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Preliminary Overview of Global Ballast Water Treatment Markets

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Introduction

After more than a decade of technical analysis and political debate at the national and international level, legislation by the International Maritime Organization (IMO) to require ballast water management on ships is coming closer to ratification. Proposed rulemaking by the United States Coast Guard (USCG), which largely mirrors the IMO requirements, was published on August 28, 2009, adding to the momentum for implementation of ballast water discharge standards which are expected to be met by installing onboard ballast water treatment systems that operate during ballasting, during deballasting, during transit, or in some combination.[1]

The IMO convention is scheduled to take effect 12 months after ratification by 30 countries representing 35% of the world's commercial tonnage. As of October 31, 2009, 18 countries had ratified the convention, representing 15.36% of the world's shipping tonnage.[2] Ratification by Panama, with more than 20% of the global shipping tonnage, would be sufficient to meet the 35% requirement, and a number of European Union countries would be expected to follow suit.

Because of delay in ratification by a sufficient number of countries, IMO granted a delay for the first set of ships subject to the regulations, those ships constructed in 2009 or later with a ballast capacity of less than 5000m^3. These ships now have until the vessel's second annual survey, but no later than December 31, 2011, to comply.[3] But, by 2016, all ships subject to the regulations will be required to have operational ballast water treatment systems (BWTS) on board.

For planning purposes it would be useful for industry leaders and governments in IMO member nations to have preliminary answers to questions about: the potential size and value of the global markets for BWTS; how they are likely to develop after the ratification and implementation of IMO ballast water standards; and how they will be affected by the way IMO and U.S. ballast water standards are monitored and enforced.

To develop preliminary answers to these questions we first examined the expected cost of purchasing and installing various types of BWTS on representative ships in eight ship type/size categories that make up most of the global merchant fleet that will be affected by IMO ballast water regulations. That research and preliminary cost estimates are presented in a 2009 University of Maryland, Maritime Environmental Resource Center (MERC) discussion paper titled: "A Preliminary Analysis of Ballast Water Treatment Costs" which is available on-line at http://www.maritime-enviro.org/reports/Reports.html/.

We then examined Lloyds global shipping fleet data as of November 9, 2009 to determine the size, type, flag, and age of the vessels in the global fleet that are likely to install BWTS to meet IMO ballast water discharge standards. With full compliance, we estimate that more than 68,000 vessels in the global merchant fleet will eventually install on-board BWTS. Depending on a number of factors that are still uncertain this estimate of the relevant global fleet may result in high or low estimates in the corresponding size of the global BWTS market. For purposes of our analysis, for example, we assume that all vessels will comply regardless of their age. However, it is likely that some older vessels will either be retired, rerouted so that they are not subject to BW regulations, or simply not comply. This would make our estimate of the relevant fleet high. On the other hand, we also assume that only one unit will be installed per ship in the relevant global fleet when, in fact, some larger vessels may require multiple units. This would make the market for BWTS larger than what is reflected by our estimate of the number of ships complying. And while we include more than 8,000 fishing vessels under 1000 DWT, we assume that these smaller vessels in this fleet are likely to comply through use of less expensive products that are still to be determined and approved and are not considered in our analysis of BWTS.

Even with these caveats, the number of ships in the affected global fleet represents a massive global market for BWTS, perhaps 10,000 units per year (or 30 installations per day). This means that if the IMO "D-2" regulation timetable is to be met, the capacity to produce and install BWTS will need to grow enormously between now and 2016. Of course, once existing ships are in compliance, hopefully by 2017 or so, only newly built ships will require the installation of BWTS, so global BWTS markets will then shrink to around 2,000 ships per year (five or so installations per day).

In anticipation of this large emerging market for BWTS, many entrepreneurs and potential vendors have developed a range of technologies that could serve the global BWTS market. As of July 2009, however, only eight BWTS had been fully certified by the IMO as achieving levels of efficacy at removing or killing organisms that will meet IMO ballast water discharge standards. We contacted technology vendors whose systems had been approved by IMO to obtain information about the cost of purchasing, installing and operating various BWTS and to help understand what types and sizes of ships and on which shipping routes they are most likely to be used. Based on information we collected about the range of costs and the suitability of these systems, we estimate that the value of the global market for purchasing and installing BWTS between 2010 and 2016 will be in the range of US$43 to $74 billion.

Ballast water treatment vendors will of course be competing with each other in this new global market. However, they will also be competing against another factor: ship owners and operators who choose not to comply with regulations, or who use various legal, political, and diplomatic tools to delay compliance. Because the emerging global markets for BWTS will be regulation-driven, the market information in this report includes descriptions of some significant enforcement issues that will arise as the ballast water convention comes into force between now and 2016 and will affect implementation and compliance. How these issues are addressed by IMO member nations will have an enormous influence on the supply, demand, and price of BWTS, and on the effectiveness of U.S. and IMO ballast water discharge restrictions.

The paper has four sections. Section 1 provides a preliminary profile of the global fleet of ships that is likely to make up the market for BWTS. Section 2 summarizes our analysis of the cost of acquiring and installing BWTS aboard "typical" ships in a variety of ship sizes and classes and uses these representative costs and the number of ships in each ship class and the IMO tiered compliance schedule. In Section 3, we develop a preliminary assessment of the value and pattern of development of global BWTS markets. Section 4 describes some of the monitoring and enforcement issues that will strongly influence when and how global BWTS markets will evolve.

Part 1: The Potentially Affected Global Fleet

To understand the potential global demand for ballast water treatment systems, we queried the Lloyds database of global shipping, most recently on November 9, 2009, and examined data for flag of vessel, ship size (in deadweight tonnage), ship type, and ship age.

Vessel Flag Characteristics

We reviewed the Lloyds world merchant fleet data to understand the flag characteristics of the fleet, both by size in deadweight tonnage, and by number of ships. Deadweight tonnage is significant for implementation of the IMO convention, which is scheduled to take effect 12 months after ratification by 30 countries representing 35% of the world's commercial tonnage. As of October 31, 2009, 18 countries had ratified the convention, representing 15.36% of the world's shipping tonnage.[4] Ratification by Panama, with more than 20% of the global shipping tonnage, would be sufficient to meet the 35% requirement, and a number of European Union countries would be expected to follow suit.

To illustrate the status of ratification of the convention, we first sorted the data by deadweight tonnage for the total world's commercial fleet (not just for those types of vessels we consider to be subject to the IMO ballast water treatment regulations). (See Table 1a for a list of the top 35 countries by deadweight tonnage.) We also sorted the data by number of merchant ships to demonstrate the potential market for ballast water treatment technologies represented by the top 35 countries as measured by number of ships. (See Table 1b.) Note that the United States, for instance, has a much lower number of ships in the latter table. This is largely because we have excluded smaller fishing vessels (less than 300 gross tons) from our analysis.

Table 1a. Top 35 Flag Countries, by Deadweight Tonnage. Countries that have ratified the Ballast Water Convention as of October 31, 2009 are highlighted in bold.

Flag	**Flag % by DWT**	**Number of Ships**	**% Ships of World Fleet**
Panama	22.52%	8,881	7.87%
Liberia	**10.49%**	**2,565**	**2.27%**
Marshall Islands	5.93%	1,541	1.37%
Hong Kong	5.47%	1,487	1.32%
Greece	5.36%	1,682	1.49%
Bahamas	5.29%	1,566	1.39%
Singapore	5.07%	2,786	2.47%
Malta	4.22%	1,639	1.45%
China	3.53%	4,347	3.85%
Cyprus	2.46%	1,109	0.98%
Korea (South)	1.73%	3,087	2.74%
Norwegian International Register	**1.50%**	**579**	**0.51%**
Germany	1.46%	1,111	0.98%
United Kingdom	1.43%	2,189	1.94%
United States of America	1.39%	8,257	7.32%
Italy	1.27%	1,812	1.61%
Japan	1.26%	6,555	5.81%
Isle of Man	1.17%	453	0.40%
India	1.15%	1,368	1.21%
Danish International Register	1.02%	500	0.44%
Antigua	**1.01%**	**1,231**	**1.09%**
Bermuda	0.87%	197	0.17%
Malaysia	0.84%	1,375	1.22%
Unknown	0.81%	5,457	4.84%
Indonesia	0.64%	5,100	4.52%
France (FIS)	**0.62%**	**787**	**0.70%**
Netherlands	0.62%	1,746	1.55%
Turkey	0.62%	1,424	1.26%
Russia	0.60%	3,682	3.26%
Philippines	0.57%	2,335	2.07%
St Vincent	0.57%	1,143	1.01%
Belgium	0.56%	373	0.33%
Vietnam	0.43%	1,439	1.28%
Cayman Islands	0.32%	611	0.54%
Taiwan	0.32%	663	0.59%
TOTAL	93.11%	81,077	71.86%

Table 1b. Top 35 Flag Countries, by Number of Merchant Ships.

Flag	Number of Ships	Flag % of World Fleet Subject to Ballast Water Treatment Regulations	Flag % by DWT
Panama	7,484	10.98%	23.10%
Japan	4,376	6.42%	1.29%
China	3,167	4.64%	3.46%
Unknown	3,068	4.50%	0.64%
Indonesia	2,829	4.15%	0.62%
Russia	2,525	3.70%	0.56%
Liberia	2,292	3.36%	10.68%
Korea (South)	1,905	2.79%	1.79%
Singapore	1,793	2.63%	5.13%
Philippines	1,661	2.44%	0.59%
Malta	1,530	2.24%	4.41%
Hong Kong	1,401	2.05%	5.70%
Greece	1,326	1.94%	5.63%
Bahamas	1,289	1.89%	4.87%
Marshall Islands	1,254	1.84%	6.02%
Vietnam	1,252	1.84%	0.40%
United States of America	1,239	1.82%	1.16%
Turkey	1,177	1.73%	0.65%
Antigua	1,112	1.63%	0.99%
Netherlands	1,106	1.62%	0.57%
Italy	1,054	1.55%	1.32%
Norway	979	1.44%	0.15%
United Kingdom	957	1.40%	1.38%
Cyprus	943	1.38%	2.55%
Cambodia	832	1.22%	0.21%
Thailand	730	1.07%	0.32%
Germany	719	1.05%	1.52%
Malaysia	717	1.05%	0.75%
St Vincent	687	1.01%	0.52%
Honduras	659	0.97%	0.06%
India	621	0.91%	1.16%
Spain	557	0.82%	0.05%
Norwegian International Register	494	0.72%	1.53%
Canada	470	0.69%	0.26%
Sweden	389	0.57%	0.19%
TOTAL	54,594	80.06%	90.23%

Vessel Types in Potentially Affected Global Fleet

We analyzed data by type of ship for "delivered" ships listed in the Lloyds Fairplay database, and our analysis determined that the sub-types listed in Tables 2a and 2b would be subject to IMO regulations for ballast water treatment. In the case of fishing vessels, we included only vessels of 300 gross tons or more, and we excluded other sub-types we determined were not carrying ballast water or would only be operating within one captain of the port zone (COPTZ). We then estimated ballast capacity for different sized vessels in each sub-type fleet, using information for actual ships listed in the American Bureau of Shipping database as the basis for our estimates.

Our analysis indicates that more than 21,000 ships will be subject to the first round of IMO retrofit requirements, which includes those ships with ballast water capacity of 1500-5000 m3. These ships will be required to have ballast water treatment starting in 2014.[5] Of those ships, the vast majority—more than 16,000—are general cargo ships. (See Table 2a.) Of U.S.-flagged vessels, we estimate that only 183 ships will be in this first category of vessels required to retrofit by 2014, with 131 of those ships either being general cargo or refrigerated cargo ships. (See Table 2b.)

About two-thirds of the demand for installation of technology to meet IMO D2 Standard will be associated with meeting the 2016 deadline for ships with less than 1500 m3 capacity (more than 16,000 ships) or with more than 5000 m3 capacity (more than 45,000 ships).

Table 2a. Number of Vessels by Vessel Type and Estimated Ballast Capacity

Sub Type	Count	Ballast Capacity of <1500m3	Ballast Capacity of 1500-5000m3	Ballast Capacity of >5000m3
Barges[6]	574	0	0	574
Bulk Carriers	8,110	0	0	8,110
Container Ship	4,724	0	0	4,724
Crude Oil Tanker	2,160	0	0	2,160
Chemical Tanker	1,474	0	0	1,474
Chemical/Oil Products Tanker	9,323	0	0	9,323
General Cargo Ship	18,187	0	16,535	1,652
Fishing Vessels	8,001	7,970	30	1
LNG Tanker	327	0	0	327
LPG Tanker	1,194	540	0	654
OSVs	2,000	1,923	0	77
Passenger (Cruise) Ship	515	0	479	36
Passenger-Passenger/Cargo (Ro-Ro)	3,359	3,324	35	0
Passenger Ship	2,942	2,941	1	0
Refrigerated Cargo Ship	2,542	0	2,538	4
Ro-Ro Cargo Ship	1,873	0	1,700	173
Livestock Carrier	101	0	90	11
Vehicle Carrier	784	0	196	588
TOTAL	**68,190**	**16,698**	**21,604**	**29,888**

Table 2b. Number of U.S. flag Vessels by Vessel Type and Estimated Ballast Capacity

Sub Type	Count	Ballast Capacity of <1500m3	Ballast Capacity of 1500-5000m3	Ballast Capacity of >5000m3
Barges	9	0	0	9
Bulk Carriers	73	0	0	73
Container Ship	87	0	0	87
Crude Oil Tanker	17	0	0	17
Chemical Tanker	5	0	0	5
Chemical/Oil Products Tanker	100	0	0	100
General Cargo Ship	89	0	62	27
Fishing Vessels	334	332	2	0
LNG Tanker	0	0	0	0
LPG Tanker	0	0	0	0
OSVs	121	103	0	18
Passenger (Cruise) Ship	31	0	31	0
Passenger-Passenger/Cargo (Ro-Ro)	104	103	1	0
Passenger Ship	114	113	1	0
Refrigerated Cargo Ship	71	0	71	0
Ro-Ro Cargo Ship	62	0	15	47
Livestock Carrier	0	0	0	0
Vehicle Carrier	22	0	0	22
TOTAL	**1239**	**651**	**183**	**405**

Vessel Size

We further sorted the Lloyds data by deadweight tonnage to develop a more comprehensive view of the various-sized vessels in what we consider to be the world merchant fleet subject to ballast-water regulations (Table 3). Again, in the case of fishing vessels, only those of 300 gross tons or more were included in our analysis. More than 92% of our estimated 8,001 fishing vessels subject to IMO ballast water regulations are less than 1000 DWT. Given the slim operating profit margins of smaller fishing vessels, it is unlikely that they will be able to afford the types of BWTS that are the focus of our research, or will have room aboard to accommodate them. Our assumption is that these smaller fishing vessels will need to find some other way to comply with IMO ballast water regulations.

Table 3. Number of Vessels by Vessel Type and Deadweight Tonnage.

	World Fleet DWT						
Vessel Type	0 – 999	1,000 - 9,999	10,000 - 29,999	30,000 - 49,999	50,000 - 69,999	>=70,000	Total
Barges	274	275	15	8		2	574
Bulk Carriers	392	878	1703	1743	1264	2130	8110
Container Ships	6	788	1628	1013	812	477	4724
Crude Oil Tankers	16	112	37	163	120	1712	2160
Chemical Tankers	423	806	164	79	1	1	1474
Chemical/Oil Products Tankers	1665	4621	1206	1249	245	337	9323
General Cargo Ships	5921	10612	1409	223	22	0	18187
Fishing Vessels	7395	604	2	0	0	0	8001
LNG Tankers	1	5	12	11	36	262	327
LPG Tankers	193	678	154	71	98	0	1194
OSVs	600	1399	1	0	0	0	2000
Passenger (Cruise) Ships	243	227	45	0	0	0	515
Passenger -Passenger/Cargo (Ro-Ro) Ships	2327	997	35	0	0	0	3359
Passenger Ships	2883	58	1	0	0	0	2942
Refrigerated Cargo Ships	832	1453	254	3	0	0	2542
Ro-Ro Cargo Ships	840	726	292	15	0	0	1873
Livestock Carriers	22	68	9	2	0	0	101
Vehicle Carriers	13	183	558	28	2	0	784
TOTAL	**24,046**	**24,490**	**7,525**	**4,608**	**2,600**	**4,921**	**68,190**

Age of the Merchant Fleet

We queried the Lloyds merchant fleet data by age of ship, as well. Table 4 shows the world fleet by vessel type and age. The general cargo ship and fishing vessel fleets are the oldest, which suggests they would be less likely to adopt the treatment technologies approved by IMO to date. More than half of the ships comprising these two sub-types are 25 years or older.

The table includes 2009 new-builds (1,804 ships) listed in the database. Because of delay in ratification by a sufficient number of countries, IMO granted a delay for the first set of ships subject to the regulations, those ships constructed in 2009 or later with a ballast capacity of less than $5000m^3$. These ships now have until the vessel's second survey, but no later than December 31, 2011 to comply. However, more than 60% of the new vessels under construction in 2009 are bulk carriers, container ships, or tankers that we estimate to have greater than 5000 m3 ballast water capacity, which do not require treatment technology for new builds until 2012.

Table 4. Number of Vessels by Vessel Type and Vessel Age

Vessel Type	0-4 years		5-14 years		15-24 years		25+ years		2009 Builds		Total	
	#	%	#	%	#	%	#	%	#	%	#	%
Barges	27	0.3%	30	0.2%	125	0.8%	387	1.4%	5	0.3%	574	0.8%
Bulk Carriers	1592	15.7%	2328	16.5%	1894	12.3%	1938	7.2%	358	19.8%	8110	11.9%
Container Ships	1650	16.3%	1881	13.3%	675	4.4%	323	1.2%	195	10.8%	4724	6.9%
Crude Oil Tankers	624	6.2%	788	5.6%	473	3.1%	127	0.5%	148	8.2%	2160	3.2%
Chemical Tankers	281	2.8%	278	2.0%	501	3.3%	338	1.3%	76	4.2%	1474	2.2%
Chemical/Oil Products Tankers	2088	20.7%	1781	12.6%	1748	11.4%	3283	12.2%	423	23.4%	9323	13.7%
General Cargo Ships	1705	16.9%	2692	19.1%	3779	24.6%	9794	36.5%	217	12.0%	18187	26.7%
Fishing Vessels	283	2.8%	1119	7.9%	2454	16.0%	4132	15.4%	13	0.7%	8001	11.7%
LNG Tankers	18	0.2%	78	0.6%	151	1.0%	52	0.2%	28	1.6%	327	0.5%
LPG Tankers	217	2.1%	322	2.3%	289	1.9%	320	1.2%	46	2.5%	1194	1.8%
OSVs	491	4.9%	245	1.7%	220	1.4%	889	3.3%	155	8.6%	2000	2.9%
Passenger (Cruise) Ships	58	0.6%	157	1.1%	109	0.7%	183	0.7%	8	0.4%	515	0.8%
Passenger -Passenger/Cargo (Ro-Ro)	287	2.8%	674	4.8%	670	4.4%	1702	6.3%	26	1.4%	3359	4.9%
Passenger Ships	222	2.2%	788	5.6%	776	5.1%	1128	4.2%	28	1.6%	2942	4.3%
Refrigerated Cargo Ships	62	0.6%	298	2.1%	945	6.2%	1232	4.6%	5	0.3%	2542	3.7%
Ro-Ro Cargo Ships	283	2.8%	441	3.1%	333	2.2%	785	2.9%	31	1.7%	1873	2.7%
Livestock Carriers	0	0.0%	7	0.0%	6	0.0%	88	0.3%	0	0.0%	101	0.1%
Vehicle Carriers	221	2.2%	213	1.5%	191	1.2%	117	0.4%	42	2.3%	784	1.1%
TOTAL	**10,109**	**100.0%**	**14,120**	**100.0%**	**15,339**	**100.0%**	**26,818**	**100.0%**	**1,804**	**100.0%**	**68,190**	**100.0%**

Section 2: BWTS Equipment and Installation Costs

In order to assess and compare the cost of various ballast water treatment (BWT) systems, we contacted by email and telephone the technology vendors whose systems had been approved by IMO as of May 2009, and conducted follow-up telephone interviews and email exchanges with industry representatives.

The following types of systems were evaluated:

- Filtration and UV
- Filtration and Chemical
- Deoxygenation and Cavitation
- Electrolysis and Electrochlorination
- Filtration, Deoxygenation and Cavitation

We examined the costs associated with each of these systems installed and operated aboard ships in the following types/size categories:

- Bulker: Cape-sized Vessel
- Bulker: Panamax
- Container: 2500 TEU
- Container: 8000 TEU
- General Cargo: Breakbulk
- General Cargo: Ro-Ro
- Tanker: TAPS Trade
- Tanker: VLCC

This list of eight ship types/sizes is not comprehensive with regard to the scope of the proposed IMO regulations, but it provides a fair representation of the cost profiles for the BWTS we analyzed, over a range of typical applications. We did not examine vessels that routinely treat less than 70,000 metric tons of ballast water annually, since these vessels are likely to end up using alternative methods to be in compliance with regulations, such as continuing to use ballast water exchange if allowed, taking on fresh water for use as ballast, or foregoing ballasting when in restricted or regulated waters.

Based on analysis that incorporated information from vendors and other sources, the range of expected BWTS purchase costs across system types and categories of ship types/sizes listed above was estimated to be $640,000 to $947,000. For all types of systems, there are some economies of scale when purchasing, with bulk orders reducing the cost of a system by $40,000 to $104,000 per unit, depending on the system type.[7]

Table 5. Estimated Purchase Price of Ballast Water Treatment Systems

Type of Unit	Base Price	Bulk Price
Filtration and UV Light	$ 933,333	$ 840,000
Filtration and Chemical	$ 946,667	$ 852,000
Deoxygenation and Cavitation	$ 640,000	$ 600,000
Electrolysis & Electrochlorination	$ 666,667	$ 600,000
Filtration, Deoxygenation & Cavitation**	$ -	$ -

**Not enough data found on Filtration, Deoxygenation & Cavitation Systems to include

We also analyzed the range of costs to install these systems. The range of costs outlined in Table 6 is based on an analysis of six installation options, including:

- New Build - U.S. Yard
- New Build - Foreign (Asian) Yard
- Shore-based Retrofit -U.S. Yard
- Shore-based Retrofit - Foreign (Asian) Yard
- Retrofit While Ship is in Service - U.S. Vessel/Installation
- Retrofit While Ship is in Service - Foreign Vessel/Installation

It is important to note here that installation costs will vary widely even within a particular ship type/size depending on the characteristics of individual ship and space and other requirements of specific types of BWTS. The installation cost estimates provided here can be viewed as "typical," but they were based on installing a single system aboard eight particular ships that were selected as being "typical" of ships in each of our eight ship categories.

The most critical factor affecting BWTS installation costs is the space requirements of the BWTS and whether various components of a particular BWTS can be located in a single location on the ship or need to be placed in separate locations and linked together. Because of "footprint problems" many BWTS vendors offer modular systems that can be installed wherever there is adequate space and connected together. While these modular features make them potential candidates for installation aboard more types and sizes of ships, taking advantage of these modular features can add significantly to installation costs.

Table 6. Range of Installation Costs by Vessel Type (in thousands of US$).[8]

	New Construction		Retrofit		Retrofit in Service	
	US Yard	Foreign Yard	US Yard	Foreign Yard	US Vessel	Foreign Vessel
VLCC	32-70	23-62	78-147	67-136	111-210	96-197
Tanker TAPS Trade	27-60	18-58	72-131	63-119	106-170	92-100
General Cargo RO-RO	27-67	18-61	48-132	33-120	29-185	24-170
General Cargo Breakbulk	27-57	18-50	48-114	33-97	29-140	24-131
Container 8000 TEU	30-67	23-62	65-143	57-128	103-197	91-180
Container 2500 TEU	22-62	18-56	51-115	47-106	74-140	67-131
Bulker Panamax	22-64	18-56	60-125	54-115	93-155	85-142
Bulker Cape Size	22-68	18-62	62-173	73-143	85-190	74-169

Retrofit in Service based on use of riding crew

A separate MERC report titled: "Preliminary Analysis of Ballast Water Treatment Costs" includes detailed analyses of purchase, installation, and fixed annual operating costs (e.g., maintenance) and variable annual operating costs (per metric ton of ballast treated) for selected ships in the eight types/sizes of vessels. This report is available at http://www.maritime-enviro.org/reports/Reports.html and presents all of the assumptions used to develop preliminary cost estimates and the vessel-specific cost development spreadsheets that were used to develop the cost estimates and resulting market value estimates presented here. The cost spreadsheets presented in that earlier report can be modified and refined easily to accommodate new cost data or different ship types/sizes/patterns of use. A summary of our preliminary cost analysis of fixed annual maintenance costs is in Table 7 below.

Table 7. Annual Operating Costs associated with BWTS Types*

Vessel Type	Filtration/UV	Filtration/ Chemical	Deoxygenation/ Cavitation	Electrolysis/ Electrochlorination
General Cargo, Breakbulk	$11,000	$31,000	$9,000	$17,000
General Cargo, RO-RO	$11,000	$37,000	$9,000	$17,000
Container, 2500 TEU	$11,000	$44,000	$9,000	$17,000
Bulker, Panamax	$11,000	$56,000	$9,000	$17,000
Container, 8000 TEU	$11,000	$82,000	$9,000	$17,000
Bulker, Cape Sized	$11,000	$100,000	$9,000	$17,000
Tanker, TAPS Trade	$11,000	$142,000	$9,000	$17,000
VLCC	$11,000	$296,000	$9,000	$17,000

* Includes fixed annual costs (e.g., BWTS maintenance) as well as annual costs that vary with the amount of BW treated. Filtration/Chemical system cost estimates vary significantly by ship type and by the amount of ballast treated because of the the cost of consumables. (e.g., chemicals).

Using life-cycle costs per metric ton of ballast treated, we estimate that Filtration/UV and Electrolysis/Electrochlorination appear to be the least expensive solutions for most types/sizes (Table 8). For all ship types/sizes, not enough data were found on Filtration, Deoxygenation and Cavitation systems to include this treatment system type in our analysis.

Table 8. Life Cycle Cost per MT of BW treated (Based on an expected 25-year life cycle).

Type of Ship	Filtration and UV Light	Filtration and Chemical	Deoxygenation and Cavitation	Electrolysis and Electro-chlorination
Bulker Cape Sized	$0.14 - 0.15	$0.36 - 0.38	$0.27 - 0.28	$0.14 - 0.16
Bulker Panamax	$0.25 - 0.29	$0.51 - 0.55	$0.36 - 0.39	$0.27 - 0.30
Container 2500 TEU	$0.34 - 0.39	$0.61 - 0.67	$0.44 - 0.47	$0.32 - 0.37
Container 8000 TEU	$0.15 - 0.17	$0.38 - 0.41	$0.29 - 0.31	$0.14 - 0.16
General Cargo Breakbulk	$0.67 - 0.75	$1.00 - 1.12	$0.70 - 0.77	$0.65 - 0.74
General Cargo RO-RO	$0.45 - 0.51	$0.74 - 0.83	$0.53 - 0.59	$0.44 - 0.51
Tanker TAPS Trade	$0.10 - 0.11	$0.31 - 0.33	$0.24 - 0.25	$0.11 - 0.12
Tanker VLCC	$0.07 - 0.08	$0.28 - 0.29	$0.22 - 0.23	$0.08 - 0.09

Not enough data found on Filtration, Deoxygenation & Cavitation Systems to include

Our preliminary interviews suggest that there will be minimal or no lost revenue from retrofitting a merchant ship with a BWTS as long as installation time fits within normal shipyard time. Hull painting is typically the critical path item in terms of shipyard capacity availability and usually requires a minimum of seven days, while preliminary interviews indicate that ballast water treatment retrofit should take fewer than seven days to complete. With large, modern fleets in particular, ships may utilize Underwater Inspection in Lieu of Drydocking (UWILD) to meet their periodic hull exam requirements. This would extend the time between dockings to once every five to seven years, which may make it more suitable for some ships to have BWTS installed while a ship is in service (at sea). While the cost of having a dedicated crew install a BWTS while the ship is at sea is slightly more expensive than having the system installed at a shipyard, our research did not indicate that this would be a cost-prohibitive option for most vessel types if BWT installation needs did not correspond with a routine shipyard visit. Our interviews indicated that such installations have been successfully completed with no vessel down-time recorded.

For most technologies our interviews and other research indicate that annual fixed operating costs for maintenance of BWT systems would typically be in the $9,000 to $17,000 range, depending on vessel type and size. The exception among approved technologies is for filtration/chemical systems which have a much wider range of annual operating costs--an estimated $31,000 to $296,000--because of the use of consumables (chemicals) that will vary widely based on vessel type and size.

For each vessel type/size, operating costs were estimated to amount to two to five cents per metric ton of ballast water treated. The exception is for deoxygenation/cavitation systems, which we estimated to cost 19 to 20 cents per metric ton due to fuel costs.

For all ship types analyzed, our analysis indicated that the installation of BWTS during new ship construction, on average, is about $100,000 lower than the cost of a comparable retrofit. Due to variations in individual ships, shipyard labor rates, new construction price guarantees, and shipyard volume price incentives, this number will vary widely. Subsequent interviews suggest that this estimate of $100,000 in cost savings associated with new builds is probably low.

From a supply perspective, our interviews and analysis indicates that the biggest potential bottleneck in response to the IMO timetable will most likely be related to production of systems and the availability of engineers to design and oversee installation, not from insufficient capacity in shipyards to install them. In Figure 1, we describe some of the issues other than costs that shipowners will be considering when they choose which types of BWTS to install and how to install them.

Figure 1. Ballast Water Treatment Technology Installation Checklist

- How/where will systems be installed (i.e., dry dock, in water, during a voyage)?
- How long will installation take?
- What are the dimensions (in particular the footprint) of the required equipment?
- Are there any restrictions on where the required equipment should be placed?
- Are there any restrictions on the location of different parts of the equipment and their location relative to other parts of the installation?
- Are any alterations to existing ship equipment required beyond installation of the treatment system, i.e., to plumbing or electrical systems?
- Is the system scalable to allow for different flow rates and different vessel configurations?
- What lead times should be expected for receipt of the system?
- What kinds of man-hours, material, and equipment are estimated for installation?
- Are there any physical or environmental conditions that might limit or reduce the effectiveness of the treatment (e.g., turbidity/sediments, temperature, vessel service)?
- If chemicals are used, what is the anticipated amount of chemicals required per $1000m^3$ of ballast treated. What, if any, storage requirements and cargo-segregation of the active ingredient is needed to allow for safe operation of the vessel?
- What types of spares would be required to be maintained onboard for 180 days of continuous operation of the vessel?
- Are there any shoreside storage requirements, i.e., for chemicals or filter replacements, at each load port?
- Who provides spare parts and shore-based equipment repairs, and how extensive is their local service network?
- Who provides on-site service support and telephone support for maintenance and onboard repairs of the units? How extensive is their technical service network?
- Are there special crew or vessel safety requirements when operating the equipment or handling associated materials?
- Are there special environmental safety requirements relating to the equipment or supporting materials? (i.e., active ingredient getting wet, humidity, etc.)?
- Do storage, use and handling of active ingredients require special training?
- What method/s will be used to monitor performance and report about compliance?
- Does any similar equipment onboard have common spares and operating procedures?
- What salinity water is expected during the service life of the vessel?
- Does the equipment contain proprietary equipment or closed-source system architecture or does the system use an open source platform?
- What is the expected service life of the vessel?
- What are the operational requirements restricting ballast exchange or retention of all ballast onboard?
- What penalties may be expected due to non-compliance with the regulations?
- How much training is required for crewmembers to successfully operate, maintain and conduct routine repairs to the system?

Part 3: Pattern of Global Market Development

In this section, we develop estimates of how the global market for ballast water treatment systems is likely to develop through 2020. These estimates are based on the following assumptions: (1) the IMO Convention will be ratified in 2011, and be enforced by IMO member nations one year later, starting in 2012; (2) upon ratification, vessels will begin to comply with IMO BW treatment guidelines starting in 2011; and (3) all ships required to comply with IMO regulations will comply by proposed IMO deadlines. We then estimated that the percentage of ships in each IMO designated BW capacity category that will comply each year prior to the proposed IMO deadline will be as shown in Table 9 until all ships in all categories have complied.

Table 9. Assumed compliance scheduling

BW Capacity	2011	2012	2013	2014	2015
<1,500 m^3	5%	10%	10%	25%	50%
1,500 - 5,000 m^3	15%	35%	50%	0%	0%
>5,000 m^3	5%	10%	10%	25%	50%

Our estimates of the numbers of vessels built in 2009 or before are based Lloyd's Fairplay Database, November 2009. The estimated numbers of vessels built from 2010 through 2020 are based on the average number of new vessels delivered per year from 2005 through 2009 (datasource: Lloyd's Fairplay Database, November 2009).

Figure 2. BWTS Installation 2011-2020.

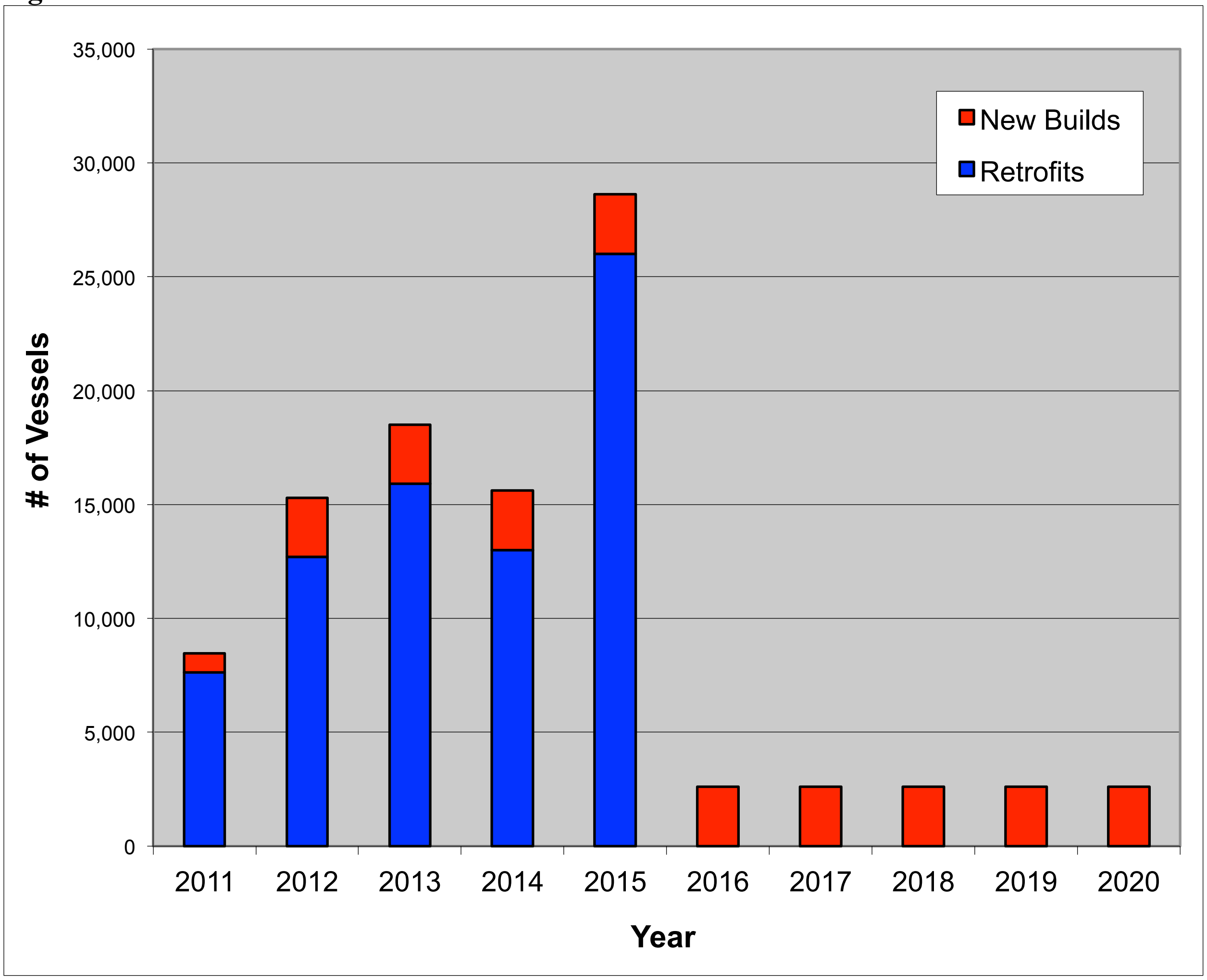
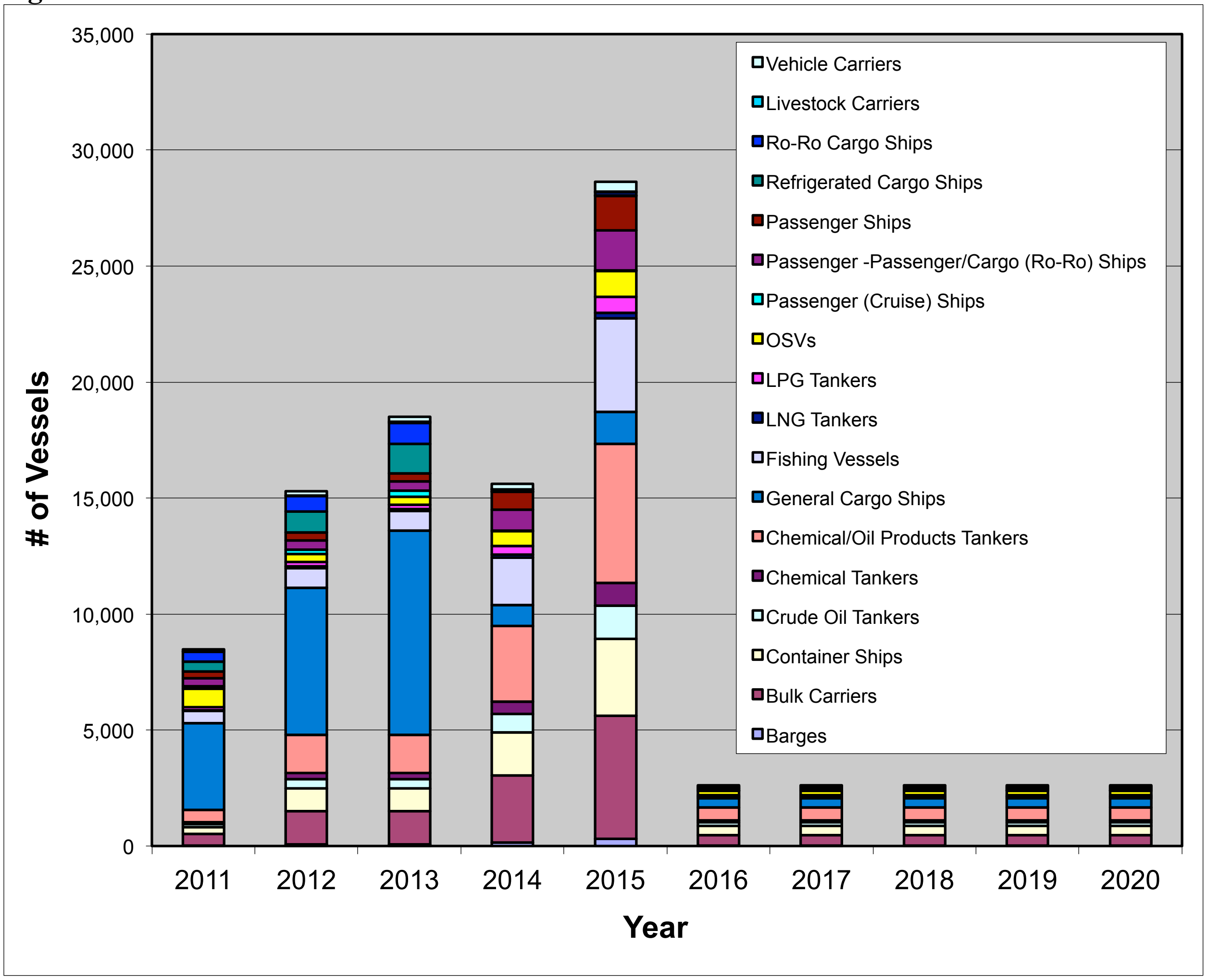


Figure 3. BWTS Retrofits and New Builds 2011-2020.

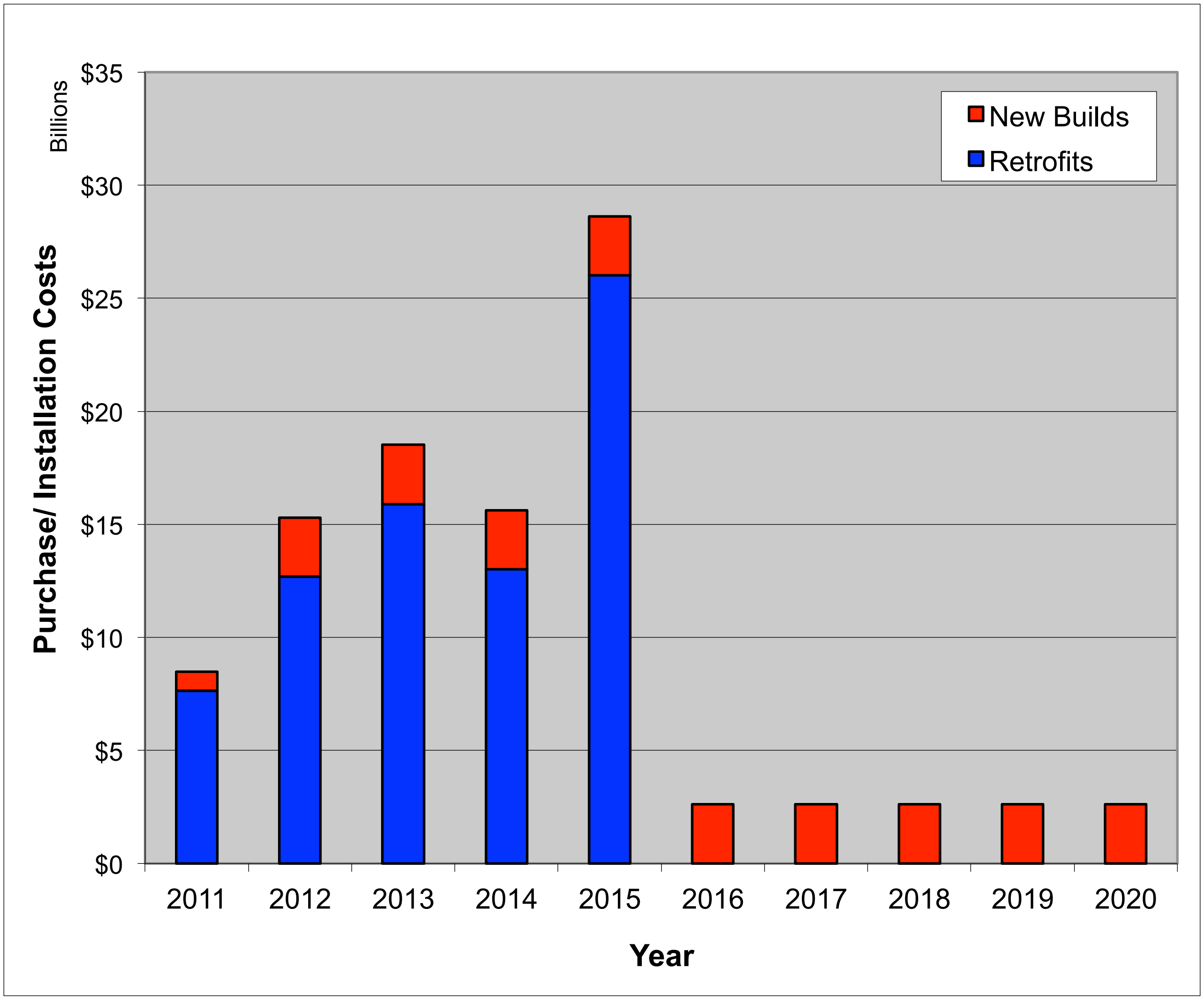


Annual Dollar Value of the Global BWTS Market

Based on the equipment and installation cost estimates developed in Part 2 of this report and the detailed cost analysis presented in a MERC report titled: "Preliminary Analysis of Ballast Water Treatment Costs" (available at http://www.maritime-enviro.org/reports/Reports.html) we determined that for general planning purposes it is reasonable to project that the "typical" cost per ship of purchasing and installing a BWTS will be about $1 million. Based on the number of ships in various ballast water capacity and age categories described above, and the assumptions listed above regarding when ships in those categories are likely to comply with the tiered IMO implementation schedule, we estimate the annual value of the global BWTS market to follow the pattern as shown in Figure 4.

The market is expected to spike in 2015 with annual equipment and installation costs for existing ships and new builds in all ship categories totaling more than $28 billion. In 2016, when the above analysis results in all existing ships having installed BWTS, the global BWTS market is then expected to drop to about $2 billion per year and to remain at that level until 2020 and, presumably, beyond.

Figure 4. Estimated Value of Global BWTS Market: 2011-2020.



Part 4: Affects of Enforcement/Compliance on Emerging BWTS Markets

The sizable global market for ballast water treatment technologies described in the previous section demonstrates the large opportunity for ballast treatment technology vendors. These vendors will be competing with each other to claim a share in this new global market. However, they will also be competing against another factor: ship owners and operators who choose not to comply with regulations, or who delay compliance. In this regulation-driven market, we highlight some significant enforcement issues that regulators in IMO member nations and suppliers of BWTS will face as the ballast water convention comes into force between now and 2016.

There are a number of long-term questions with regard to liability once a BWTS is installed and is operational and pumping water. All of these technologies are in their relative infancy, so the question remains, what if it turns out an approved system doesn't work over time? At least two systems have been running on ships since 2006 or earlier. However, should one of these systems or one used on another ship be found not to be operating properly, will a port regulator's response be to prohibit a ship from discharging ballast? Our interviews indicate that, within the industry, there is little if any questioning of the "magic box" approach to monitoring compliance —if the equipment is turned on and functioning, it should be sufficient evidence that the ship meets regulatory requirements. At this time there is little regulation developed to establish the long-term reliability of systems or methodologies for determining the continued effectiveness of a system. In time, this will likely change and a metric will have to be developed to verify the continued function of an installed system.

In this sense, there is an analogy to the experience with implementation of oil/water-separator regulations in the 1980s. Experience showed that the separators were initially unreliable, but as long as a device passed a standard test, it was considered acceptable. Both technology and enforcement regimes for oil/water separators have evolved since that time, and now there are requirements for more stringent testing as well as requirements for off-site calibration of the oil content sensing equipment. These changes and improvements of the technologies, as well as more meaningful penalties for non-compliance have caused numerous older vessels to be retrofitted with newer oil/water separators even though their existing older units were still functional and may have been considered acceptable under older regulations.

For each of the technologies other than ultraviolet filters, there appears to be a straightforward way to measure effectiveness, such as water temperature or the percentage of chemical in the water. But for UV filters, it is difficult to determine when a filter is not working or has not been working. Is there a method to analyze when a new filter is needed without having to test the BW discharge water? Most importantly, how can a ship owner/operator prove compliance with the IMO guidelines to regulatory inspectors and flag-state officials during routine inspections?

The USCG proposed rulemaking notes that for its proposed (stricter) Phase Two standards, there is not currently a testing protocol capable of establishing that a given technology consistently meets the standard. Because of this uncertainty, USCG has proposed a practicability review to determine whether technology can in fact meet the Phase Two standard, which is potentially 1,000 times more strict than Phase One standards. The USCG proposed rules suggest that an initial review be completed by 2013.

The USCG proposed rules also suggest that a five-year grandfather clause be instituted for those vessels adopting Phase One treatment technologies on schedule. Our initial analysis of the global merchant fleet suggests that this will have little impact (either positively or negatively) on adoption of Phase One technologies.

A key challenge for enforcement of ballast water treatment regulations will be the cost and technical problems that may be associated with verifying compliance. King and Tamburri (2009) assessed the challenges involved with verifying compliance with proposed U.S. ballast water regulations, and applied an economic deterrence model to BW regulations.[9] Noncompliance with U.S ballast water regulations involves discharging ballast water into U.S. waters that does not meet U.S. discharge standards. Assessing enforcement deterrence in this case involves comparing the expected benefits and expected costs of noncompliance under various enforcement regimes, where

Expected Cost = **C** = $\boldsymbol{a}$ x $\boldsymbol{b}$ x $\boldsymbol{c}$ x $\boldsymbol{d}$ x $\boldsymbol{e}$

where:

$\boldsymbol{a}$ = Probability that a discharge violation will be detected

$\boldsymbol{b}$ = Probability of a detection resulting in a citation

$\boldsymbol{c}$ = Probability of a cited violation being prosecuted and resulting in a penalty

$\boldsymbol{d}$ = Average assessed or schedule-based penalty for a violation

$\boldsymbol{e}$ = Average "final settlement" amount expressed as the % of the average "assessed or schedule-based penalty" the ship owner/operator expects to pay.

Expected Benefits = **B** **=** cost savings of not properly installing, operating, and maintaining a certified BWTS.

So, for example, if someone had a…

- 50% probability that a discharge violation would be detected
- and a 50% probability of an enforcement action, if in fact the violation is detected
- and a 50% probability of prosecution, if there is an enforcement action for a detected violation
- and a 50% probability of conviction, if the detected violation is prosecuted…

…then the probability of conviction, if there is a violation, would be .0625 (.50 x .50 x .50 x .50). If the expected penalty is $10,000, then the cost of not complying would be $10,000 x .0625, or $625. If the individual can expect a delay between initial detection and payment of penalty, the $625 cost of not complying could be discounted further.

There is a big gap between proving that ballast water treatment technologies work in the laboratory and in field trials and are "certified," and having full-blown markets emerge that will allow these technologies to be purchased, installed, and employed on vessels in sufficient numbers to meet regulatory timetables or have any significant impact on ballast water management problems.

While it is too early to fully assess and compare the costs and risks associated with implementing available technologies under various circumstances, it is not too early to consider the one treatment option with which all technology vendors are competing: no treatment. To succeed, markets for ballast water treatment technologies, like all other markets, require only two things: willing buyers and willing sellers. However, markets for these technologies are regulation-driven, and the nuances of when and how the regulations are written, implemented, and enforced determines when there will be willing buyers and whether willing sellers will be able to accommodate them.

In the previous section, we outlined the likely pattern of demand over time for ballast water treatment technologies under the assumption that all ships will comply with IMO regulations, once ratified by a sufficient number of countries and percentage of the world's fleet. However, this would require that these regulations be fully implemented, enforced and, most critically, that enforcement provisions provide penalties and/or sanctions that are certain enough and meaningful enough to provide incentives for shippers to comply. What kinds of penalties do we expect, and who will pay?

Role of Protection and Indemnification (P&I) Clubs

The demand-side may also be complicated because of the way shipowners deal with liability issues. An estimated 95% of the global shipping fleet is insured through protection and indemnity, or "P&I" clubs, which are associations of shipowners who share each other's liabilities. In effect, the members of P&I clubs are both the insurers and the insured. There are currently 13 P&I clubs, mostly based in the United Kingdom and Norway.[10] How will liability for penalties for violating IMO BW regulations be distributed across the fleet? How will P&I clubs discipline shippers and/or ship owners and/or ship operators or ship engineers who are responsible for a ship failing to comply with ballast water regulations?

The "mutual" nature of P&I Clubs suggests that there is a joint interest among members in working toward risk minimization, such as a high rate of compliance with ballast water treatment regulations. If something with safety and environmental benefits *also has economic self-interest benefits* for the members, this makes sense.[11]

Owners reluctant to comply with international regulations are less likely to be allowed to join P&I Clubs, and there is reduced incentive to switch clubs because the 13 major clubs also belong to the International Group of P&I Clubs, which spreads the risk among the 13 clubs for larger claims. An agreement between these clubs limits competition by not undercutting rates for a full year after switching from one club to another.

However, the rise of Asian shipping and newly emerging Asian P&I clubs suggests that there might be an incentive for London or Norway-based P&I Clubs to keep these shipowners in the fold by lowering premiums, rather than having new P&I Clubs established in Asia.[12] We estimated the number of ships by flag of vessel that are likely to be subject to IMO ballast water treatment regulations and found that seven of the top eleven flag countries are Asian, representing more than 25% of the vessels we consider to be subject to the regulations (See Table 1b).

Despite the role that P&I Clubs might play in risk minimization, or high compliance with health and safety regulations, some observers have argued that these clubs may play a strong role in the opposite direction in the case of ballast water regulations by spreading the deterrent effect of fines imposed for lack of compliance. A persistent offender of these regulations, for example, might find his "calls" (premiums) rise as a P&I Club member. However, the increase in these "calls" may not be enough to serve as a significant deterrent.[13] If this is the case, chronic noncompliance could be the least cost solution for some ship owners and ship operators to deal with ballast water regulations.

This could be a particular problem if ballast water regulators have difficulty distinguishing between violations that are accidental and those that are intentional. P&I Clubs are unlikely to spread risk of fines for violating regulations, but if a discharge is considered "accidental," the cost of a fine could be covered under some club risk sharing arrangements unless there is evidence of gross negligence. If the "magic box" doesn't work, then blame would be included in an inspection report where a decision will need to be made about how blame should be shared among the vessel owner, the ship master, the responsible crewmember, or the manufacturer or company hired to service the BWTS. If the crew and owner have acted in good faith, but the unit is found to have lost effectiveness, who will bear the cost of repairs or replacement? Additionally, what penalties will be levied against a vessel or owner who does not knowingly violate the standards, but has a unit that is faulty? Of course, competition means that it is still possible for substandard ships to obtain coverage from less discriminating clubs/insurers, but the central question remains: how will P&I Clubs evaluate and share the risks associated with new IMO ballast water regulations.

Despite these caveats, our assessment is that P&I Clubs are positioned to be a positive force for supporting the development of healthy BWTS markets and widespread compliance with IMO ballast water regulations.

Figure 4 outlines some of the possible players involved with compliance with international, national, and state ballast water treatment regulations.[14] Penalties for non-compliance can be expected to be imposed on shipowners and masters, unless it can be demonstrated that there is specific fault assigned to a crew member (who would have little reason to risk such penalties). If there is any incentive to cut corners, it would be by the vessel Master or Chief Engineer who may be looking for cost savings when compared to other ships in his company's fleet.

Figure 4. Ballast Water Liability and Enforcement: Possible Players[15]

- Shipowners and Operators
- Charterers and Cargo Owners
- Masters
- P&I Clubs
- Other Marine and Specialty Insurers
- Classification Societies (IACS)
- Flag States and Open Registries ("flags of convenience")
- IMO
- National enforcement (USCG, EPA)
- State enforcement (i.e., California, Great Lakes states)
- Individual Ports
- Trade associations, i.e., Intertanko
- Databases for tracking compliance (i.e., Globallast, Equasis, NBIC)

Role of Classification Societies

Classification societies are likely to have a significant inspection role in implementing the regulations, particularly through enforcement of the flag-state and IMO requirements. Similar to the P&I club discussion above, most classification societies belong to the International Association of Classification Societies (IACS) which helps eliminate the advantages of ship owners shifting between Societies to avoid regulations. The largest class societies form a more stringent group, colloquially known as "Super IACS", which insures that calls for strict compliance with international standards are uniformly applied across the IACS members.

Regardless of which entity has inspection responsibility, the addition of ballast water treatment technology inspections potentially compounds a problem at times for ship crew distracted by multiple inspections (from insurers, classification societies, ports, etc.).[16] Another open question is the extent to which state and national regulators will be sufficiently staffed to handle inspection regimes that would be required. Sensor technologies may provide the answer to that question.

Flag States will play an important role as well. With open registries ("flags of convenience") financially dependent on foreign ships registering under their flags, they have little incentive to enforce pollution regulations. Similarly, individual ports, even within nations, compete with one another for shipping business. This also may affect their willingness to enforce new ballast water regulations

Trade Associations

Trade associations, i.e., Intertanko, have a possible role in helping members decide which technology to use. With regard to enforcement questions, their members will simply want to know about the easiest way to be in compliance.

Explicit inclusion of ballast water treatment information in global databases might also play an important role in encouraging compliance. Other compliance information on the Equasis website, for example, can be searched not only by ship, but also by fleet manager or operator, which helps the insurer evaluate both the quality of the operator and of the ship.[17]

Alternative Verification Approaches

King and Tamburri (2009) outline three basic alternatives for validating that ballast water meets discharge standards: reporting, monitoring, and measurement. These alternatives have different costs and will result in different levels of confidence that discharge violations are being detected. Their preliminary analysis of alternative verification approaches suggests that verification based on mandatory *reporting and/or inspection* alone will not achieve acceptable levels of confidence that regulations are meeting their goals. Verification based on direct measurements (sampling of ballast water) requires sampling a high enough volume of water to provide an acceptable level of confidence; but it appears that for this option to provide acceptable levels of confidence the amount of ballast water sampling will be prohibitively costly. Verification based on indirect monitoring using sensors appears to be the best alternative, because it has the potential to provide a high level of confidence at a far lower cost than even the lowest-cost, least-reliable biological sampling strategies. The key to this option, of course, is the development of accurate, reliable sensors that can meet enforcement goals and pass, what the USCG is calling a "practicability" test.

Ultimately, the success of any monitoring, reporting, and verification regime will depend on whether detected violations result in penalties and sanctions that are certain and meaningful, and how these sanctions are shared by ship operators, ship owners, equipment vendors, insurance companies and clubs, and other factors.

Conclusions and Recommendations

The global market for ballast water treatment technologies is at a critical juncture. If Panama ratifies the International Maritime Organization regulations, sufficient other countries are likely to follow suit so that the "Phase One" treatment standards will enter into force between now and 2016. The United States of course is a critical player in this regard and with the comment period for the U.S. Coast Guard proposed rulemaking having passed on December 4, 2009, the United States moves one step closer to implementing its own regulations that largely mirror the IMO standards.

Potential suppliers are positioning themselves to meet the high level of global demand for BWTS that is expected to begin once IMO regulations are ratified and it becomes clear that they will be implemented and enforced on schedule by IMO member nations. We estimate that more than 68,000 ships will be subject to the IMO regulations between now and 2016. Many of these ships are relatively small fishing vessels that are not likely to be in a financial position to adopt the technologies that have been approved by IMO or that are close to receiving approval. This suggests that other technologies will be developed to meet this segment of the market. On the other hand, many larger merchant ships will need to install more than one BWTS in order to treat their large volume of ballast water and meet IMO ballast water discharge standards. Some observers are placing the number of ships that will need to comply with IMO ballast water regulations at around 50,000.[18] This may mean that demand for BWTS will be significantly higher than 50,000 units.

Assuming that the regulations receive 100% compliance, our review of the Lloyds Fairplay world merchant fleet database suggests that there will be a spike in demand for treatment systems as vessels attempt to meet Phase One standards for 2016. Whether the system supply capacity will have been developed in time has yet to be determined.

International success in achieving the goal of reducing the environmental and economic risks from harmful aquatic invasive species depend on three factors: 1) the limits regulations place on allowable concentrations of living organisms in ballast water discharge water; 2) the availability of technologies to meet those limits; and 3) the willingness of ship operators to comply with the regulations. A major challenge in understanding the size of the ballast water treatment technology global market is the extent to which regulators will meet their goal of 100% compliance. In this sense, technology vendors are competing with each other, but also with a market share consisting of those shipowners who decide not to comply. Compliance monitoring, measurement, and verification methods require further analysis and development to ensure that the goals of international and national ballast water regulations are achieved.

If enforcement and penalties are significant enough to provide real incentives for shippers to compete with each other to have BWTS installed in anticipation of implementation, will demand for BWTS be spread out enough to avoid supply bottlenecks? How are vendors and shipyards likely to change their pricing strategies as demand grows and begins to outstrip supply and installation capacity? How will their pricing strategies be affected by the knowledge that a spike in demand by the existing fleet to meet Phase 1 standards will be followed by a crash in demand as only newly-built vessels need to install systems in subsequent years? Will the market be driven by expectations of high demand, or of low supply; and will venture capitalists be willing to invest significantly in manufacturing capacity to satisfy a temporary rush in demand for equipment that is predicted based on expectations of strong political will to support a costly international environmental program? If the regulations are successful, will the market crash after the global fleet is outfitted? These questions merit further research, particularly in light of the proposed stricter “Phase Two” regulations anticipated after 2016.

[1] The U.S. Coast Guard Notice of Proposed Rulemaking, “Standards for Living Organisms in Ships’ Ballast Water Discharged in U.S. Waters,” is available at http://openregs.com/regulations/view/99303/standards_for_living_organisms_in_ships_ballast_water_discharged_in_u.s._waters

[2] Sources: http://www.imo.org/TCD/mainframe.asp?topic_id=247
http://www.imo.org/TCD/mainframe.asp?topic_id=248

Last reviewed November 23, 2009, 2009

The 18 countries are as follows: Albania, Antigua & Barbuda, Barbados, Egypt, France, Kenya, Kiribati, Liberia, Maldives, Mexico, Nigeria, Norway, Saint Kitts & Nevis, Sierra Leone, South Africa, Spain, Syrian Arab Republic, Tuvalu.

[3] IMO Resolution A.1005(25) of November 29, 2007 delayed the compliance deadline for 2009-built vessels until the vessel’s second annual survey, but no later than December 31, 2011. Source: California State Lands Commission 2009. See also Ballast Water Treatment Technology: Current Status. Lloyds Register. September 2008; CSLC 2009; IMO Globallast at http://globallast.imo.org/index.asp?page=mepc.htm; and Silent Invaders (World Wildlife Fund 2009) for discussion of ratification timetables.

[4] Sources: http://www.imo.org/TCD/mainframe.asp?topic_id=247
http://www.imo.org/TCD/mainframe.asp?topic_id=248

Last reviewed November 23, 2009, 2009

The 18 countries are as follows: Albania, Antigua & Barbuda, Barbados, Egypt, France, Kenya, Kiribati, Liberia, Maldives, Mexico, Nigeria, Norway, Saint Kitts & Nevis, Sierra Leone, South Africa, Spain, Syrian Arab Republic, Tuvalu.

Of the 35 flags of registration with the largest deadweight tonnage, representing 92% (chk) of the global fleet’s deadweight tonnage, only Liberia, Antigua, Norway, France, and Spain had ratified the convention as of June 30, 2009.

[5] See *Ballast Water Treatment Technology: Current Status*. Lloyds Register: September 2008.

[6] Barges include the following subcategories: Barge, Barge Carrier, Cement Storage Barge, Container Barge, Hopper Barge, Offshore Cargo Barge.

[7] See King, Dennis M., Mark Riggio and Patrick T. Hagan. 2009. Preliminary Analysis of Cost of Ballast Water Treatment Systems for detailed preliminary purchase cost summaries. Available at www.maritime-enviro.org/reports/Reports.html/. Base and bulk prices for different types of units are calculated as averages of quoted purchase prices for that type of system. For Filtration/UV Light, three quotes were received; for Filtration/Chemical, three quotes were received; for Deoxygenation/Cavitation, one quote was received; for Electrolysis/Electrochlorination, three quotes were received. The lowest quote received for purchase of any type of system was $400,000, for one of the Filtration/Chemical systems; the highest quote was $1,670,000, for a Filtration Chemical system from another vendor.

[8] See King, Dennis M., Mark Riggio and Patrick T. Hagan. 2009. Preliminary Analysis of Cost of Ballast Water Treatment Systems for detailed installation cost summaries of ballast treatment systems for these eight categories of vessels. Available at www.maritime-enviro.org/reports/Reports.html/

[9] King, Dennis M. and Mario Tamburri. 2010. Verifying Compliance with Ballast Water Discharge Regulations. Ocean Development & International Law, 1521-0642, Volume 41, Issue 2, pages 152-165.

[10] http://www.intertanko.com/pubupload/protection%20%20indemnity%20HK%202002.pdf

[11] For a discussion of cooperative self-regulation, or co-management, in safety and environmental regulation in the shipping industry, see Bennett, Paul. 2000. Mutual risk: P&I clubs and maritime safety and environmental performance. Marine Policy 25 (2001) 13-21.

[12] See Bennett, Paul. 2000. Mutual risk: P&I clubs and maritime safety and environmental performance. Marine Policy 25 (2001) 13-21.

[13] See "Compliance with Victoria's Ballast Water Management System" in Report on Ballast Water and Hull Fouling in Victoria. Submitted to Parliament by the Environment and Natural Resources Committee. Web site last updated March 1, 2002: http://www.parliament.vic.gov.au/enrc/inquiries/old/enrc/ballast/Ballast-60.htm

[14] For a review of U.S. national and state ballast water regulations, see Read D. Porter and Jordan Diamond, *New Tools for Responsible Shipping in the Great Lakes: Using Financial Responsibility Policies to Prevent Ballast-Borne Biological Pollution*. Environmental Law Institute White Paper. July 2009.

[15] For a detailed discussion of the actors in the regulation of vessel-source marine pollution, see Tan, Alan Khee Jin. 2006. *Vessel-Source Marine Pollution: The Law and Politics of International Regulation*. Cambridge: Cambridge University Press.

[16] See further discussion of this inspection issue in *The World Merchant Fleet in 2007: Statistics from Equasis*. https://extranet.emsa.europa.eu/index.php?option=com_docman

[17] Organisation for Economic Co-operation and Development. 2004. *Maritime Transport Committee Report on the Removal of Insurance from Substandard Shipping.*

[18] See for example Frost and Sullivan report, which suggests a market size of 57,000 vessels or more (http://www.frost.com/reg/file-get.do%3Fid%3D73927%26file%3D1).