis of a statewide network of ballast water treatment barges (treatment barges), versus upgrading shipboard systems to meet the CA Interim Standards. Costs are calculated on the basis of costs to the maritime industry (vessel owners/operators and port authorities) to comply, and costs to state regulatory agencies to implement.

This task report only addresses the cost side of the cost-benefit balance. There is clearly a benefit side from the reduction in risk from invasive species and pathogens. That benefit has not been calculated herein.

Section 2 Data Description and Methods

The National Ballast Information Clearinghouse (NBIC), a joint program of the Smithsonian Environmental Research Center (SERC) and the United States Coast Guard, provides an online tool to access ballast water management reports from all vessels reporting in the United States (Reference 5). Ballast water discharge activity in California waters were characterized by the NBIC data.

2.1 Quality Control

All data entered into the NBIC database undergoes extensive quality control checks to ensure reporting data field accuracy, but does not otherwise include verification of regulatory compliance. According to the NBIC, their quality assurance measures include direct communication with ballast water management report submitters. When direct communication results in the need for a corrected form to be submitted, the NBIC replaces the originally submitted data with corrected data in their database. For this analysis, additional quality checks were not performed by Glosten and the data was used as-is.

2.2 Approach

Vessel arrivals and ballast tank detail data were downloaded from the NBIC website in the form of comma-separated values (CSV) files for vessels arriving in California for years 2011 to 2015. The ballast tank detail data only were used to characterize ballast water discharge activity in California.

2.3 Tools

Microsoft Excel (2013) was used to process the NBIC data.

Section 3 Marine Vessel Outfitting and Operations

This section covers the cost of outfitting and operating the marine vessels themselves with ballast transfer stations. Outfitting costs are associated with modifying these vessels with new transfer stations as detailed in Task Report 2. Operating costs include the cost of personnel required to operate transfer stations and fuel to pump the ballast water through the transfer stations. This section adds additional detail, specifically in regard to the number of vessels that are required to be outfitted.

		Containership	Bulkers	Tankers	Passenger	RoRo	Others	**California**
Life Cycle Cost	***(Million USD)***	**191.3**	**1,250.2**	**528.3**	**18.8**	**39.6**	**144.6**	**2,173**
Capital Expenses	*(Million USD/yr)*	11.3	73.6	30.8	1.0	2.4	8.3	**127**
Operating Costs	*(Million USD/yr)*	0.59	4.10	2.03	0.16	0.03	0.66	**7.6**

3.1 Transfer Stations Overview

Ballast water transfer stations do not typically exist on marine vessels. These will need to be added to existing marine vessels in order to allow the vessel's existing piping system to lift the ballast water to an accessible location where the treatment barge can receive the ballast water. The below figures provide example of main deck and side port locations.

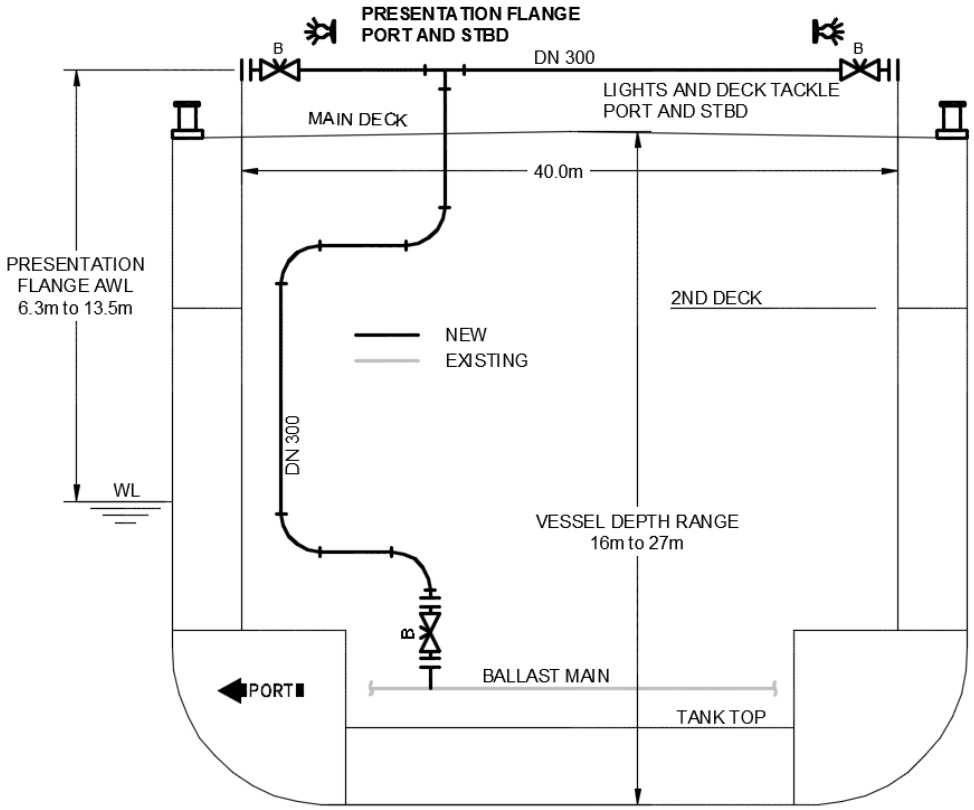

Figure 1 Diagram of containership piping modifications

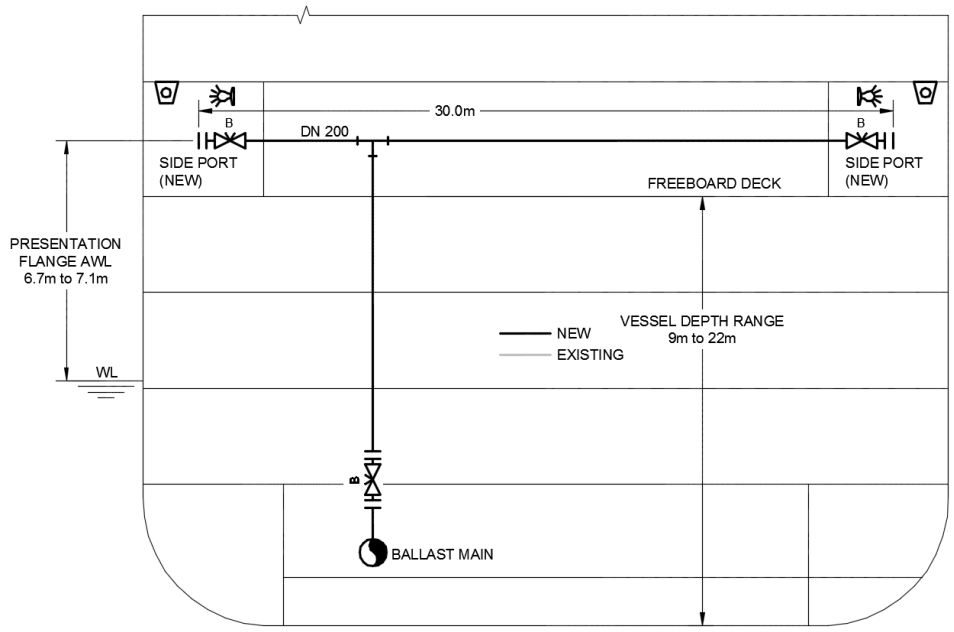

Figure 2 Diagram of passenger cruise ship piping modifications

3.2 Capital Costs, Per Vessel

Transfer station costs were estimated in Task 2. These are further broken down here as follows:

- Structure is applicable where new side ports are required.
- Auxiliary systems include piping from the ballast water system to the new station.
- Outfitting includes deck tackle for making the hose connection, lighting, and communications.
- Integration includes design, regulatory review, and approvals.

Different from Task 2 is that the costs of outfitting a handy-sized tanker estimated at $182,738, as compared to the estimated $425,900 for a larger tanker, was used to best reflect the required transfer rate.

Capital costs estimates per vessel type are given in Table 2.

Table 2 Capital costs per vessel

		Containership	Bulkers	Tankers	Passenger	RoRo	Others
Modification Costs, One Vessel	*(USD)*	**152,633**	**308,893**	**182,738**	**135,323**	**135,323**	**182,738**
Structure (Side Port, if needed)	*(USD)*	0	0	0	162,000	162,000	0
Auxiliary Machinery (Piping)	*(USD)*	86,990	183,140	98,440	49,370	49,370	98,440
Outfitting (Deck Station)	*(USD)*	23,980	58,140	58,140	19,520	19,520	58,140
Integration (Eng, Class Review)	*(USD)*	41,663	67,613	26,158	66,433	66,433	26,158

3.3 Per Vessel Capital Cost, Scaled-up Statewide

Scaling up capital cost statewide is based on the per-vessel-type cost and the number of first-time calls in the state by vessels that are either going to discharge or might want to discharge but haven't.

Each year, there is a relatively steady number of new vessels calling in state waters that have not yet been to California. Further, it is expected that the requirement to outfit ballast stations would be phased in over a five year period. As such, these are presented as annual costs.

Table 3 Statewide capital cost

		Containership	Bulkers	Tankers	Passenger	RoRo	Others	**California**
Number Vessels Modified Each Year	*(#/year)*	**74**	**238**	**169**	**8**	**18**	**46**	**552**
Unique Calls, Discharging	*(#/year)*	45	217	115	5	3	30	
Unique Calls, Not Discharging	*(#/year)*	116	85	107	5	60	61	
Of the No Disch, Outfit Anyway	*(%)*	25%	25%	50%	50%	25%	25%	
Annual Cost, Outfitting All Vessels	*(million USD/yr)*	11.2	73.6	30.8	1.0	2.4	8.3	**127.5**

3.4 Operating Costs, per Event

The marine vessel has three primary costs in supporting ballasting operations:

- Receiving the treatment barge and making the hose fast to the transfer station, and then letting it go once operations are complete.
- Managing the transfer, which mostly consists of the pre-transfer conference, watching the hose for leaks, and maintaining communications with the treatment barge.
- Fuel costs for pumping the ballast water to the transfer station.

Table 4 Vessel costs per ballasting event

		Containership	Bulkers	Tankers	Passenger	RoRo	Others
Volume, Average per Event	*(MT/event)*	3,680	15,313	10,605	816	853	9,771
Personnel Hours, Make/Break Hose	*(hrs/event)*	6	12	12	6	6	12
Personnel Hours, Manage Transfer	*(hrs/event)*	4.0	8.0	8.0	4.0	4.0	8.0
Personnel Cost, per Event	*(USD/event)*	721	1,442	1,442	721	721	1,442
Maint. & Repair, Annual/Vessel	*(USD/yr)*	1,526	3,089	1,827	1,353	1,353	1,827
Energy Expenses, per Event	*(USD/event)*	24	109	85	3	3	78

3.5 Per Vessel Operating Costs, Scaled-up Statewide

Overall vessel operating costs for energy is calculated based on the average number of state-wide discharge events by various vessel types each year during 2010 through 2016 as found in the NBIC database.

O&M costs assume that all vessels that will or have discharged in a five year period will maintain the equipment required for making the transfer. The annual cost for maintenance is assumed to be 1% of the cost of installing the equipment.

Table 5 Statewide operating costs

		Containership	Bulkers	Tankers	Passenger	RoRo	Others	California
Events, Ballast Water Discharges	*(#/year)*	223	375	570	167	10	210	**1,556**
Energy Expenses, Annual All Vessels	*(USD/yr)*	5,359	41,060	48,409	468	30	16,468	**111,793**
Vessels Discharges	*(#/5 years)*	278	1,139	637	26	14	184	**2,278**
OM&R, All Vessels & Events	*(Million USD/yr)*	0.59	4.06	1.99	0.16	0.03	0.64	**7.45**
Operating Costs, Annual	***(Million USD/yr)***	**0.59**	**4.10**	**2.03**	**0.16**	**0.03**	**0.66**	**7.6**

Section 4 Treatment Barges, Capital Expenses

Cost estimates were developed for treatment barges in three distinct size categories, as identified in Task 13. The average capacity of barges in each category is paired to the maximum practical ballast water volume that a typical barge in each category can receive and process over a ten-hour discharge period.

Table 6 Standardized barge designs for service in California

BWTB Design	Small Barge	Medium Barge	Large Barge
Service Capacity			
Ballast Volume	10,000 m^3	20,000 m^3	35,000 m^3
Particulars			
Length	200 ft	240 ft	280 ft
Breadth	62 ft	74 ft	84 ft
Summary Totals			
Treatment Plant, Rate	721 m^3/hr	1,450 m^3/hr	2,570 m^3/hr
Surge Capacity, Volume	2,789 m^3	5,502 m^3	9,297 m^3
Cost, Barge and Outfitting	$6,273,599	$10,192,858	$15,451,111
Cost, Treatment Plant	$4,609,943	$7,009,470	$9,883,075
Cost, Total	$10,883,542	$17,202,328	$25,334,186

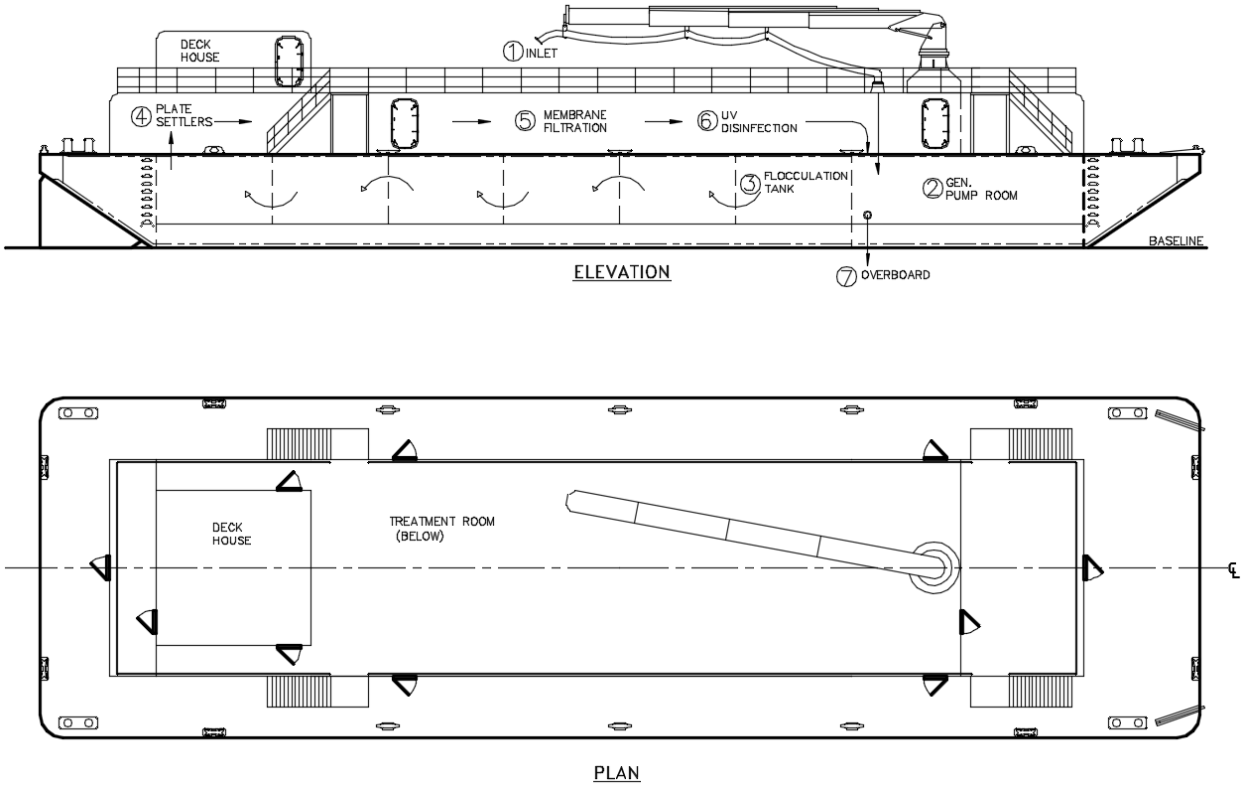

Figure 3 Notional treatment barge design

4.1 Treatment Barges, Cost of the Treatment Plants

The treatment plant sizing, and subsequent costs were based on scaling up the estimated land-based LA/LB ballast water treatment plant from the 6 April 2017 scale-up memo, Reference 7. Those details are outlined in Table 7.

Table 7 Treatment plant assumptions

			LA/LB plant findings, land-based plant, Scale-up Memo, 6 April 2017
Capacity	455	m3/hr	Processing capacity, excluding surge.
Treatment Footprint	6,100	ft^2	Excludes equalization and flocculation.
Flocculation Footprint	2,400	ft^2	Excludes equalization.
Cost (without tanks)	3,495,000	$	For one plant only, no redundancy.

The assumed service requirements used here were based on the Task 2 memo which estimated annual discharge volumes at various ports in California. The scale up of these requirements was conducted through the following steps:

- The service requirements determined the treatment rate requirement.
- Particulars for a barge with adequate volume and deck space for the ballast water storage and treatment were estimated.
- The treatment plant requirements were scaled-up based on the LA/LB land-based plant to suit the resulting treatment plant rate requirements.

Table 8 Treatment plant rate requirements

Description	**Units**	**Small**	**Medium**	**Large**
Service Requirements				
Ballast Volume	m3	10,000	20,000	35,000
Discharge Duration	hours	10	10	10
Treatment Plant				
Influent Rate	m3/hr	1,000	2,000	3,500
Surge Capacity	m3	2,789	5,502	9,297
Effluent Rate	m3/hr	721	1,450	2,570
Settling/Flocculation Time	minutes	232	228	217
Deckspace, Required	ft^2	8,046	12,234	17,249
Tankage, Required	ft^2	3,807	7,655	13,571
Cost, Estimated	$	4,609,943	7,009,470	9,883,075
Power Required	kW	180	362	643

4.2 Treatment Barge, Cost of the Steel Hull and Outfitting

The barge hull size is based on the estimates made during the treatment plant sizing. As the barge gets larger and has more pre-treated ballast water storage capacity, the treatment plant can get smaller and less expensive. However, those savings are quickly offset by steel costs for increasing the size of the treatment barge.

The barge hull sizing is an optimization routine that finds the smallest barge size that results enough deck space for the treatment equipment and enough tankage to provide adequate settling/flocculation of the ballast water prior to final treatment. Table 9 shows those parameter checks.

The cost of the barge itself is estimated based on its steel weight, typical costs for steel barge construction based on that weight, and costs for outfitting based on pumping rates and power generating requirements.

Table 9 Barge hull sizing parameters

Description	Units	Small	Medium	Large
Barge Particulars, Estimate				
Length	ft	200	240	280
Breadth	ft	62	74	84
Depth	ft	16	20	24
Rake (fwd + aft)	ft	32	40	48
Design Verification, Checks				
Deckspace, Margin	ft^2	418	758	703
Tankage, Margin	ft^2	4,401	4,489	2,845
Barge Costs				
Hull, Lightship Weight	LT	634.88	1136.64	1806.336
Hull, Cost	$	4,266,394	7,638,221	12,138,578
Outfitting, Pumping	$	750,000	1,000,000	1,375,000
Outfitting, Machinery	$	385,205	521,837	731,933
Outfitting, General	$	872,000	1,032,800	1,205,600
Barge, Sub-total	$	6,273,599	10,192,858	15,451,111

4.3 Treatment Barges, Capital Costs by Zone

Zone capital costs are based on the number of barges of various sizes determined for each zone in Task 13 and the cost of various size treatment barges. These are outlined in Table 10.

Table 10 Zone capital costs

	Barges Sizes	**Small**	**Medium**	**Large**	**Total**	**Cost**
Service Area	***Unit Cost (million USD)***	***10.88***	***17.20***	***25.33***	***BWTBs***	***(USD)***
Zone 1	San Francisco Bay (North Part) and Humboldt Bay	1	1	2	4	78,754,000
Zone 2	San Francisco Bay (South Part) and Monterey Bay	2	0	2	4	72,435,000
Zone 3	Carquinez Strait and Suisun Bay	1	1	2	4	78,754,000
Zone 4	Stockton	0	1	2	3	67,871,000
Zone 5	Los Angeles/Long Beach and Vicinity	3	1	3	7	125,856,000
Zone 6	San Diego	2	0	0	2	21,767,000
	TOTALS	**9**	**4**	**11**	**24**	**445,437,000**

4.4 Treatment Barge, Lifecycle Costs by Zone

Estimates of the lifecycle costs of operating the treatment barge network are provided in Table 11. Lifecycle costs are presented in current dollars using a discount rate of 6%, and assuming annual cost inflation of 2.5% and annual fuel cost escalation of 3%. Approximately one third of lifecycle costs are associated with the procurement of the barges themselves; the remaining two thirds of lifecycle costs are associated with operating the barge networks.

Table 11 Zone lifecycle costs

	Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego	Totals
Lifecycle Cost (million USD)	228.6	224.1	254.8	159.7	534.7	51.4	1,453.3
Operating Costs (million USD/ year)	8.0	8.2	9.6	4.6	23.2	1.5	55.3

The NBIC database was used to determine operating particulars, as detailed in Table 12. These were divided by zone and used to estimate the annual number and volume of discharges that will need to be treated by the barge network The distances shown are average distances required to shift a barge to service a marine vessels at various ports within each zone.

Table 12 Zone annual operating particulars

	Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego	Totals
Discharges, Number	236	236	259	88	915	28	1,762
Discharges (mill MT)	1.94	1.77	2.54	1.11	5.42	0.03	12.81
Barges, Number	4	4	4	3	7	2	24
Port Distance, Barge Shifts (nautical miles)	7.5	11.5	13.5	1.3	9.0	4.5	47.3

Table 13 provides estimates of total one-time investment costs, including construction, engineering/design, regulatory permitting, and a contingency. These are based on estimated costs per barge in the three barge size categories and the number of barges of each size required for each zone.

Table 13 Zone investment costs

(1,000 USD)	Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego	Totals
Initial Investment, One Time	***97,634***	***89,800***	***97,634***	***84,142***	***156,028***	***26,985***	***552,223***
Barge Procurement Total	109,074	100,322	109,074	94,001	174,311	30,147	616,930
Construction of Barges	78,754	72,435	78,754	67,871	125,856	21,767	445,437
Engineering, Design	5,907	5,433	5,907	5,090	9,439	1,633	33,408
Regulatory, Permitting	4,725	4,346	4,725	4,072	7,551	1,306	26,726
Contingency	19,689	18,109	19,689	16,968	31,464	5,442	111,359

Operations, maintenance, and repair (OM&R) expenses are indicated in Table 14. These include costs for tug-boats to relocate barges within each zone and reflect a flat rate plus additional costs based on distances, barge berth costs, cost of personnel to administer and maintain the barges, and operator costs based on the expected number and length of service calls.

Table 14 Zone OM&R expenses

(1,000 USD)	Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego	Totals
OM&R expenses, annual	6,785	7,109	7,971	3,914	19,702	1,492	46,972
Tug Boat	2,596	2,974	3,471	880	10,614	280	20,814
Barge Berthing	324	324	324	243	567	162	1,944
Admin & Maint Personnel	600	600	600	450	1,050	300	3,600
Operators	902	1,038	1,214	305	3,695	97	7,251
M&R of system	2,363	2,173	2,363	2,036	3,776	653	13,363

Section 5 Treatment Costs, Cargo Metrics

Per-unit treatment costs were estimated using various cargo metrics, such as per ton of cargo moved or per passenger on board. Calculating these metrics and per-unit treatment costs based on these metrics requires more assumptions than the previous calculations, and results are highly dependent on how those assumptions are applied. For example, consider the cost of a treatment barge servicing containerships at LA/LB:

- LA/LB has approximately 3.8 million outbound twenty-ton equivalent unit (TEU) containers each year aboard ships that are associated with 143 ballast water discharges. Assuming that treatment costs are spread evenly across these discharges the cost per service event would be $36,751 per service event and the cost per outbound TEU would be $1.38.
- LA/LB sees container ships ranging between 14,000 and 1,300 TEU. If the $36,751 cost of treating one ship was evenly spread across the ships TEU capacity, then per-unit cost would be relatively high for the smaller ship ($28.18/TEU) and relatively low for the larger ship ($2.55/TEU).

5.1 Cargo Metrics, Unit Costs

Cargo metrics are provided in the tables below, with the note that the details of the assumptions must be considered carefully in order to understand the actual impacts. This first table provides unit costs by zone location. Notice that San Diego is an outlier because there are so few discharge events and such low discharge volumes that the unit costs of providing treatment are extremely high.

Table 15 Zone cargo metrics

		Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego
Discharges, Number	*(#/yr)*	236	236	259	88	915	28
Discharges, Volume	*(MT million)*	1.94	1.77	2.54	1.11	5.42	0.034
Volume per Discharge, Average	*(MT/disch)*	8,220	7,500	9,807	12,614	5,923	1,214
Cost per Discharge	*($/disch)*	61,593	60,295	62,282	116,414	36,751	118,321
Cost per Volume	*($/MT)*	7.49	8.04	6.35	9.23	6.20	97.44

Note that these costs do not include the marine vessel costs, which are assumed to be borne by the ship operators. Including marine vessel costs would increase the costs presented here by an average of about150%. These costs also do not include any profit for the treatment barge operators who may face significant investment risks. If they are not able to reduce or share some of these risks their expected return on investment could add an additional 20% to 30% to the cost per discharge and cost per volume presented here.

5.2 Tankers and Bulkers

Costs to bulkers and tankers can be reliably estimated because there is a fairly narrow ratio of ballast water discharged per ton of cargo loaded, typically between 3:1 and 4:1 cargo to ballast water. In other words, for every 3 to 4 tons of cargo loaded, 1 ton of ballast water needs to be discharged. This establishes the unit cost of ballast water treatment per ton of cargo loaded in

each zone which, when applied to typical shipping operations, for example, would be between $127,200 and $169,600 for a tanker loading 80,000 tons of cargo in Zone 3.

Table 16 Zone cargo metrics for bulkers and tankers

		Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego
Bulker and Tanker	***($/MT)***						
High Volume	*(Cargo/Ballast)*	4	4	4	4	4	4
Low Volume	*(Cargo/Ballast)*	3	3	3	3	3	3
Low Cost	*($/MT)*	1.87	2.01	1.59	2.31	1.55	24.36
High Cost	*($/MT)*	2.50	2.68	2.12	3.08	2.07	32.48

5.3 Containers

As noted above, it is more difficult to estimate the potential cost of treatment per container being shipped than per ton of bulk cargo being shipped The below table first presents ship capacity based on discharges and then estimates costs assuming that the cost of using the treatment barge is applied evenly to all containers on board. Given the large range of containership TEU capacity and the relatively fixed cost of the treatment barge servicing marine vessels, this results in significant potential variability in treatment costs per TEU for various size containerships.

For example, ignoring San Diego as an outlier, the range in treatment costs per container varies between $2.55 and $37.08 per TEU. Based on outbound containers, the range narrows a bit, to $1.38 and $7.24 per TEU. Zones where there are typically no discharges from this vessel class were not evaluated.

Table 17 Zone cargo metrics for containerships

		Zone 1	Zone 2 SF South	Zone 3	Zone 4	Zone 5 LA/LB	Zone 6 San Diego
Containers (ship capacity)							
High Volume	*(TEU/event)*		8,721			14,414	1,400
Low Volume	*(TEU/event)*		1,626			1,304	1,400
Low Cost	*($/TEU)*		6.91			2.55	84.52
High Cost	*($/TEU)*		37.08			28.18	84.52
Containers (port throughput)							
Annual Container Discharges	*(events/yr)*		72.00			143.00	
Cost of those Discharges	*($/event)*		4,341,254			5,255,346	
Annual Outbound TEUs	*(TEU mill/yr)*		0.60			3.80	
Cost per TEU	*($/TEU)*		7.24			1.38	

5.4 Automobiles

Like containers, it is important to consider the metrics of estimating these per-unit costs. The table below uses the capacity of the marine vessel in car equivalent units (CEUs), and applies this to the cost for a treatment barge in that zone for one event. The variability is due to the range of car carrier capacities, resulting in a range between $6.68 and $30.63 per automobile.

Table 18 Zone cargo metrics for car carriers

		Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego
Automobiles							
High Volume	*(CEU/event)*	8,000	8,000			5,500	1,200
Low Volume	*(CEU/event)*	8,000	8,000			1,200	1,200
Low Cost	*($/CEU)*	7.70	7.54			6.68	98.60
High Cost	*($/CEU)*	7.70	7.54			30.63	98.60

5.5 Passengers

The table below states the capacity of passenger carrying marine vessels in terms of numbers of passengers and uses this measure of capacity to estimate cost per capacity for one ballast water discharge event in each zone. The variability in costs shown per passenger is due to the range of cruise ship passenger capacities, which results in a cost range between $17.48 and $123.05 per passenger. The passenger capacity ranges were identified by searching the NBIC database for all passenger ship ballast water discharges over the past five years, aligning those with the relevant zones, and identifying the range of passenger capacities for those vessels.

Table 19 Zone cargo metrics for cruise ships

		Zone 1 SF North	Zone 2 SF South	Zone 3 Carq. Suisun	Zone 4 Stockton	Zone 5 LA/LB	Zone 6 San Diego
Passengers (Cruise)							
High Volume	*(passengers)*		3,450			3,450	3,100
Low Volume	*(passengers)*		490			1,070	2,000
Low Cost	*($/person)*		17.48			10.65	38.17
High Cost	*($/person)*		123.05			34.35	59.16

Appendix A Study Overview and Definitions

Study Overview

Marine vessels routinely uptake ambient sea or harbor water as ballast, transit to another port, and then discharge that ballast water. Unfortunately, the resulting ballast water discharges have been linked to the introduction of aquatic invasive species and harmful pathogens. In an effort to reduce or possibly eliminate further introductions, marine vessels are being required to manage ballast water discharges by a myriad of international, federal, and regional guidelines and rules. Vessels discharging in California will be required to meet an interim standard that is more stringent than international and US federal standards.

In response, there has been significant development work and commercial installations of ballast water management systems (BWMS) onboard marine vessels themselves. However, there is a lack of data to determine if shipboard BWMS are capable of meeting the CA Interim Standards. Therefore, shore-based ballast water reception and treatment is under consideration as an approach to meet the CA Interim Standards.

This study evaluates the feasibility of shore-based ballast water reception and treatment in 13 separate tasks, beginning with a review of shore-based treatment research, followed by a series of detailed analyses, including: permitting and legal requirements, detailed cost estimates, timeline to implementation, and market implications.

Tasks Overview

Tasks 6 through 13 are submitted together to discuss the practical implementation of shore-based ballast water reception and treatment throughout California state waters, accomplished by a "network" of six (6) independently operating fleets of mobile treatment barges (see Table A-1).

During the course of this study, following completion of Tasks 2-5 and the comparative scale-up exercise described in Reference 8, this approach was deemed most technically, operationally, and financially feasible of the five approaches that were evaluated (i.e. new onsite treatment facility, new offsite treatment facility, existing wastewater treatment facility, shore-side mobile treatment, mobile marine vessel-based treatment).

Table A-1 Tasks 6 through 13

Task	Description
6	Assessment of construction related to outfalls for treated ballast water discharges, and provision for disposal of solids as needed.
7	Summarize pertinent permitting and legal requirements.
8	Comparative review of shipboard vs. barge-based ballast water management operations.
9	Assessment of current practices related to ballast water discharges in California.
10	Cost analysis.
11	Implementation timeline.
12	Market implications.
13	Other analysis and findings. Introduces the concept of a statewide network of mobile treatment barges for the provision of ballast water reception and treatment services across the state, and forms the basis for assessments and analyses in Tasks 6-12.

Definitions

ABS	American Bureau of Shipping
ANSI	American National Standards Institute
ASTM	An international standards organization.
ATB	Articulated Tug Barge
AWL	Height Above Waterline
AWWA	American Water Works Association
Ballast Water	Water taken on by a ship to maintain stability in transit.
Ballast Water Exchange	The process of exchanging a vessel's coastal ballast water with mid-ocean water to reduce concentration of non-native species in accordance with regulatory guidelines.
Ballast Water Management	The entire process of treatment and handling of a ship's ballast water to meet regulatory requirements and prevent spread of non-native species.
BMPF	Ballast Manifold Presentation Flange
Booster Pump	Pump, typically centrifugal, that adds additional pumping force to a line that is already being pumped.
BWDS	Ballast Water Discharge Standards
BWE	Ballast Water Exchange
BWM	Ballast Water Management
BWMS	Ballast Water Management System
BWTP	Ballast Water Treatment Plant
BWTB, BWT Barge	Ballast Water Treatment Barge
BWTS	Ballast Water Treatment System
Capture	Capture is the method by which ballast water is transferred onto or off a marine vessel.
CD	Chart Datum
CFU	Colony Forming Units
CMSA	California Marine Sanitation Agency
DAF	Dissolved Air Floatation
DIN	Deutches Institut für Normung (German Institute for Standardization)
Discharge	Discharge of ballast water is the method by which post-treatment ballast water is disposed of in compliance with applicable standards and regulations.
DOC	Dissolved Organic Carbon
DWT	Deadweight Tonnage
EPA	Environmental Protection Agency (US, unless otherwise noted)
Filtrate	Water that has been separated from any particulate matter (used to clean ballast water treatment filters).

GA	General Arrangement
GM	Metacentric height (a measure of a ship's stability).
gpm	Gallons per minute. Any measurements quoted in gallons of ballast water per minute will also be shown in MT of ballast water per hour, or MT/h.
HDPE	High-density Polyethylene
IMO	International Maritime Organization
ISO	International Organization for Standardization
JIS	Japanese Industrial Standards (organization)
L	Liter
Lift Station	Means of receiving a liquid, typically from a drain or low-pressure piping, and 'lifting' it with pump(s) to a different location such as a remote tank.
Lightering	Cargo transfer between vessels, commonly practiced to reduce a vessel's draft before entering port.
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MARPOL	International Convention for the Prevention of Pollution from Ships
MF	Microfiltration
mg	Milligram
MG	Millions of gallons. Any measurements quoted in MG of ballast water will also be shown in MT of ballast water.
MGD	Millions of Gallons/Day
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
MPA	Megapascal (unit of pressure)
MSL	Mean Sea Level
MT	Metric tons. One cubic meter of seawater is roughly equivalent to 1.025 MT, but this value varies depending on temperature and salinity of the water. In this report, conversions between volume and weight of seawater are merely approximate and assume 1 m3 of seawater has a mass of roughly 1 MT, for convenience.
Navy Mole	A man-made peninsula in the Port of Long Beach that flanks entrance to the middle and inner harbor
NBIC	National Ballast Information Clearinghouse
NOM	Natural Organic Matter
Non-native Species	Species that are not indigenous to a particular region. Non-native species can be introduced to marine ecosystems through a ship's ballast water. "Invasive" species are non-native species with the potential to cause harm to the environment or human health.
NPDES	National Pollution Discharge Elimination System
NTU	Nephelometric Turbidity Unit
NYSERDA	New York State Energy Research and Development Authority

O&M	Operations and Maintenance (cost)
OCIMF	Oil Companies International Marine Forum
POTW	Publicly Owned [Wastewater] Treatment Works
PSU	Practical salinity units.
Residuals	Particulate matter collected from cleaning ballast water treatment filters.
ROM	Rough Order of Magnitude (cost)
Ro-ro	Roll-on/roll-off (vessels designed to carry wheeled cargo such as car, trucks, trailers, and equipment)
RWCF	Regional Wastewater Control Facility (e.g. City of Stockton, CA)
Shipboard Ballast Water Treatment	Ballast water management approaches that do not require support from shore-based infrastructure and are conducted entirely by a vessel's crew.
Shore-Based Ballast Water Management	Ballast water management approaches that require support from shore-based infrastructure in order to meet ballast water management requirements. Such infrastructure may include: means of transferring ballast water to a land-based or another marine vessel facility for storage and/or processing, deployment of shore-based equipment and personnel for onboard treatment approaches, etc.
Slurry	Mixture of filtrate and filter residuals resulting from cleaning ballast water treatment filters.
Slurry Handling	Slurry handling includes activities related to the storage, treatment, and discharge of filtrate and residuals collected from cleaning ballast water treatment filters.
SOLAS	International Convention for Safety of Life at Sea
Storage	Storage of ballast water includes provision of space and containment for ballast water, either pre-or post-treatment.
STS	Ship-to-Ship. Transfer from one marine vessel to another.
TDS	Total Dissolved Solids
TEU	Twenty-foot Equivalent Unit
TOC	Total Organic Carbon
Transfer	Ballast water transfer considers the logistics and equipment required to capture the ballast water from the marine vessel and transport to a reception and treatment facility.
Transport	Transport is the method by which ballast water is moved post-capture from marine vessels to remote, non-mobile reception and treatment facilities – either land-based or otherwise.
Treatment	Treatment includes the various methods to process ballast water such that it is suitable for discharge in compliance with applicable standards and regulations.
Treatment Approach	A general method for implementing ballast water treatment. Treatment approaches may include mobile systems, land-based facilities, shipboard systems, etc.

Treatment Technology	Specific techniques for removal or inactivation of organisms in ballast water (e.g., UV disinfection, filtration, ozonation, etc.)
TRO	Total Residual Oxidant
TSS	Total Suspended Solids
UF	Ultrafiltration
UKC	Underkeel Clearance
UL	A global independent safety consulting and certification company (formerly Underwriters Laboratories).
USCG	United States Coast Guard
UV	Ultraviolet Light
UVT	UV Transmittance
VLCC	Very Large Crude Carrier
WWTF	Waste Water Treatment Facility
WWTP	Waste Water Treatment Plant

Appendix B Cost Estimates

Description	Units	Small	Medium	Large	Notes
Service Requirements					
Ballast Volume	m3	10,000	20,000	35,000	Marine vessel ballast water discharge volume total
Discharge Duration	hours	10	10	10	Discharge duration from marine vessel to barge
Barge Particulars, Estimate					Particulars of Barge to suit treatment plant and storage
Length	ft	200	240	280	Length overall, including rakes
Breadth	ft	62	74	84	Width of the barge, including room for walkways and ladders
Depth	ft	16	20	24	Height from keel to main weather deck, not including deck house
Rake (fwd + aft)	ft	32	40	48	Rake = 2 * depth. Sloped portion of front and back of barge
Design Verification, Checks					Positive values required for workable solution
Deckspace, Margin	ft^2	418	758	703	Is there enough room for treatment plant? Positive number = yes
Tankage, Margin	ft^2	4,401	4,489	2,845	Is there enough tankage for flocculation step? Positive num = yes
Summary Totals					
Treatment Plant, Rate	m3/hr	721	1,450	2,570	How quickly treatment plant needs to process ballast water
Surge Capacity, Volume	m3	2,789	5,502	9,297	How much storage volume is in barge, excluding double hull, rakes
Cost, Barge and Outfitting	$	6,273,599	10,192,858	15,451,111	Steel, paint, crane, pipes, pumps, electrical, generators, etc.
Cost, Treatment Plant	$	4,609,943	7,009,470	9,883,075	Deck house, settling equipment, UV lamps, etc.
Cost, Total	$	10,883,542	17,202,328	25,334,186	Completed costs, not including design, permits, engineering
Barge Restrictions					
Generator/Pump Room Length	ft	16	16	16	Length of barge, plus full breadth of barge
Double Hull Depth	ft	4	4	4	Protection all around ballast water storage tankage, in case of breach
Deck Access Width	ft	8	8	8	Clear area all around deck house for line handling, walkways, etc.
Resulting Availability					
Gen/Pp Rm Footprint	ft^2	992	1,184	1,344	Below deck footprint for generators, pumps, and auxiliaries
Treatment Plant Footprint	ft^2	8,464	12,992	17,952	Available footprint for treatment plant, new deckhouse to suit
Tankage Capacity	ft^3	98,496	194,304	328,320	Total underdeck tankage volume for ballast water flocculation
Treatment Plant					
Influent Rate	m3/hr	1,000	2,000	3,500	Transfer rate from marine vessel to the barge
Surge Capacity	m3	2,789	5,502	9,297	Ballast capacity of barge w/out treatment
Effluent Rate	m3/hr	721	1,450	2,570	Required treatment rate, when deducting ballast capacity of barge
Settling/Flocculation Time	minutes	232	228	217	Time it takes for ballast water to cycle through barge tankage
Deckspace, Required	ft^2	8,046	12,234	17,249	Treatment plant required footprint, scaling LA plant by power 6/10
Tankage, Required	ft^2	3,807	7,655	13,571	Flocculant required footprint, scaling LA plant by power 6/10
Cost, Estimated	$	4,609,943	7,009,470	9,883,075	Treatment plant cost, scaling LA plant by power 6/10
Power Required	kW	180	362	643	Power for treatment plant, using 0.25 kW/m3 treated ballast water
Barge Costs					
Hull, Lightship Weight	LT	634.88	1136.64	1806.336	Length * Breadth * Depth times rule of thumb factor of 0.0032
Hull, Cost	$	4,266,394	7,638,221	12,138,578	$2,720 per long ton. Includes steel, paint, testing, misc.
Outfitting, Pumping	$	750,000	1,000,000	1,375,000	$500,000 + $250 per m3/hr. Includes pumps, crane, piping, etc.
Outfitting, Machinery	$	385,205	521,837	731,933	$250,000 + $750 per kW. Includes generator, wiring, swbd, etc.
Outfitting, General	$	872,000	1,032,800	1,205,600	$500,000 + $30 per ft^2. Includes deckhouse, mooring, lighting, etc.
Barge, Sub-total	$	6,273,599	10,192,858	15,451,111	Not including treatment plant
Treatment Plant Assumptions				LA/LB plant findings, land-based plant, Scale-up Memo, 6 April 2017	
Capacity		455	m3/hr	Processing capacity, excluding surge.	
Treatment Footprint		6,100	ft^2	Excludes equalization and flocculation.	
Flocculation Footprint		2,400	ft^2	Excludes equalization.	
Cost (without tanks)		3,495,000	$	For one plant only, no redundancy.	

	Barges Sizes	Small	Medium	Large	Total	Cost
Service Area	***Unit Cost (USD)***	***10,883,542***	***17,202,328***	***25,334,186***	***BWTBs***	***(USD)***
Zone 1	San Francisco Bay (North Part) and Humboldt Bay	1	1	2	4	78,754,000
Zone 2	San Francisco Bay (South Part) and Monterey Bay	2	0	2	4	72,435,000
Zone 3	Carquinez Strait and Suisun Bay	1	1	2	4	78,754,000
Zone 4	Stockton	0	1	2	3	67,871,000
Zone 5	Los Angeles/Long Beach and Vicinity	3	1	3	7	125,856,000
Zone 6	San Diego	2	0	0	2	21,767,000
	TOTALS	**9**	**4**	**11**	**24**	**445,437,000**

Analysis: Shore-based Ballast Water Treatment Solutions ***Summary Figures in Present Value.*** *Totals and sub-totals rounded to 100,000.*		Zone 1 San Fran North & Humboldt	Zone 2 San Fran South & Monteray	Zone 3 Carquinez Strait, Suisun Bay	Zone 4 Stockton	Zone 5 Los Angeles Long Beach & Vicinity	Zone 6 San Diego	Totals California	
NET COST, LIFE CYCLE	***(1,000 USD)***	**228,600**	**224,100**	**254,800**	**159,700**	**534,700**	**51,400**	**1,453,300**	**Life cycle cost, present value of investment & operations**
Operating Costs, Annual	*(1,000 USD/yr)*	8,027	8,243	9,622	4,635	23,225	1,514	55,266	Annual operating costs, in today's dollars
Initial Investment, One Time	***(1,000 USD)***	***97,634***	***89,800***	***97,634***	***84,142***	***156,028***	***26,985***	***552,223***	***Present value of that future investment***
Barge Procurement Total	*(1,000 USD)*	109,074	100,322	109,074	94,001	174,311	30,147	616,930	Sum of investment costs at time spent
Construction of Barges	*(1,000 USD)*	78,754	72,435	78,754	67,871	125,856	21,767	445,437	Construction of barges
Engineering, Design	*(1,000 USD)*	5,907	5,433	5,907	5,090	9,439	1,633	33,408	7.5% of construction costs
Regulatory, Permitting	*(1,000 USD)*	4,725	4,346	4,725	4,072	7,551	1,306	26,726	5% of construction costs
Contingency	*(1,000 USD)*	19,689	18,109	19,689	16,968	31,464	5,442	111,359	25% of construction costs
Operating Particulars, Annual									
Discharges, Number	*(#/yr)*	236	236	259	88	915	28	1,762	Number of discharges, for tug costs
Discharges, Volume	*(MT million)*	1.94	1.77	2.54	1.11	5.42	0.03	12.81	Total volume of ballast water that requires treatment
Barges, Number	*(#)*	4	4	4	3	7	2	24	Barges required per zone, for personnel and berth costs
Port Distance, Barge Shifts	*(n.miles)*	7.5	11.5	13.5	1.3	9.0	4.5	47.3	Weighted distance of barge moves, for tug costs
Chem, Energy Expenses, Life Cycle	***(1,000 USD)***	***21,800***	***19,900***	***28,900***	***12,600***	***61,700***	***400***	***145,300***	
MUPV (project period)	*(1,000 USD)*	26,727	24,385	35,511	15,519	75,775	475		Uniformily scales multi rates from today thru project end
MUPV (delay period)	*(1,000 USD)*	4,955	4,521	6,583	2,877	14,048	88		Deducts expenses from today, until asset enters service
Chemical expenses, annual	*(1,000 USD/yr)*	20	19	51	22	108	1	221	Chemical cost is $0.02 per 1 MT treated.
Energy expenses, annual	*(1,000 USD/yr)*	1,222	1,115	1,600	699	3,415	21	8,073	Energy cost is $0.63 per 1 MT treated.
OM&R Expenses, Life Cycle	***(1,000 USD)***	***109,200***	***114,400***	***128,300***	***63,000***	***317,000***	***24,000***	***755,900***	
UPV (project period)	*(1,000 USD)*	135,884	142,377	159,651	78,385	394,594	29,881		Uniformily scales rates from today through project end
UPV (delay period)	*(1,000 USD)*	26,712	27,989	31,384	15,409	77,569	5,874		Deducts expenses from today, until asset enters service
OM&R expenses, annual	*(1,000 USD/yr)*	6,785	7,109	7,971	3,914	19,702	1,492	46,972	Annual costs for operations, excluding chem and fuel
Tug Boat	*(1,000 USD/yr)*	2,596	2,974	3,471	880	10,614	280	20,814	Tug charges, $5,000 per 5 n.miles shift, plus $500 per extra n.mile
Barge Berthing	*(1,000 USD/yr)*	324	324	324	243	567	162	1,944	Dockage charges for barges
Admin & Maint Personnel	*(1,000 USD/yr)*	600	600	600	450	1,050	300	3,600	One person (admin &/or maint.) per barge in zone
Operators	*(1,000 USD/yr)*	902	1,038	1,214	305	3,695	97	7,251	Four pers * 12 hours per event w/in 5 n.miles. Extra 1 hr per extra 2 n.miles
M&R of system	*(1,000 USD/yr)*	2,363	2,173	2,363	2,036	3,776	653	13,363	Based on 3% of capital cost of barges and treatment plants

Investment Terms		*Analysis based on NIST Handbook 135, published 1995*		
Base (Analysis) Date		20-Sep-17	Tug drop/rtn *(1,000 USD)*	5
Construction Date		1-Jan-21	Barge Dockage *(1,000 USD)*	81
Service Date		1-Jan-22	Rate of Inflation	2.5%
Service Period	*(years)*	30	Discount Rate	6.0%
Operational Staff	*(1,000 USD/yr)*	150	Enrgy & Chem. Escalation	3.0%

Analysis: Outfitting and Operating Marine Vessels for Treatment Barges *Summary Figures in Present Value.*		Container-ships	Bulkers	Tankers	Passenger	RoRo	Others (Gen Cargo, Reefer, etc.)	**California**	
NET COST, LIFE CYCLE	***(Million USD)***	**191.3**	**1,250.2**	**528.3**	**18.8**	**39.6**	**144.6**	**2,173**	Life cycle cost, present value of investment & operations
Capital Expenses, Annual	*(Million USD/yr)*	11.3	73.6	30.8	1.0	2.4	8.3	**127**	Annual cost of modifying ships planning to discharge in California
Operating Costs, Annual	*(Million USD/yr)*	0.59	4.10	2.03	0.16	0.03	0.66	**7.6**	Annual costs OM&R and Energy, in today's dollars
Particulars and Assumptions									
Vessels, Unique Dischargers/5 Years	*(#/5 years)*	278	1,139	637	26	14	184	**2,278**	Number of vessels discharging at least once in five year period
Events, Ballast Water Discharges	*(#/year)*	223	375	570	167	10	210	**1,556**	Event includes hose connection, transfer, and breaking connection
Number Vessels Modified Each Year	*(#/year)*	**74**	**238**	**169**	**8**	**18**	**46**	**552**	How many vessels would install new piping and deck station each year
Unique Calls, Discharging	*(#/year)*	45	217	115	5	3	30		Number of vessels arriving/discharging that hadn't in previous five years
Unique Calls, Not Discharging	*(#/year)*	116	85	107	5	60	61		Number of vessels arriving/not discharging that hadn't in previous five years
Of the No Disch, Outfit Anyway	*(%)*	25%	25%	50%	50%	25%	25%		Number of vessels outfitting with ballast station, even if not discharging
Modification Costs, One Vessel	*(USD)*	**152,633**	**308,893**	**182,738**	**135,323**	**135,323**	**182,738**	**230,978**	Cost to outfit a single vessel with transfer station
Structure (Side Port, if needed)	*(USD)*	0	0	0	162,000	162,000	0		
Auxiliary Machinery (Piping)	*(USD)*	86,990	183,140	98,440	49,370	49,370	98,440		Piping and valves
Outfitting (Deck Station)	*(USD)*	23,980	58,140	58,140	19,520	19,520	58,140		Deck station, including lighting, deck tackle
Integration (Eng, Class Review)	*(USD)*	41,663	67,613	26,158	66,433	66,433	26,158		Engineering, design, regulatory review and inspections
Volume, Average per Event	*(MT/event)*	3,680	15,313	10,605	816	853	9,771	**9,519**	How much ballast water is discharged from vessel to barge
Volume, Total Annual	*(MT)*	822,265	5,746,574	6,040,409	136,415	8,530	2,054,802	**14,808,996**	Ballast water discharged into state waters each year
Pumping Head	*(meters)*	13.5	14.8	16.6	7.1	7.2	16.6		Required lift for pumping, including head and piping losses
Personnel Hours, Total Annual	*(hrs)*	2,234	7,506	11,391	1,671	100	4,206	**27,109**	Total marine vessel personnel time, excluding M&R
Personnel Hours, Make/Break Hose	*(hrs/event)*	6	12	12	6	6	12		Personnel time to tie-up/let-go barge, make/break hose connection
Personnel Hours, Manage Transfer	*(hrs/event)*	4.0	8.0	8.0	4.0	4.0	8.0		Personnel time to watch discharge, communications with barge
Capital Expenses, Life Cycle	***(USD)***	***181,745,457***	***1,184,200,117***	***495,464,350***	***16,331,125***	***39,194,700***	***133,973,854***	***2,050,909,603***	*Present value of that future investment*
UPV (project period)	*(USD)*	226,214,894	1,473,949,931	616,694,454	20,327,021	48,784,850	166,754,546		Uniformly scales rates from today through project end
UPV (delay period)	*(USD)*	44,469,437	289,749,814	121,230,104	3,995,896	9,590,150	32,780,692		Deducts expenses from today, until asset enters service
Annual Cost, Outfitting All Vessels	*(USD/yr)*	11,294,805	73,593,638	30,791,269	1,014,919	2,435,805	8,325,977	**127,456,413**	Cost to outfit all marine vessels with transfer station, annually
Energy Expenses, Life Cycle	***(USD)***	***93,900***	***719,400***	***848,200***	***8,200***	***500***	***288,500***	***1,958,700***	*Life cycle cost, present value of fuel oil costs for pumping operations*
MUPV (project period)	*(USD)*	115,269	883,155	1,041,216	10,057	638	354,197		Scales costs over life cycle, accounting for inflation and escalation
MUPV (delay period)	*(USD)*	21,369	163,722	193,024	1,864	118	65,662		Deduction to account for time from today till start of operations
Energy Expenses, Annual All Vessels	*(USD/yr)*	5,359	41,060	48,409	468	30	16,468	**111,793**	Cost of fuel for pumping to transfer station, all vessels in a year
Energy Expenses, per Event	*(USD)*	24	109	85	3	3	78		Cost of fuel for pumping to transfer station, average discharge event
Pumping Energy, per Event	*(kW-hrs)*	213	974	756	25	26	697		Energy required to pump ballast, assumes 65% pump/motor efficiency
OM&R Expenses, Life Cycle	***(USD)***	***9,420,400***	***65,322,700***	***31,949,400***	***2,505,700***	***420,900***	***10,290,800***	***119,909,900***	*Life cycle cost, present value, including personnel, maintenance, repair*
UPV (project period)	*(USD)*	11,725,419	81,305,841	39,766,744	3,118,786	523,872	12,808,725		Scales costs over life cycle, accounting for inflation
UPV (delay period)	*(USD)*	2,304,989	15,983,143	7,817,366	613,093	102,983	2,517,946		Deduction to account for time from today till start of operations
Total Cost, All Vessels & Events	*(USD/yr)*	585,445	4,059,563	1,985,535	155,720	26,157	639,534	**7,451,953**	Total M&R based on unique vessels discharging over a five year period
Personnel Cost, per Event	*(USD)*	721	1,442	1,442	721	721	1,442		Annual costs for operations, excluding chem and fuel
Maint. & Repair, Annual/Vessel	*(USD/yr)*	1,526	3,089	1,827	1,353	1,353	1,827		Based on 1% of capital cost of new transfer station

Investment Terms			*Analysis based on NIST Handbook 135, published 1995*	
Base (Analysis) Date		20-Sep-17	Distillate Fuel Cost *(USD/MT)*	535
Construction Date		1-Jan-21	Generator (gram/kW-hr)	210
Service Date		1-Jan-22	Rate of Inflation	2.5%
Service Period	*(years)*	30	Discount Rate	6.0%
Operational Staff	*(USD/yr)*	150,000	Enrgy & Chem. Escalation	3.0%

	Container	*Bulker*	*Tanker*	*Passenger*	*RoRo*	*Others*	*Combo*	*General*	*Other*	*Reefer*	*Totals*
Not Discharging (7 years)	27,656	2,698	11,220	2,732	5,937	**4,965**	*7*	*1,049*	*2,865*	*1,044*	***55,208***
Discharging (7 years)	1,564	2,627	3,987	1,170	70	**1,472**	*6*	*270*	*1,167*	*29*	***10,890***
Discharges (#/year)	223	375	570	167	10	**210**	*1*	*39*	*167*	*4*	***1,556***
% Discharging	5.4%	49.3%	26.2%	30.0%	1.2%	**22.9%**	*46.2%*	*20.5%*	*28.9%*	*2.7%*	***16.5%***
Unique Discharges (5 years)	278	1,139	637	26	14	**184**	*2*	*127*	*49*	*6*	***2,278***
Unique Discharges (1 year average)	45	217	115	5	3	**30**	*0.3*	*23*	*6*	*1*	***415***
Unique No Discharges (1 year average)	116	85	107	5	60	**61**	*0.3*	*36*	*16*	*9*	***434***
Annual Discharge Total (m3)	822,265	5,746,574	6,040,409	136,415	8,530	**772,351**	*1,125*	*174,569*	*595,153*	*1,503*	***13,526,545***
Average Discharge Volume/Event (m3)	3,680	15,313	10,605	816	853	**9,771**	*1,313*	*4,526*	*3,570*	*363*	***8,695***
Modifications, Structure ($)	0	$0	0	162,000	162,000	**0**					
Modifications, Aux ($)	86,990	$183,140	98,440	49,370	49,370	**98,440**					
Modifications, Outfit ($)	23,980	$58,140	58,140	19,520	19,520	**58,140**					
Modifications, Integration ($)	41,663	$67,613	26,158	66,433	66,433	**26,158**					
Modifications, Total ($)	152,633	308,893	182,738	297,323	297,323	**182,738**					

Analysis: Shore-based Ballast Water Treatment Solutions ***Summary Figures in Present Value.*** *Totals and sub-totals rounded to 100,000.*		Zone 1 San Fran North & Humboldt	Zone 2 San Fran South & Monteray	Zone 3 Carquinez Strait, Suisun Bay	Zone 4 Stockton	Zone 5 Los Angeles Long Beach & Vicinity	Zone 6 San Diego	Totals California	
Value of barge/plant assets	*(1,000 USD)*	97,634	89,800	97,634	84,142	156,028	26,985	552,223	Present value of assets, includes discount rate
Initial operating company payment	*(1,000 USD)*	0	0	0	0	0	0	0	Assume California finances all capital assets
Annual payment for assets	*(1,000 USD)*	6,509	5,987	6,509	5,609	10,402	1,799	36,815	Operating company payment to California, based on 15 year life of a
Operating Costs, Annual	*(1,000 USD/yr)*	8,027	8,243	9,622	4,635	23,225	1,514	55,266	Annual operating costs, in today's dollars
Total Costs, Annual	***(1,000 USD/yr)***	***14,536***	***14,230***	***16,131***	***10,244***	***33,627***	***3,313***	***92,081***	
Operational Parameters									
Discharges, Number	*(#/yr)*	236	236	259	88	915	28	1,762	Typical number of discharges per year
Discharges, Volume	*(MT million)*	1.94	1.77	2.54	1.11	5.42	0.034	12.81	Typical total volume discharged per year
Volume per Discharge, Average	*(MT/disch)*	8,220	7,500	9,807	12,614	5,923	1,214	7,272	Average volume of discharges
Unit Costs									
Cost per Discharge	*($/disch)*	61,593	60,295	62,282	116,414	36,751	118,321	52,259	Cost to service each discharge event, on average
Cost per Volume	*($/MT)*	7.49	8.04	6.35	9.23	6.20	97.44	7.19	Cost to service each metric ton of ballast water, on average

Cargo Impacts		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Totals	
Bulker and Tanker	***($/MT)***							***2.18***	***Average, excluding San Diego***
High Volume	*(Cargo/Ballast)*	4	4	4	4	4	4		
Low Volume	*(Cargo/Ballast)*	3	3	3	3	3	3		
Low Cost	*($/MT)*	1.87	2.01	1.59	2.31	1.55	24.36	***1.55***	***Minimum, state-wide***
High Cost	*($/MT)*	2.50	2.68	2.12	3.08	2.07	32.48	***32.48***	***Maximum, state-wide***
Containers (ship capacity)								***18.68***	***Average, excluding San Diego***
High Volume	*(TEU/event)*		8,721			14,414	1,400		
Low Volume	*(TEU/event)*		1,626			1,304	1,400		
Low Cost	*($/TEU)*		6.91			2.55	84.52	***1.38***	***Minimum, state-wide***
High Cost	*($/TEU)*		37.08			28.18	84.52	***84.52***	***Maximum, state-wide***
Containers (port throughput)									
Annual Container Discharges	*(events/yr)*		72.00			143.00			
Cost of those Discharges	*($/event)*		4,341,254			5,255,346			
Containerships	*(TEU mill/yr)*		2.40			15.20			Includes inbound and outbound moves
Annual Outbound TEUs	*(TEU mill/yr)*		0.60			3.80			Assume 25% of moves are outbound
Cost per TEU	*($/TEU)*		7.24			1.38			
Automobiles								***11.30***	***Average, excluding San Diego***
High Volume	*(CEU/event)*	8,000	8,000			5,500	1,200		
Low Volume	*(CEU/event)*	8,000	8,000			1,200	1,200		
Low Cost	*($/CEU)*	7.70	7.54			6.68	98.60	***6.68***	***Minimum, state-wide***
High Cost	*($/CEU)*	7.70	7.54			30.63	98.60	***98.60***	***Maximum, state-wide***
Passengers (Cruise)								***46.38***	***Average, excluding San Diego***
High Volume	*(passengers)*		3,450			3,450	3,100		
Low Volume	*(passengers)*		490			1,070	2,000		
Low Cost	*($/person)*		17.48			10.65	38.17	***10.65***	***Minimum, state-wide***
High Cost	*($/person)*		123.05			34.35	59.16	***123.05***	***Maximum, state-wide***

		Ballast Cost ($)	Cargo Value ($)	Percentage (%)	Market Impact
Automobile	*(CEU)*	11.30	35000	0.03%	None
Container	*(TEU)*	18.68	100000	0.02%	None
Passenger	*(trip)*	46.38	800	5.80%	Moderate
Wheat	*(m.ton)*	2.18	440	0.50%	Low
Crude Oil	*(m.ton)*	2.18	390	0.56%	Low

	Zone	Ballast Cost ($/shipcall)	Day Rate ($/day)	Time Equivalent (days)	Market Impact	Possible Action
Car Carrier	2	60,295	35,000	1.7	Low/None	
Car Carrier	6	118,321	35,000	3.4	Moderate	Divert to another CA port
Containership	1	61,593	35,000	1.8	Low	Divert to another CA port
Containership	5	36,751	35,000	1.1	None likely	
Cruiseship	5	36,751	120,000	0.3	None likely	
Bulker	4	116,414	12,000	9.7	High	Divert away from CA, or another CA port
Bulker	5	36,751	12,000	3.1	Moderate	Divert away from CA
Tanker	3	62,282	16,000	3.9	Mixed	If discretionary, divert
Tanker	5	36,751	16,000	2.3	Mixed	If discretionary, divert