Review Draft

May 7, 2013

UMCES Ref. No. : [UMCES]CBL 2013-011

MERC Ballast Water Economics Discussion Paper No. 6

Economic and Logistical Feasibility of Port-based Ballast Water Treatment:

A Case Study at the Port of Baltimore (USA)

Prepared by:

Dennis M. King* and Patrick T. Hagan

Maritime Environmental Resource Center (MERC)
at the
University of Maryland
Center for Environmental Science (UMCES)

*Dennis M. King is the corresponding author and can be reached at *dking@umces.edu*

Executive Summary

U.S. Coast Guard (USCG) ballast water (BW) regulations issued in 2012 require that ships be equipped with and use a USCG-certified ballast water treatment system (BWTS) or, temporarily, an approved Alternate Management System (AMS) certified by other entities, in order to legally discharge BW into U.S. waters. Ships that cannot meet this requirement for onboard BW treatment may be allowed to discharge BW to a port-based BW reception facility, which is generally understood to mean either a shore-based or barge-based BW treatment facility. Pending International Maritime Organization (IMO) regulations are likely to include a similar “contingency” port-based BW treatment option.

From a regulatory perspective, allowing BW to be discharged to a certified port-based BW treatment facility makes sense; and it is technically feasible to build such facilities. It is also feasible for ships to install BW discharge couplings and related plumbing that would be required for them to use such facilities. However, there is widespread skepticism that port-based BWT facilities would be logistically or economically feasible, except in very rare instances. So far, there have been very few attempts to test the feasibility of port-based BW treatment facilities, and nearly no investments in either port-based BW treatment facilities or ship retrofits that would be needed to use them.

This paper presents results from a preliminary study of the logistical and economic feasibility of a “contingency” barge-based ballast water treatment (BBBWT) facility at the Port of Baltimore (PoB). For purposes of analysis, we assumed that potential users of such a facility would be ships that arrive at the PoB needing to deballast in order to take on cargo, but without an approved onboard BWTS or AMS. If such ships would not be allowed to discharge untreated BW in order to take on cargo, it is reasonable to assume that they would be willing to pay dearly to use the services of a BBBWT facility if one were available, and if they were equipped to use it.

However, the results presented here indicate that because of basic logistical constraints related to where and how ships deballast and the distance between terminals at PoB, it is highly unlikely that such a facility will become a viable BW discharge option for ships visiting the PoB. There may be situations at other ports where a BBBWT facility may be logistically and economically feasible. However, we believe our preliminary conclusion regarding the infeasibility of such a facility at the PoB is the same conclusion that would be reached if the same analysis were performed for most other ports.

Our study examined the cost of constructing and operating a BBBWT facility, the cost of outfitting ships to use them, and the combinations of users and user fees that would allow the BBBWT facility to break even financially. The study also examined the conditions under which ship owners are likely to accept the costs and potential lost ship time associated with using such a BBBWT facility, and also the likelihood of them relying on such facility to comply with USCG BW regulations. Because of channel configurations and the locations of terminals at the PoB, the study examined the logistical and practical challenges associated with a BBBWT facility that operated in two different ways: located at a relatively fixed central location where it would be used by visiting ships as they arrive at the PoB; and a highly mobile BBBWT facility that could attempt to provide BW treatment services at various PoB terminals where ships often need to

deballast as they take on cargo. The study did not address the logistical or economic challenges of a BBBWT facility attempting to serve ships that currently manage port time by deballasting while underway in U.S. coastal waters and in PoB approach channels within the Chesapeake Bay.

During 2011 282 overseas ships and 189 coastwise ships arrived and discharged BW at PoB. These ships deballasted and took on cargo at more than 20 different marine terminals that are widely distributed throughout the outer harbor and inner harbor at the PoB (See Figure 1). For reasons discussed in this paper, we assumed for our initial analysis that because of BWTS supply and installation bottlenecks, BWTS malfunctions, and a variety of other technical and market problems, at least 20% of these ships, or 50 to 60 ships per year, will not be able to comply with on-board BWT regulations, and would, if possible, choose to discharge into a BBBWT facility. if such one existed and they were equipped to use it.

We estimate that capital and operating expenses for a BBBWT facility with the capacity to treat BW from 50 to 60 ships would be roughly $1 million annually, which means the BBBWT facility would need to generate revenues of $1 million to break even. This means the average breakeven BBBWT service charge would be about $20,000 per ship or, based on average annual volumes of BW discharged at the PoB, a volume-based BW discharge fee of at least 63 cents per ton.[1]

The cost to a ship owner/operator of using a BBBWT facility would include these service charges plus the cost of ship retrofits necessary to use such a facility (a decision that must be made prior to arrival at PoB) and the opportunity cost of lost ship time associated with using the facility. And, these costs of complying with BW regulations must always compete with the cost of not complying, so a ship's "willingness to pay" to comply by discharging into a BBBWT facility will also depend on the expected financial penalties and other sanctions of discharging BW illegally, and the likelihood of illegal BW discharges being detected.

In our analysis, we also discovered several practical problems associated with the use of BBBWT facilities that significantly limit their potential use, and will make it difficult or impossible for such a facility to break even financially at the PoB, or at most other ports. These problems, listed below, could all be overcome. However, the amount of coordinated global investments and the amount of trust and risk-sharing that would be required among ship owners, ship operators, marine insurers and as yet nonexistant BBBWT facility operators at multiple ports are unlikely to materialize in the foreseeable future. We believe this limits the viability of BBBWT facilities from the perspective of ship owners looking for compliance options, regulators looking for a "contingency" strategy for dealing with noncompliant ships, and entrepreneurs considering investing in BBBWT as a commercial venture.

For this option to have any potential in the near future the following problems would need to be overcome: problems with the BBBWT option are as follows:

First, there are currently no universal couplings that would allow a BBBWT facility to accept BW discharged from all ships. Individual ship owners would need to invest in ship retrofits (e.g., specialized couplings and related piping) in order to discharge into a BBBWT facility. Our analysis indicated that this may be nearly as costly as installing an on-board BWTS.

Second, except in the unusual situation where a ship owner decides to discharge BW only at ports that have a BBBWT facility, the retrofit costs required to do so are not offset by cost savings from not installing an onboard BWTS system that will be necessary to discharge BW at most ports.

Third, assuming expected penalties and sanctions for not complying with BW regulations are certain and meaningful, ship owners and operators cannot afford to manage noncompliance costs and risks by trusting that foreign port operators of BBBWT facilities will be willing and able to meet their BW treatment needs. A ship arriving at a port with the intention of discharging to BBBWT facility and taking on cargo, for example, could find the BBBWT unavailable or inadequate and face costly options that include: not picking up cargo, discharging illegally and accepting the consequences or,possibly, being required to return to sea for an at-sea BW exchange.

And, finally, there are the unacceptable risks associated with potential delays and lost ship time associated with using BBBWT facilities, especially since there is potential for logistical complications and bottlenecks, and also all the same types of equipment malfunctions that are possible with on-board BWTS.

The outcomes of regulation-driven investments, especially those based on new regulations and applications of technologies that are in their infancy, are notoriously difficult to predict. In the case of a BBBWT facility, where the intent is to supply a “contingency” BW discharge service market for ships that cannot comply with on-board BWTS requirements, the demand outlook and investment risks are especially difficult to predict.

It seems likely that inadequate BWTS production and installation capacity, and the fact that most BWTS technologies are still under development and being tested, will result in a significant number of ships arriving in ports, intentionally or not, without an approved BWTS. However, it is unlikely that these ships will have made the necessary onboard investments in equipment and piping that would allow them to use a BBBWT facility, or that significant investments will be made in such BBBWT facilities on the assumption that ship owners will be making these investments. With little or no demand and little or no supply, and no global standard for couplings installed on ships and at BBBWT facilities located in various ports, it is unlikely that this is a viable option for most ships at most ports.

There will, of course, be rare situations where a managed fleet of vessels, with relatively small ballast volumes, operating on regular routes, and deballasting at only a few designated locations, will find that investing in a barge-based or shore-based BW treatment facilities, and in outfitting each ship to use them, will be a more cost-effective BW compliance strategy than purchasing, installing, and operating an onboard BWTS on each ship.

The best near-term strategy, therefore, is to watch for investments being made in these “best case” situations before considering the possibilities of similar investments being made to make BBBWT facilities a realistic BW discharge option at typical ports that are used by a mix of unaffiliated ships that discharge BW at many locations as they enter, dock, and take on cargo at multiple terminals.

Background

Owners and operators of ships in the world's merchant fleet are entering a challenging new era where they are facing significant new costs required to comply with increasingly stringent regulatory demands related to energy conservation and air and water emissions, and, at the same time, are facing higher costs associated with new world-wide worker health and safety and labor compensation standards.

Complying with new ballast water (BW) regulations is one of the most significant cost challenges the shipping industry can expect to face over the next few years. However, the introduction of marine invasive species to coastal waters when ships take on BW at one port and then discharge it at other, sometimes distant, ports is a significant threat to coastal and ocean ecosystems and economies.[2]

BW regulations are already implemented in the United States, and global BW regulations are expected to be ratified by the IMO in 2013 or 2014 and go into effect one year later.[3] In order to legally discharge BW into U.S. waters, new U.S. Coast Guard (USCG) rules introduced in 2012 require ships arriving from foreign ports to be outfitted with, and properly maintain and use, an approved on-board ballast water treatment system (BWTS) or, temporarily, an approved Alternative Management System (AMS). When similar IMO regulations are put in force, with full compliance they will affect as many as 70,000 ships between now and 2020 at an average cost of $1 million per ship, according to a study we conducted in 2009 and 2010.CITE With the cost of purchasing and installing a BWTS estimated at over $1 million per ship, initial compliance costs to ship owners are expected to be over $70 billion, with global purchase and installation costs expected to be about $10 billion per year for a few years after IMO BW regulations are implemented. The annual costs of operating and maintaining these BWTS are expected to add another $770 million per year to fleet-wide compliance costs.[4] And if BW regulations require ships to routinely upgrade BWTS to "limit of technology" standards as BW treatment technologies improve, fleet-wide compliance costs over a twenty-year planning period could approach $100 billion. To meet the IMO schedule, nearly ten thousand ships per year would need to install BWTS during 2014-2016.[5]

It is unlikely that fledgling BWTS markets will grow fast enough to allow all ships to install certified BWTS according to the IMO schedule. Because BWTS technologies are so immature, there are also likely to be significant malfunctions resulting in significant noncompliance problems even among ships that do install certified BWTS. At least over the next 10 years, this situation can be expected to result in many ships, perhaps because of negligence or willful misconduct or perhaps as a result of uncontrollable problems with BWTS technologies or markets, not being in compliance with U.S. and IMO ballast water regulations.

Given this situation, some shipping industry leaders have called for leniency during the early years of the expected BWT regime. "We need port state control to be given guidance on how to implement the (BWT) convention in the first three to five years to show leniency," Tim Wilkins of INTERTANKO told Sustainable Shipping.[6] As Wilkins pointed out, there is concern that vessel owners may install and operate BWTS according to guidelines, but be faced with penalties should the system fail.

This situation is compounded by the average age of the global merchant fleet. Our analysis using November 2009 Lloyds Fairplay data estimates that of the more than 68,000 vessels that would be required to treat ballast water, more than 42,000 of these vessels are 15 years or older, and more than 26,000 are 25 years or older. Noting economic concerns, the International Chamber of Shipping recently proposed that ships 18 years of age or older be exempted from the regulations.[7] This would amount, in our estimation, to more than 44,000 ships, or about 64% of the relevant global fleet being exempt from BW regulations.

Many port nations have not determined how they will enforce BW regulations, which means that noncompliant ships may merely receive a warning or pay a fine and be allowed to discharge untreated BW. In many ports, however, arriving noncompliant ships may be prevented from discharging BW and taking on cargo, or be required to take the time to discharge into a barge-based or shore-based BWTS, or be forced to steam 200 miles back out to sea and exchange ballast water before being allowed to deballast and take on cargo.

It is likely that some of the direct compliance costs incurred by shipping companies will be passed back to their customers (shippers/exporters) in the form of higher shipping costs. It is also likely that some of these higher costs to exporters will be passed forward to the world's importers in the form of higher import prices, and then they, in turn, will pass them along to the businesses and households that purchase imported goods.[8] However, it is certain that the initial shock of BW compliance costs will be borne by merchant ship owners at a time when excess ship capacity and a global economic slowdown are lowering their revenues while fuel prices and other environmental regulations are pushing up their costs.

USCG regulations require that foreign ships must install, maintain, and use a properly scaled on-board BWTS that has been certified by one of several U.S-based BWTS testing facilities in order to legally discharge BW into U.S. waters. To add some temporary flexibility while producers of BWTS have their technologies approved, these regulations allow ships that have already installed a foreign type-approved BWTS to discharge BW in U.S. ports as long as that BWTS has been accepted by the USCG as an alternate management system (AMS); has been installed before the vessel was set to be covered by USCG regulations, and is certified by the USCG or replaced by a USCG certified BWTS within 5 years of the vessel becoming covered by USCG regulations.

For a variety of reasons, including limited at-sea testing of BWTS, unavoidable BWTS malfunctions, unproven BWTS maintenance and repair protocols, and anticipated BWTS supply and installation bottlenecks, most observers are expecting that a significant number of ships will be arriving in U.S. ports needing to deballast in order to take on cargo, but unable to discharge legally by treating BW with an approved on board BWTS or AMS. If this situation is anticipated a year in advance of when a ship is scheduled to be required to have an approved BWTS, the ship owner can request an extension to the implementation schedule that will temporarily exempt the ship from BW regulations.

It is unlikely, however, that many ship owners will be able to anticipate a year in advance all the reasons why a ship may arrive in a U.S. port needing to deballast, but without the onboard capacity to legally treat BW. It can be expected, therefore, that many ships, for a variety of reasons, will arrive in a U.S. port without a certified BWTS or an approved AMS, and without an approved extension.

Current USCG regulations offer the operators of such ships two other compliance options: the ship can simply not discharge BW; or the ship can discharge BW to a port-based BW treatment facility. For ships that need to deballast to take on cargo, the first of these two options would be enormously costly and could make certain that bankruptcy is, in effect, the penalty for some ship owners who may be victims of perhaps unavoidable BWTS market bottlenecks or BWTS malfunctions. That is why the second "contingency" option of making shore-based or barge-based BW treatment (BBBWT) facilities available has been suggested frequently as an attractive alternative to either refusing to allow a non-compliant ship to discharge BW or accepting the environmental costs of allowing a noncompliant ship to discharge untreated BW. Although there have been only a few studies of this option, there is widespread skepticism about it being physically, logistically, or economically feasible at most ports and for most ships.

In 2013, shipping industry leaders and BW regulators are beginning to view global BW regulations as a near certainty. They are, therefore, looking more carefully at the sometimes unimpressive track record of available BWTS technologies and the limited global BWTS production and installation capacity. Industry leaders and regulators are now also considering the advantages of "phasing in" BW regulations and, initially, not strictly enforcing them when they are first put into effect. And, they are also giving more attention to potential "contingency" compliance options, such as BBBWT facilities, that can help reduce environmental risks during this "phase-in" period. This paper provides information to help shipping industry leaders, BW regulators, and potential investors in BBBWT facilities make decisions about the conditions under which the BBBWT option makes sense.

Previous Research

U.S. Port-based and Barge-based Ballast Water Treatment Studies

Several studies dating back to the 1990s examined the feasibility of shore-based BW treatment (SBBWT) facilities and barge-based BW treatment (BBBWT) facilities in the United States. Most of these studies concluded that such facilities would be logistically and economically difficult, except in rare situations where ships that operate only between specific ports are fitted with couplings that allow them to discharge to BBBWT facilities that are available at those specific ports. At least for the foreseeable future, most ports are unlikely to have BBBWT facilities available, so most ships in the merchant fleet, in order to maintain the option of operating along multiple routes and meeting BW discharge standards, will need to install an on-board BWTS even if they choose to make the investments necessary to allow discharging to a BBBWT facility. This means that, for most ships, the cost of installing couplings and piping that would allow them to discharge BW to a BBBWT facility would be in addition to the cost of installing and operating an onboard BWTS. This significantly limits expected demand for the services of a BBBWT and makes it difficult to justify investments in BBBWT facilities.

Specific U.S.-based studies that provided information that was used in the present study include:

- A port-specific study for the Port of Seattle,[9]

- A port-specific study for the Port of Milwaukee[10]
- A statewide study for California by the California State Lands Commission.[11]
- A national study by the Ballast Water panel of the Science Advisory Board of the U.S. Environmental Protection Agency[12]

Key findings from these U.S. studies include the following:

The 2002 case study of the Port of Seattle focused on the potential for both fixed shore side facilities and mobile, truck, or barge-mounted services. In addition, the study addressed two possible methods of connecting a port-based system to a ship: “universal” connections installed above the vessel’s main deck, and external attachments to existing hull penetrations. The study found that, while port-based systems are generally technically feasible, the economic feasibility needed to be demonstrated.[13]

The 2007 report prepared for the Port of Milwaukee assessed the feasibility of onshore BWT, concluding that the only potentially feasible approach for onshore treatment would be to have ships retrofit existing on-board piping and pumping to an international standard. The report also outlined issues related to building an on-shore storage/treatment facility, such as permitting and whether or not this would be a new facility or part of an existing waste-water treatment plant. A possible approach suggested by the authors would be for ships carrying large volumes of BW to treat it on-board, with shore-based treatment available for vessels with smaller BW volumes for which on-board treatment would not be practical.[14]

In a 2010 report, the California State Lands Commission (CSLC) noted that while there are potential advantages of a port-based BWTS, including use of experienced waste-water treatment crew, there remain a number of challenges that suggest that this approach would only apply for certain ports. Challenges noted in the report include the potentially significant retrofit cost for vessels to use such a system. The CSLC report indicated that while further study of the demand potential in particular is needed, discussions continue with some companies interested in developing systems for California ports.[15]

A 2011 report by a panel of the Science Advisory Board of the U.S. Environmental Protection Agency included a discussion about the pros and cons of a port-based approach, focusing especially on shore side facilities.[16] Different viewpoints are presented in the panel’s report. Some key issues included the “chicken or egg” implementation problem: in both a solely ship-based BWTS regime and a shore side BWTS regime, there is a potential production lag time before facilities would be operational on a wide scale. In the case of shore-based systems, this would include the time needed to find land and receive permits. This all boils down to compliance. One viewpoint of panel members was that a vessel operator will want assurance that there is an operational system in each port in which they call. Another panelist’s view was that such shore-based systems have not been developed because of the focus by regulatory agencies on ship-based systems as the ballast water management solution. One potential benefit noted for a port-based system (whether shore- or barge-based) is that the effort and cost of monitoring and enforcement could be much less than for the larger number of systems aboard mobile, transient ships. But in the analysis of Baltimore presented in this report, we assume that such a shore-based facility would be in addition to ship-board-based BWTS.

Other Barge-based Ballast Water Treatment Studies

Barge-based facilities have been suggested internationally as well. One approach proposed for the Port of Rotterdam would export irrigation-quality fresh ballast water to areas such as the Middle East and Western Australia that are sources of commodities such as oil, iron, and coal and are also in great need of fresh water.[17]

Many of the pros and cons of barge-based and shore-based BW treatment that were addressed in the reports noted above were also addressed at an international workshop on port-based BW treatment technologies held in Singapore in November 2012.[18] Additional questions raised by workshop participants there, and pertinent to both barge- and shore-based systems, involve liability and potentially expensive insurance requirements that might be required by the owners and operators of the port facility (e.g. the port itself, a port contractor, or an independent commercial entity) under the assumption that the operator would be responsible for safe discharge of treated BW.

Research Approach

In this project, our research team at the University of Maryland Center for Environmental Science is examining the economic aspects of operating a barge-based BWTS in the Port of Baltimore to service ships that arrive in port, need to deballast to take on cargo, but do not have an adequate onboard BWTS to meet U.S. or IMO ballast water discharge standards.

Our analysis of economic constraints and opportunities associated with BBBWT facilities drew on the results of these earlier studies, and on four other sources of information: (1) due diligence performed by the University of Maryland, Maritime Environmental Resource Center (MERC) before the construction of the MERC barge-based BWTS testing facility; (2) several years of cost data related to the operation of the MERC barge-based BWTS testing facility, (3) interviews with port managers, shipping companies and commercial fuel barge operators about logistical issues, especially at PoB; and (4) records of ship visits and ballast water discharges at PoB.

Research focused on both supply-side issues (e.g., the feasibility of constructing and operating an economically viable BBBWT facility) and demand-side issues (e.g., the number of ships that might arrive at the PoB in need of a BBBWT facility, how much BW they can be expected to need to discharge, how much they would be willing to pay to use it, etc.).

For our Port of Baltimore case study, we developed preliminary estimates of capital and operating costs associated with a 240-foot by 60-foot barge operating with two certified 10,000 metric tons per hour BWTSs. The assumption is that the barge-based BWTS will be designed to accept, treat, and discharge ballast water at flow rates that do not require the barge to have significant ballast water storage capacity.

The case study also involved developing some preliminary estimates of potential usage rates (e.g., number of ships using the service and amount of ballast water treated) and the price per ton of ballast water that would need to be charged to ship operators for the operation to break even.

Opportunities and constraints associated with designing, constructing, and operating an economically viable BBBWT facility will be very port-specific. However, we believe that the challenges described in this report with respect to operating an economically viable BBBWT venture in the PoB are typical of what will be encountered in most other U.S. and foreign ports.

Because our preliminary economic analysis is based on many assumptions and projections about BWTS markets, and about enforcement and compliance with BW regulations, several important caveats are in order. We believe our estimates of overall capital and operating costs for a BBBWT facility operating in the PoB are fairly reliable, and that costs we estimated would be similar in many other ports. However, our projections of potential ship demand for the services of such a facility at the PoB, and associated revenue potential for the BBBWT facility operator, are much less reliable. These will differ significantly from port to port; and, there will besignificant uncertainty about demand and potential revenues because of the difficulty of projecting: (1) how many ships in the world's merchant fleet will not be able to install approved BWTS, (2) how many will make the ship-board modifications in BW discharge ports necessary to use a BBBWT facility; (3) how strictly BW regulations will be enforced; and (4) what penalties and other sanctions will be imposed for illegal BW discharges.

For a variety of reasons (including BWTS supply and installation bottlenecks, and malfunctions and high failure rates typical of new technologies) we assume, for purposes of analysis, that a significant percentage of ships arriving at the PoB over the next ten or so years will not have an adequate onboard BWTS, and will have BW that cannot be legally discharged without treatment. We do not believe that using a BBBWT facility will be an available option at the PoB or at most other seaports. However, to provide information that can support further analysis of this option we assume here, for purposes of analysis that noncompliant ships arriving at PoB will not be allowed to deballast without treatment, and will choose to comply by using a BBBWT services.

Preliminary Research Findings

The National Ballast Information Clearinghouse (NBIC) indicates that 282 overseas ships and 189 coastwise ships arrived and discharged BW at PoB during 2011. For purposes of our initial analysis, we assumed that in the coming years 20% of these ships will not be able to comply with on-board BWT regulations and will choose, or be required by port enforcement authorities, to use port-based BBBWT services. Considering only those ships arriving from overseas, this would amount to roughly 50 to 60 ships per year demanding services from a BBBWT facility.

Preliminary "screening level" analysis of potential demand indicated the most significant category of potential users of a BBBWT facility at the PoB would be coal-exporting bulkers. Preliminary analysis of potential supply issues indicated that the costs and logistical challenges associated with operating a BBBWT facility to serve just those ships would make such a venture cost prohibitive. The logistical and economic challenges associated with designing and operating a BBBWT facility to serve these coal bulkers and other ships that may need to use such a facility from time to time are even worse. Demand for services of a BBBWT, of course, will depend critically on how many ships will be arriving in port, intentionally or unintentionally, without certified, operating, on-board BWTS; and on how U.S. BW regulations are enforced.

Based on past research, there is no reason to doubt that it would be technically feasible to design and construct a BBBWT facility with the storage/treatment capacity to serve this number of ships, or even two or three times this number of ships. Our current research, however, indicates that it will not be logistically or economically feasible, at least for the foreseeable future, for the following reasons.

The first challenge is the geographic distribution of marine terminals within the PoB that are visited by the most likely potential users of a BBBWT facility. The distance between the harbor entrance and the inner harbor at PoB is five miles; and there are active terminals and cargo handling facilities located across both sides of the harbor entrance and in the inner harbor. While navigable channels link these terminals to the main harbor channel, there is no obvious "critical control point" in or near the main harbor channel where it would be practical or safe for a BBBWT facility to be located to meet incoming ships and accept their BW before they head for various terminals. Of course, to protect hull integrity and, in some cases, to allow ships to fit under terminal-based offloading equipment many ships require deballasting as they take on cargo, which means the BBBWT facility would need to be available to provide services at various terminals. The logistical challenges associated with a business plan that involves a BBBWT facility moving from terminal to terminal are daunting, and the cost of having separate BBBWT facilities at multiple terminals would be prohibitive. For the foreseeable future, therefore, it is likely that neither a relatively stationary BBBWT facility that could be visited by arriving ships before taking on cargo, nor a highly mobile BBBWT facility that would service ships at terminals as they are taking on cargo, would be viable. Either approach would be costly, would require ships to be outfitted with standard BW discharge couplings and would result in costly losses in ship time, especially if there are unexpected logistical problems, channel or terminal congestion, BWT equipment malfunctions, etc.

Another potential source of lost ship time and costs to ship operators is potential delays due to treatment bottlenecks. Our analysis of NBIC data, for example, indicates that on 36 days in 2011, two or more ships reported arriving and discharging BW at the PoB. Given typical BW discharge and treatment times, an unfortunate, but not unlikely, scenario would involve an overlap where two ships require "emergency" BW treatment at the same time. With only one BBBWT facility available, this could mean significant deballasting and cargo loading delays costing an individual ship owner/operator perhaps hundreds of thousands of dollars. The alternative, having a second BBBWT facility available to allow two ships to be treated simultaneously, would result in one facility and operating crew sitting idle and incurring costs with no revenue source during most of the year. Investing in a second BBBWT facility under these circumstances would not make economic sense.

There are also serious cost considerations from the ship owners' perspective. Under most assumptions, hundreds of thousands of dollars will need to be spent on piping, plumbing, a universal coupling, and perhaps on special pumps required for a ship to have the option to discharge BW effectively into a BBBWT facility. Based on interviews with shipping industry experts and ship managers, most ships considering this investment would still need to spend millions of dollars to purchase, install, maintain, and operate a shipboard BWTS in order to maintain the option to deballast at ports that do not have shore-based or barge-based BWT facilities. As a result, retrofit costs to ship owners to allow the use of a port-based BWTS will not significantly reduce ship owner costs associated with the purchase and installation of legally mandated shipboard BWTS. Until the notion of BBBWT facilities moves past "proof of concept," it is unlikely that ship owners will invest in what will be needed to use them. That means that it is unlikely that government or business entities will invest in BBBWT facilities.

Although port-side treatment has been considered for more than a decade, very little research has been focused on the technical, logistical, and especially the economic feasibility of port-based BW treatment, particularly as a back-up to shipboard BW treatment. It is clear that the feasibility of such a system will be influenced at each port by channel, terminal, and berthing characteristics, by the numbers, sizes, and types of ships expected to arrive with BW that may need "emergency" treatment, and by when and how port states monitor and enforce BW regulations.

Initial interviews with shipping industry experts indicated some skepticism that a shore-based or barge-based BW treatment operation could be undertaken in most ports, and that in ports where it could be logistically feasible, it would be prohibitively costly in terms of capital and operating expenses and lost ship time. On the other hand, those experts who want BW regulations to succeed are in favor of ports having enforcement options in place that put the least risk on the environment and question whether any level of costs should be considered unacceptable. They point out, correctly, that the high costs of port-based BW treatment, if they are paid by users, would provide necessary incentives for ship owners and operators to comply with shipboard BWTS requirements.

Revenues

We examined reports submitted to the National Ballast Information Clearinghouse (NBIC) for 2010 and 2011 to determine possible demand for ballast water treatment for ships entering the Port of Baltimore. We developed very preliminary assumptions on both the revenue and cost sides.

In the early days of the regulatory regime, we are assuming that 20% or more of the ships entering the Port of Baltimore and needing to deballast would not be in compliance and, if it were required, would use the barge-based treatment system. Based on preliminary assessment of ships discharging ballast water in the Port of Baltimore in 2010 and 2011, we estimate that about 50 vessels arriving from overseas, or roughly one per week, would require barge-based treatment.

Table 1a. Ships Entering Port of Baltimore Reporting Open-ocean Ballast Water Discharges, by Amount of Reported Discharge.

	BALTIMORE 2010		BALTIMORE 2011	
Metric Tons Discharged	**Overseas Ships Discharging**	**Coastwise Vessels Discharging**	**Overseas Ships Discharging**	**Coastwise Vessels Discharging**
80,000-89,999	0	0	1	0
70,000-79,999	14	0	37	0
60,000-69,999	9	0	22	0
50,000-59,999	8	0	6	0
40,000-49,999	9	1	9	0

30,000-39,999	17	6	30	2
20,000-29,999	35	11	48	18
10,000-19,999	33	12	30	19
1,000-9,999	43	53	46	55
Under 1,000	70	73	53	95
TOTAL	238	156	282	189

Source: National Ballast Information Clearinghouse. http://invasions.si.edu/cgi/search-nbic Last reviewed October 2012

Table 1b. Ships Entering Port of Baltimore Reporting Open-ocean Ballast Water Discharges, by Type of Vessel

	2010			2011		
Ship type	**Total**	**Overseas**	**Coastwise**	**Total**	**Overseas**	**Coastwise**
Bulker	277	214	63	347	278	69
Combo	8	2	6	1	1	0
Container	393	1	392	396	0	396
General Cargo	138	90	48	140	94	46
Other	218	5	213	183	2	181
Passenger	95	84	11	114	98	16
RoRo	687	167	520	680	175	505
Tanker	127	29	98	133	31	102
Total Baltimore Arrivals	1,943	592	1,351	1,994	679	1,315

We considered a range of scenarios for potential revenues. Initially we are assuming that a ship arriving in port with ballast water that does not meet discharge standards would be willing to pay $25,000 to $50,000 to have its ballast water treated in order to avoid the possibility of:

- being prevented from deballasting and taking on cargo,
- facing delays, ballast water testing, and/or daily financial penalties,
- perhaps being asked to return to sea and exchange ballast water,
- being restricted from future use of the Port,
- facing time consuming inspections and delays on future visits.

Based on one ship per week or about 50 ships per year using the barge-based BWTS at $25k to $50k per use, the enterprise would yield annual gross revenues of $1.25 million to $2.5 million.

Preliminary annual fixed-cost estimates of $588,500 include the annualized cost of purchasing the barge and purchasing and installing two 10,000 tons per hour capacity filtration/UV BWTS, plus fixed operating costs as follows:

- $144,000 annually to service debt on a 240 foot by 60 foot barge ($1.8 million over 20 years at 5%)
- $168,500 annually to service debt on purchase and installation of two BWTS ($2.1 million over 20 years at 5%)

- $10,000 annually in barge maintenance costs
- $100,000 in annual salary for one FTE manager (direct plus indirect costs)
- $160,000 in annual salaries for two skilled FTE to maintain the barge and operate it during BWT activities (direct plus indirect labor at $80,000 per FTE)
- $6,000 in barge docking costs (est. $500/month)

Costs

Preliminary annual operating costs (which vary with BW volume treated) are estimated with the following assumptions:

- Per ship cargo loading operations: 10 hours
- Bulker BW discharge of 70,000 MT
- Four cents per metric ton treated, based on filtration/UV system costs[19]

With these assumptions, the cost for treating 70,000 metric tons would be $2,800 per treatment, plus tug and other costs. We estimated tug costs of $400 per hour while moving, or $800 per treatment, and tug costs of $300 per hour while alongside the ship during BWT, or $3,000 per treatment. The total estimated cost is $6,600 per treatment, or $330,000 annually, based on 50 ships treated. The total fixed and variable costs would be $918,500, based on 50 ships treated.

This would likely be reduced if smaller ships with fewer metric tons of ballast water were treated. However, we suspect this would only reduce the cost for operation of the BWTS itself, and not for use of tugs unless cargo operations can be performed more quickly than a 12-hour turnaround.

Further research is needed on the size and ballast water capacity of the full range of ships potentially needing treatment, so that a per-ton cost estimate could be developed.

Logistical Considerations for the Port of Baltimore

Our interviews with experts familiar with the operations of the Port of Baltimore identified a number of potential technical or logistical constraints that we considered in our analysis.

First, it is important to recognize that there is no certainty that a BBBWT system will be any more reliable than the shipboard-based systems for which they would serve as a backstop. This might require expensive redundancies and might inhibit investment in a particular system until it is proven to perform reliably over a period of time.

Second, we considered possible locations for a BBBWTS. Our analysis of the National Ballast Information Clearinghouse database indicates that most arrivals reporting ballast water discharges are bulkers, representing virtually all of the ballast water discharged in port. Figure 1 gives a graphic representation of the terminals used by bulkers, and demonstrates that they are spread fairly evenly around the Port inside the Key Bridge. Would this situation present problems for a barge and/or the ships requiring treatment? Given this geographic spread, where might a BWT barge or shore-based facility ideally be located?

Third, what if any challenges might be added for ships that might need to conduct deballasting operations as they steam up the Bay? Would a need to wait until the ship is in port present problems in those cases?

Fourth, given the pattern of (particularly bulker) traffic at PoB, would any bottleneck issues arise from multiple ships needing treatment at the same time? A key element of this issue is the "hold time" involved for certain treatments to be effective in killing invasive species—as much as 24 hours.

Interviews with individuals familiar with PoB cargo operations as well as our review of NBIC ballast water discharge reports for 2011, suggest the potential for treatment delays due to demand on certain days when more than one bulker arrives in Port. 2011 was a record-breaking year for coal bulkers departing PoB, and 2012 followed suit.[20] NBIC data for 2011 indicates that 347 bulkers arrived in 2011, up from 277 (of which 134 reported discharging BW) in 2010, a 25% increase. These vessels taking on coal for export are virtually the only major source of discharges in PoB, since so much of the port traffic is importing cargo, not exporting. In 2010, about half (134) of the bulkers reported BW discharges (Tables 2a and 2b).

But even with the record year, if only one in five of these bulkers needs "emergency" treatment, that would mean the demand would be about 35 vessels in a year (2011) compared to about 27 (estimate for 2010). This does not suggest a dramatic difference in demand or revenues.

Table 2a. Overseas Transit Ballast Water Management by Ship Type Discharged in Baltimore

Ship type	2010 Overseas Ships Discharging	2010 Total Discharge (MT)	2011 Overseas Ships Discharging	2011 Total Discharge (MT)
Bulker	134	4,055,341	198	7,743,081
Combo	5	5,829	1	1,906
Container	37	78,907	27	60,130
General Cargo	17	17,594	28	46,377
Passenger	23	78,187	6	3,692
RoRo	17	14,355	16	16,924
Tanker	4	42,359	6	4,580
Total	237	4,292,572	282	7,876,690

Table 2b. Coastwise Transit Ballast Water Management by Ship Type Discharged in Baltimore

Ship type	2010 Coastwise Ships Discharging	2010 Total Discharge (MT)	2011 Coastwise Ships Discharging	2011 Total Discharge (MT)
Bulker	34	765,904	46	736,887
Container	22	26,291	23	20,483
General Cargo	6	16,377	10	25,268

Other	23	154,456	38	121,696
Passenger	50	52,458	49	40,427
RoRo	4	733	6	2,802
Tanker	16	71,887	17	263,373
Total	155	1,087,376	189	1,210,936

A big concern is with bottlenecks on certain days. The NBIC data sorted by arrival date demonstrates the potential problem. How likely is it that two or more ships will arrive at the same time and need emergency treatment? Perhaps very likely, particularly in the early years of the international BWTS regulatory regime, when some ships might not have been able to install a certified system, or find it is not functioning properly. Tables 3a and 3b summarize month-by-month reports of numbers of vessels reporting discharges, and an illustration is presented below, derived from daily reports for the month of January 2011:

1. January 4, 2011: three overseas bulkers arrive, with reported BW discharge volumes of 24,000 metric tons (MT), 67,000 MT, and 75,000 MT.

2. January 8, 2011: three overseas bulkers arrive, with reported BW discharge volumes of 5,000 MT, 73,000 MT, and 74,000 MT, plus a container vessel reporting a 4,000 MT discharge.

3. January 9, 2011: two overseas bulkers arrive, with reported BW discharges of 22,000 MT and 69,000 MT, followed by another on January 10th reporting 36,000 MT.

4. January 15, 2011: one overseas bulker arrives, with reported BW discharges of 18,000 MT, followed by another on January 16th reporting BW discharges of 23,000 MT.

5. January 27, 2011: one overseas bulker arrives, with reported BW discharges of 20,000 MT, followed by another on January 28th reporting 18,000 MT.

6. January 29, 2011: two overseas bulkers arrive, with reported BW discharge volumes of 35,000 MT and 75,000 MT.

7. January 30, 2011: one overseas bulker arrives, with reported BW discharges of 66,000 MT, followed by another on January 31st reporting 70,000 MT.

Table 3a. 2010 Monthly Summary of Ballast Water Discharges

Monthly Summary	**Overseas Ships Discharging**	**Overseas Discharge (MT)**	**Average Discharge per Overseas Ship**	**Coastwise Ships Discharging**	**Coastwise Discharge (MT)**	**Average Discharge per Coastwise Ship**
January	17	384,701	22,629	13	29,794	2,292
February	14	130,219	9,301	10	15,209	1,521

March	14	197,694	14,121	10	65,867	6,587
April	31	690,993	22,290	17	73,768	4,339
May	22	404,905	18,405	16	94,770	5,923
June	16	160,239	10,015	10	48,237	4,824
July	21	367,956	17,522	15	77,881	5,192
August	21	482,069	22,956	15	98,145	6,543
September	20	357,277	17,864	11	48,162	4,378
October	20	399,585	19,979	14	165,664	11,833
November	17	423,224	24,896	9	17,197	1,911
December	24	528,984	22,041	15	118,244	7,883
Total	237	4,527,846	19,105	155	852,938	5,503

Table 3b. 2011 Monthly Summary of Ballast Water Discharges

Monthly Summary	Overseas Ships Discharging	Overseas Discharge (MT)	Average Discharge per Overseas Ship	Coastwise Ships Discharging	Coastwise Discharge (MT)	Average Discharge per Coastwise Ship
January	31	901,527	29,082	19	53,248	2,803
February	32	975,872	30,496	14	71,019	5,073
March	27	671,927	24,886	23	188,508	8,196
April	22	643,212	29,237	11	85,473	7,770
May	19	586,682	30,878	12	89,768	7,481
June	20	489,269	24,463	14	68,450	4,889
July	13	184,837	14,218	15	41,659	2,777
August	23	683,108	29,700	18	103,671	5,760
September	29	874,852	30,167	13	75,289	5,791
October	18	551,441	30,636	18	138,549	7,697
November	24	723,941	30,164	16	74,869	4,679
December	24	572,496	23,854	16	83,675	5,230
Total	282	7,859,164	327,782	189	1,074,178	68,146

Our review of the 2011 NBIC data indicates that on at least 42 days, two or more vessels arrived at the Port of Baltimore reporting BW discharges, thus presenting a possible conflict on those days for use of any port-based BWTS. If we assume that 20% of these 84-plus vessels will need "emergency" treatment, then a bottleneck would occur on as many as 16 days per year.

The barge-based BWTS we describe in our assumptions would have the capacity to treat 20,000 MT of ballast water per hour, so in the January 4th example, the ships would need from about one hour (to treat 24,000 MT) to about four hours (to treat 75,000 MT). These estimates do not include any additional time to transport a barge or ship from one PoB site to another. These delays can cost tens of thousands of dollars to ship owners, so if two or more ships needing treatment arrive at the same time, this could present a significant logistical challenge. To ensure that a working BWTS is available in port could require two, three, or even four systems in place at additional capital cost, with the likelihood that they would sit idle almost every day. (This redundancy is likely to be necessary anyway for reliability purposes, since this would be an issue for any BWTS whether shipboard or port-based.)

Retrofitting requirements

Regardless of the particular port, our initial interviews suggest that for a ship to take advantage of a barge-based BWT facility, it might require significant retrofitting to ensure that it is able to couple properly with piping on the barge. These retrofit requirements include universal connection, piping, and pumping capacity. We did not develop detailed retrofit cost estimates for this report, but for illustration purposes we updated to 2012 dollars the cost estimates developed in a 2002 study that examined retrofit requirements for four types of ships to be able to take advantage of a port-based BWTS.[21] For a tanker, retrofits would cost $2,433,000; for a grain ship, $137,000; for a break-bulk, $390,000; and for a car-carrier (RO-RO), $207,000. These figures are for illustration only; further study would be needed for bulkers carrying coal exports in the case of the Port of Baltimore. It is important to keep in mind that some if not all of these costs would be in addition to those incurred for a shipboard-based BWTS.

A Shore-based Alternative at Port of Baltimore

For some of the same reasons described for barge-based treatment, notably the geographic spread of the Port of Baltimore, we do not consider a shore-based system to be a viable option. Finding a viable, universally convenient site for a shore-based system would be a challenge, whether such a system would be owned and operated by a public or private entity. A second issue which could cause delays is obtaining permitting from relevant local, state, and federal authorities.

The cost of such a system, even if an affordable site could be located and permitted, would be considerable. One observer familiar with waste water treatment plants (WWTPs) noted that the flow rate required would be the equivalent of Baltimore's Back Bay WWTP. The difference for BWTS is that the system would not be running 24 hours a day, seven days a week, but would in fact most likely sit idle for days or even weeks at a time in between treatments.

Conclusions

Use of a barge- or land-based BWTS in port has been considered as an option for BWT for more than a decade. For a variety of port-specific reasons, no operational barge- or land-based systems are in place. The analysis presented in the report leads to the following preliminary conclusions for this case study of the Port of Baltimore.

First, our preliminary analysis indicates that at least 22 ships per year would need to be treated at an estimated $50,000 per treatment to break even on the investment. However, technical and logistical limitations might not make that practicable in any case.

Similar systems would need to become operational simultaneously at the other ports of call servicing each vessel that might require treatment in Baltimore. This presents a serious challenge, particularly for a land-based system requiring acquisition of land. Ship traffic at the Port of Baltimore might support a BWTS in port, but our analysis of other eastern seaboard ports suggests that not every port could support a facility.

For a ship to take advantage of such a port-based system, retrofit of ship piping to an international standard, as well as additional pumping capacity, is needed. This would be in addition to the investment by ship owners in shipboard BWTS.

A port-based BWTS with the storage/treatment capacity to serve ships in need of BWT may be technically feasible, but may be logistically impractical from the ship owner's perspective.

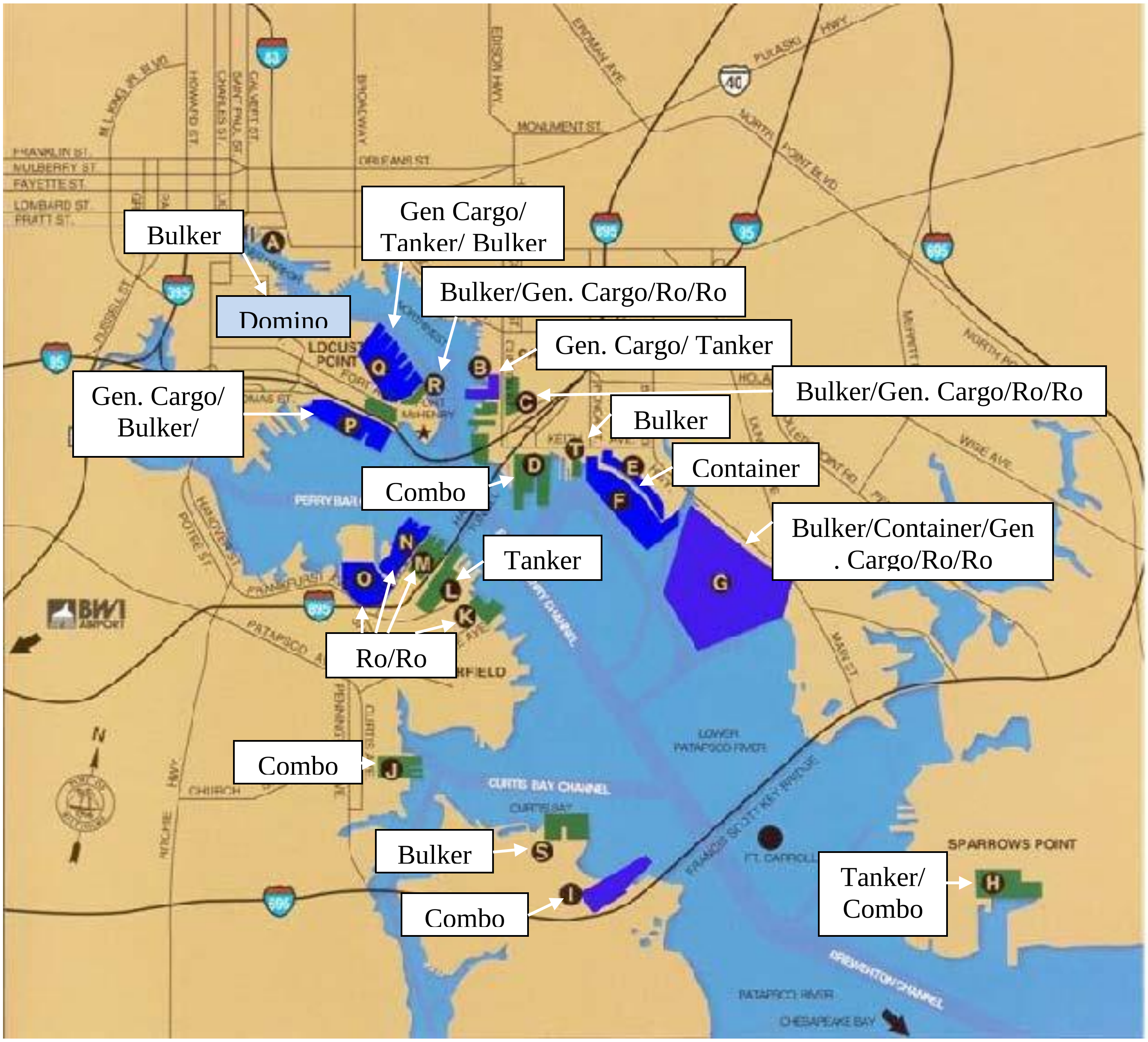
In a port such as the Port of Baltimore, the capital and operating expenses would be significant for a port-based BWTS with the capacity to treat BW from even a small portion of the ships that would need to use it to comply with BW regulations.

To make this investment worthwhile, a steady source of ships needing ballast water treatment would be necessary; however, the demand outlook over time is uncertain and might not justify the investment.

For a ship owner, a key consideration is the possibility of delays with cargo operations that may be incurred due to connection to a BWTS, and any incremental costs that such delays might entail. The major source of ballast water discharges for ships arriving at the Port of Baltimore is from bulkers taking on coal exports. The Port of Baltimore often services two or more large bulkers taking on coal shipments at different terminals at the same time. In a worst-case scenario, two ships might require "emergency" treatment on the same day, thus incurring significant delays and costs (perhaps tens of thousands of dollars) to the vessel owner.

Since most ships will still need to install on-board BWTS in order to maintain the option to deballast and take on cargo in ports that do not have port-based BWTS, the cost of port-based BWTS will not significantly reduce fleet-wide costs associated with the purchase and installation of ship-board BWTS.

Figure 1. Major Port of Baltimore Terminals and Type of Ship Traffic



Key To Major Port of Baltimore Terminals

Shaded areas do not receive cargo vessels

A	World Trade Center
	Domino Sugar
B	Petroleum Fuel & The Terminal Corporation
B	Clinton Street Marine Terminal
C	Rukert Terminals Corporation
D	CNX Marine Terminal (Consolidation Coal Sales Co.)
E	Intermodal Container Transfer Facility (ICTF)
F	Seagirt Marine Terminal
G	Dundalk Marine Terminal
H	Kinder Morgan Chesapeake Bulk (Sparrows Point)
I	Hawkins Point Terminal
J	CSX Transportation Chesapeake Bay Piers
K	Chesapeake Terminal (Auto Facility)
L	NuStar Energy, L.P. (ST Services)
L	Liquid Transfer
M	Atlantic Terminal (Auto Facility) (Amports)
N	Fairfield Auto Terminal (Mercedes)
O	Masonville Auto Terminal (Marine)
P	South Locust Point Marine Terminal
P	South Locust Point Cruise Terminal
Q	North Locust Point Marine Terminal
Q	Westway Terminal Co
R	Baltimore Metal & Commodities Terminal (Steinweg)
S	U.S. Gypsum
T	National Gypsum

[1] Cost per ton is based on treating 1,575,338 metric tons, which equals 20% of reported BW discharges of 7,876,690 metric tons in 2011. See table 2a.

[2] California State Lands Commission. 2009. 2009 Biennial Report on the California Marine Invasive Species Program. Produced for the California State Legislature, January 2009. http://www.slc.ca.gov/spec_pub/mfd/ballast_water/Reports_Presentations.html

[3] See https://www.federalregister.gov/articles/2012/06/13/2012-14382/standards-for-living-organisms-in-ships-ballast-water-discharged-in-us-waters#p-3 and Einemo, Unni. 2012. Full Ratification of Ballast Water Convention Expected Shortly. Sustainable Shipping. 14 September 2012. http://www.sustainableshipping.com/news/saf/i115991/Full_ratification_of_ballast_water_convention_expected_shortly#

[5] King, D.M., P.T. Hagan, M. Riggio and D.A. Wright. 2012. Preview of Global Ballast Water Treatment Markets. Journal of Marine Engineering and Technology. Volume 11, No. 1. January 2012. http://www.maritime-enviro.org/Reports.php

King, Dennis M., Mark Riggio and Patrick T. Hagan. 2010. Preliminary Overview of Global Ballast Water Treatment Markets. MERC Ballast Water Economics Discussion Paper, June 10, 2010. http://www.maritime-enviro.org/Reports.php

[6] Einemo, Unni. 2013. "Call for Lenience in Initial Phase of Ballast Water Regulation." Sustainable Shipping. January 15, 2013. http://www.sustainableshipping.com/news/saf/i118800/Call_for_lenience_in_initial_phase_of_ballast_water_regulation

[7] Macqueen, Julian. "Time is Tight on Ballast Water Regulations, Say Shipowners." http://www.sustainableshipping.com/news/i114879/Time_is_tight_on_ballast_water_regulations_say_shipowners

[8] For more detailed discussion of this point, see King, Dennis M. 2011. MEPC 62 Special: The world can afford sustainable shipping. Sustainable Shipping. 8th July 2011. The article notes that, given the scale of international shipping, if the estimated $15 billion in projected annual ballast water management compliance cost were passed on to consumers, it would result in an increase in consumer prices of imported goods of nine-thousandths of one percent, which is statistically indistinguishable from no change.

http://www.sustainableshipping.com/forum/blogs/6/104704/Dennis-King/MEPC-62-special-The-world-can-afford-sustainable-shipping

[9] Glosten Associates, Incorporated. 2002. Pacific Ballast Water Treatment Pilot Project. Ballast Water Transfer Study: Technical Feasibility with Associated Capital Costs. Prepared for Port of Seattle, WA, January 23, 2002.

[10] Brown & Caldwell. 2007. Port of Milwaukee Onshore Ballast Water Treatment Feasibility Study Report. Prepared for the Wisconsin Department of Natural Resources, October 12, 2007.

[11] California State Lands Commission. 2010. 2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. Produced for the California State Legislature, August 2010. http://www.slc.ca.gov/spec_pub/mfd/ballast_water/Reports_Presentations.html

[12] U.S. Environmental Protection Agency. 2011. Efficacy of Ballast Water Treatment Systems – A Report by the EPA Science Advisory Board. http://www.scribd.com/doc/89590829/EPA-Report-Efficacy-of-Ballast-Water-Treatment-Systems-A-Report-by-the-EPA-Science-Advisory-Board-2011

[13] Glosten Associates, Incorporated. 2002. Pacific Ballast Water Treatment Pilot Project. Ballast Water Transfer Study: Technical Feasibility with Associated Capital Costs. Prepared for Port of Seattle, WA, January 23, 2002

[14] Brown & Caldwell. 2007. Port of Milwaukee Onshore Ballast Water Treatment Feasibility Study Report. Prepared for the Wisconsin Department of Natural Resources, October 12, 2007.

[15] California State Lands Commission. 2010. 2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. Produced for the California State Legislature, August 2010. http://www.slc.ca.gov/spec_pub/mfd/ballast_water/Reports_Presentations.html

[16] U.S. Environmental Protection Agency. 2011. Efficacy of Ballast Water Treatment Systems – A Report by the EPA Science Advisory Board. http://www.scribd.com/doc/89590829/EPA-Report-Efficacy-of-Ballast-Water-Treatment-Systems-A-Report-by-the-EPA-Science-Advisory-Board-2011

[17] American Bureau of Shipping. 2012. A Moving Alternative in the Ballast Water Treatment Debate. Surveyor. Summer 2012, pp. 21-23

[18] Waite, Thomas D. Workshop on Port-Based Emergency/Contingency Measures for BWM: Final Report. November 12, 2012. Developed under: Intergovernmental Maritime Organization Consultant Contract XB/0108-01-04-2990/PO:45000 16067 HRS/G/12/808.

[19] King, Dennis M., Mark Riggio and Patrick T. Hagan. 2009. Preliminary Cost Analysis of Ballast Water Treatment Systems. Maritime Environmental Resource Center Ballast Water Economics Discussion Paper No. 1. http://www.maritime-enviro.org/Downloads/Reports/Other_Publications/MERC_Preliminary_Cost/

[20] See http://www.cruiseindustrynews.com/cruise-news/7139-port-of-baltimore-posts-major-growth-in-2011-.html

and http://mpa.maryland.gov/_media/client/News-Publications/2011/press/11072011-PortofBaltimoreExportedRecordAmountofCoalandImportedRecordAmountofSaltin2010.pdf

[21] 2002 figures (see Glosten Associates, Incorporated. 2002. Pacific Ballast Water Treatment Pilot Project. Ballast Water Transfer Study: Technical Feasibility with Associated Capital Costs. Prepared for Port of Seattle, WA, January 23, 2002) were adjusted to 2012 dollars using the Bureau of Labor Statistics inflation calculator accessed at http://www.bls.gov/data/inflation_calculator.htm