ESTIMATING THE AMOUNT OF RECYCLABLE MATERIALS AND WASTES IN DOMESTIC SHIP RECYCLING

Ship recycling is principally a subset of the scrap metal industry. While warships and merchant ships also contain such reusable equipment as diesel engines, galley equipment, pumps, pipes, and valves, about 90 percent of the total value of an old ship in domestic markets is in the metals that can be removed, reduced to mill-grade materials, and sold for remelting and reforming into other metal products. Overseas recyclers, particularly those in Asia, recycle more equipment and materials and use more metals directly without remelting than do U.S. recyclers. Warships and merchant ships contain nearly every form of metal available in worldwide commerce. Ultra-high strength nickel alloys, stainless steel, titanium, and other high-value metals can be found in some parts of nearly all warships, but they are present in such small quantities that recovery and resale are not necessarily cost-effective.

PRIMARY RECYCLABLE METALS

Four types of metals represent the bulk of the scrap-metal value in a ship: steel, aluminum, copper and copper alloys, and lead. Steel remains the most common metal used in the structure of ships, and armor plate is (except in the case of small, specialized craft) the most common scrap species present. Many varieties of steel are used in ships—including high-strength steels, mild steel, stainless steel, and many cast iron forgings—each with its own value in the recycled metal market. We did not have the information necessary to estimate how much of each type can be recovered from each type of ship. We therefore combined all varieties into a single “steel” category.

Some warships use aluminum as the major structural metal in the deckhouse. It is also used in some Navy ships for internal joinerwork bulkheads, deck plates, ventilation ducting, and other services to reduce the overall weight of the ship.

Copper and copper alloys are used in electrical systems in all ships and in seawater pipes and components in many Navy ships. We explored the idea of estimating copper amounts based on installed electric plant capacity but could find no relationship from the available data. Undoubtedly, the 61 diesel electric and turboelectric drive ships in Table A.1 that have large copper-based electric propulsion systems will have notable amounts of copper aboard. However, we found no data to suggest a proper copper recovery fraction for such ships. Because of this, the total copper recovery for the fleet may be underestimated. There also was no consistent rule that would allow us to estimate copper as distinct from its alloys. Both are treated as one aggregate quantity.

Because lead is dense, it is the most common ballast material in warships. However, because it is more costly than other, bulkier ballast materials such as concrete, drilling mud, and water, it is rarely used in merchant ships. Ships may also have many pounds of lead in the form of lead-based paint and solder in electrical equipment, but these forms have little or no value in recycling markets.

Market prices for scrap metals are very erratic, varying widely month by month and by where in the United States the recycler is attempting to sell the scrap.

REUSABLE EQUIPMENT

The value of reusable equipment such as motors and bollards varies widely as well and depends on both the item's market worth and the recycler's resourcefulness in identifying and exploiting the markets.

WASTE MATERIALS

Ships also contain waste materials, i.e., materials that have no value in any domestic recycling market. Wastes can include fabrics, small manufactured items such as switches and motors that cost more to reduce to scrap than the scrap is worth, sludges from tanks, paint flakes, gaskets, thermal and acoustic insulation, and detritus generated during the recycling process.

LIGHT SHIP WEIGHT

We used as-built LSW as the reference figure for estimating the amounts of salable scrap and reusable items and waste materials. The per-ship and total LSWs used in this analysis are presented in Appendix A, Table A.1, along with an explanation of the table's origins and development. The amounts of recoverable scrap and waste are expressed as a percentage of LSW. Use of LSW as the scaling variable is subject to the following four caveats:

1. **Fuels and lubricants.** LSW includes the weight of the ship's entire structure, its hardware, and its propulsion working fluids but does not include the weight of fuel, payload, lubricants, personnel, and personnel effects. Most if not all Navy warships under the cognizance of the Navy's Inactive Ship Maintenance Facilities have had residual fuels and lubricants removed. Some ships under the cognizance of MARAD have fuel and lubricant residuals aboard. The weight of fuels and lubricants is not reflected in the LSWs used in our analysis. MARAD examined three ships in its Retired Ship inventory for the number of tanks full or partly full of fuels or lubricants.[1] Based on the assumption that all tanks with measurable fuels or lubricants are full, the ships in this sample average about 0.2 tons of residuals per ton of LSW.

   The value of residual fuels and lubricants in the domestic marketplace depends on the quantity, purity, and locale of the disposal. Most often, residual fuels and lubricants must be analyzed to determine their purity and hence their market value. Analysis of fuels is itself expensive and often reveals impurities, such as rust and water, that reduce the material's value. Thus, ship owners usually must pay to have the materials removed. At best, an owner can expect no more than $29 per ton for well-pedigreed materials.[2] The ships in the MARAD sample thus would have a residuals value ranging from negative to no more than $6 per ton of LSW. Because there is no consistent way to estimate the amount—short of reviewing individual tank soundings for each ship and analyzing the contents for purity—we did not consider the potential value of residual fuels and lubricants.

2. **LSW growth.** The LSWs listed in Table A.1 are the as-designed LSWs reflected in the references cited in Appendix A. A warship typically grows in weight during construction and its service life by as much as 10 percent above as-built weight as it takes on different missions and mission hardware during its life. Thus, at the end of its service life, a ship will weigh a slightly different amount than nominally identical ships of the same class. This source of error leads to underestimates of actual LSWs by as much as 10 percent. We generally did not include possible LSW growth in the analysis, because it falls within the uncertainty of other factors we used.

3. **Propulsion fluids.** LSWs include up to several tons of propulsion system water that has no economic value. The amount of this water is greater in steam-propelled ships than in ships propelled by diesel or gas turbines. This

[1]MARAD, *Survey of Ships and Materials*, Report MA-ENV-820-96003-E, January 1997, p. 45.

[2]Dollar amount is courtesy of the Fuels Division of Systech Environmental Corporation, Dayton, OH.

factor leads to slight overestimates of the actual weight of valuable materials in a ship. We did not include a correction for this small effect.

4. **LSW loss.** During a ship's service life, corrosion will cause a loss of metal. In U.S. warships, this loss is slight because of the very high maintenance standards commonly employed. However, in merchant ships, corrosion loss during service life can add up to 10 percent or even more.[3] This is because merchant ships typically have large surface areas exposed to weather and sea and because they are less well maintained than Navy ships, particularly during their last five years of life.[4] Additionally, tankers have potentially corrosive cargo. Corrosion loss is seen in a ship's final steel weight measurements during the recycling process; it varies by a factor of two or more from ship to ship depending on the quality of the ship's maintenance during its life. While this factor is important to the individual recycler, we ignored it in our analysis because it is not predictable.

SHIP WEIGHT BREAKDOWNS

To determine the value inherent in a ship's salable scrap species, we need estimates of the amounts of the principal species present in each type of ship. We prepared estimates using data from three key sources:

1. The U.S. Naval Sea Systems Command (NAVSEA) provided estimates of the metals contained in two classes of destroyers, an aircraft carrier, and nuclear-powered submarines.
2. The Naval Institute Press publishes comprehensive histories of U.S. destroyers, cruisers, and aircraft carriers that include weight breakdown data for many types of ships. These weight breakdowns are not by type of metal, but by service in the ship (hull and structure, propulsion, and so forth). This information allowed us to make informed judgments about the amounts of each principal species that would be present. Although not all Navy ship types in Table A.1 were covered, there was enough information to provide a basis for reasonable estimates for all warships.

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[3]Ferrous Scrap Committee, Ministry of Steel, Government of India, *Shipbreaking Industry—Present Status in India and Its Impact on Environment*, Vol. I, August 1997, pp. 2–14.

[4]Commercial ships are required to undergo a comprehensive inspection every three to five years. Normally, at the 20- or 25-year inspection point, owners find that the cost of the inspection and anticipated repairs exceeds the value of the ship on the scrap market, and the ship is sold for scrap. During the last five years of a ship's life, many owners anticipate scrap sale and thus minimize maintenance, which leads to extensive corrosion loss.

3. For merchant ships, we used data from sources describing ship recycling in India and from a MARAD source that estimates the recoverable fractions from recycling of U.S. merchant ships.

The data from these three sources are discussed in more detail in the following three sections.

NAVSEA Data [5,6,7,8]

The data from the NAVSEA sources are summarized in Table B.1.[9] For the destroyers and the carrier, the data include only ship structure and electrical systems. Ballast information is available for the destroyers but not for the carrier. The balance of the "missing" weight in these ships is in propulsion and weapons machinery, habitability systems, and other nonstructural materials, much of which represents recyclable metals nonetheless. The submarine data are complete. The "missing" weight in the submarine data, about 9 percent of the total, represents nonrecyclable wastes such as insulation, floor tiles, and fiberboard scrap resulting from recycling the ship.

Table B.1

Materials Weight Data from NAVSEA Sources (percentage of LSW)

	DDG2	DDG37	DDG Average	CV 59	Submarines
Steel	31	33	32	72	52
Aluminum	5	4	5	0.01	1.4
Copper and copper alloys					
Copper	2	1	3	1	1.4
Brass and bronze	1	1	3	1	7
Cu-Ni	0.3	0.2	3	1	No data
Ballast lead	3	5	4	No data	29
LSW accounted for	41	43	43	73	90.8

[5]Philadelphia Naval Shipyard letter, Ser. No. 93-098, August 12, 1993 (DDG2 data).

[6]Charleston Naval Shipyard letter, Ser. No. 248/261, September 16, 1993 (DDG37 data).

[7]Norfolk Naval Shipyard letter 4010(244.1), 244.1-L2-94, March 31, 1994 (CV59 data).

[8]"U.S. Nuclear Powered Submarine Inactivation, Disposal and Recycling," 1995, submarine data. These data are for recycled nuclear submarines minus their nuclear systems. We use these metal percentages for estimating the materials recovery for conventional submarines in the inactive fleet.

[9]All of the weight data in this table and the tables in the next two sections (i.e., Tables B.1 through B.9) are in long tons (1 LT = 2,240 pounds). Note that the data do not add to 100 percent of LSW.

The 3 percent figure for copper and copper alloys in the DDGs agrees fairly well with the reported recovery of 3.5 percent of LSW (116 tons) from the recycling of the ex-USS *Patterson* (DE1061) in 1999–2000.[10] The same source reports recovery of 461 tons of aluminum, or about 14 percent of the ship's LSW—a figure that does not agree with the *Patterson* results.

Naval Institute Press Data[11,12,13,14]

Tables B.2 through B.6 present the separate data for steam-powered destroyers, steam-powered cruisers, gas-turbine-powered frigates and destroyers, aircraft carriers, amphibious ships, and battleships that were available from the Naval Institute Press sources. Table B.7 summarizes the data by ship type. These data are not by metal species but by Engineering Ship Work Breakdown Structure (ESWBS) in the seven system groups corresponding to the Navy's ESWBS weight control system:

Group 1: Hull and structure

Group 2: Propulsion

Group 3: Electrical

Group 4: Command and surveillance

Group 5: Auxiliaries

Group 6: Outfitting

Group 7: Armament

In a few instances, the Naval Institute Press data included margin allowances (for future weight growth). We included these. Note that the totals in Tables B.2 through B.7 do not always add to 100 percent. This is due to rounding of the entries and the fact that the source data often did not add to 100 percent (no reasons were stated).

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[10]Kristina Henry, "Shipbreaking May Mend Marine Yard," *Baltimore Sun*, May 14, 2000.

[11]Bernard Prezelin, *The Naval Institute Guide to Combat Fleets of the World, 1990/1991*, Naval Institute Press, 1990.

[12]Norman Friedman, *U.S. Destroyers, An Illustrated Design History*, The Naval Institute Press, 1982.

[13]Norman Friedman, U.*S. Battleships, An Illustrated Design History*, Naval Institute Press, 1984.

[14]Norman Friedman, *U.S. Aircraft Carriers, An Illustrated Design History*, Naval Institute Press, 1983.

Table B.2

Materials Weight Data from Naval Institute Press Sources, Steam-Powered Destroyers (percentage of LSW)

ESWBS	DD445 *Fletcher* (2,035 LSW tons)	DE 1040 *Garcia* (2,441 LSW tons)	DD931 *Forrest Sherman* (2,734 LSW tons)	DE1052 *Knox* (3,020 LSW tons)	DDG2 *Adams* (3,277 LSW tons)	Steam DD/DE Avgs.
1: Hull and structure[a]	36	45	35	47	37	40
2: Propulsion	34	14	26	14	25	23
3: Electrical	4	4	4	4	4	4
4: Cmd/surv	3	6	3	7	5	5
5: Aux	9	13	13	13	11	12
6: Outfitting	7	9	8	9	8	8
7: Armament[b]	7	4	10	5	8	7
Margin[c]	—	4	—	—	—	4

[a]For carriers and battleships using the old weight system, hull and structure includes hull fittings and armor.

[b]For carriers, armament includes defensive weapons systems and features needed to accommodate aircraft.

[c]Margin is available only for the DE1040 Class.

Table B.3

Materials Weight Data from Naval Institute Press Sources, Steam-Powered Cruisers (percentage of LSW)

ESWBS	CG16 *Leahy* (5,146 LSW tons)	CG 26 *Belknap* (5,409 LSW tons)	Steam CG Avgs.
1: Hull and structure	45	46	46
2: Propulsion	18	17	18
3: Electrical	4	4	4
4: Cmd/surv	7	7	7
5: Aux	11	11	11
6: Outfitting	7	8	8
7: Armament	7	6	7
Margin	—	—	

Table B.4

Materials Weight Data from Naval Institute Press Sources, Gas-Turbine Powered Frigates and Destroyers (percentage of LSW)

ESWBS	FFG7 *Perry* (2,648 LSW tons)	DD963 *Spruance* (5,826 LSW tons)	Gas Turbine DD/FF Avgs.
1: Hull and structure	47	53	50
2: Propulsion	10	13	12
3: Electrical	4	5	5
4: Cmd/surv	4	6	5
5: Aux	17	13	15
6: Outfitting	12	8	10
7: Armament	4	3	4
Margin	—	—	

Table B.5

Materials Weight Data from Naval Institute Press Sources, Aircraft Carriers (percentage of LSW)

			CV59 *Forrestal*			
ESWBS	CV9 *Essex* (24,074 LSW tons)	CV41 *Midway* (42,215 LSW tons)	Old Weight System (55,587 LSW tons)	New Weight System (55,528 LSW tons)	CV63 *Kitty Hawk* (60,005 LSW tons)	CV Avgs.[a]
1: Hull and structure	81	81	84	68	64	66
2: Propulsion	13	12	11	6	7	7
3: Electrical	N/A	N/A	N/A	2	2	2
4: Cmd/surv	N/A	N/A	N/A	1	1	1
5: Aux	N/A	N/A	N/A	15	14	15
6: Outfitting	2	2	2	6	5	6
7: Armament	4	5	2	2	2	2
Margin	—	—	—	—	7	4

NOTE: NA indicates that weights were not available. By inspection, we concluded that the weights for these three ESWBS groups were included in the ESWBS group 1, hull and structure.

[a]Averages for CVs are based on the new weight system data for *Forrestal* and *Kitty Hawk*. New system weight breakdowns are not available for the older carriers.

Table B.6

Materials Weight Data from Naval Institute Press Sources, Amphibious Ships and Battleships (percentage of LSW)

ESWBS	LPH 9 *Guam* (11,280 LSW tons)	LHA 1 *Tarawa* (25,588 LSW tons)	L-Ship Avgs.	BB61 *Iowa* (43,944 LSW tons)
1: Hull and structure	60	63	62	81
2: Propulsion	5	5	5	10
3: Electrical	2	3	3	N/A
4: Cmd/surv	2	2	2	N/A
5: Aux	15	14	15	N/A
6: Outfitting	10	9	10	1
7: Armament	1	1	1	8
Margin	—	—		—

Table B.7

Summary of Naval Institute Press Ship Weight Data (percentage of LSW)

ESWBS	Steam DD/DE Avgs.	Steam CG Avgs.	Gas Turbine DD/FF Avgs.	CV Avgs.[a]	L-Ship Avgs.	BB61 *Iowa*
1: Hull and structure	40	46	50	66	62	81
2: Propulsion	23	18	12	7	5	10
3: Electrical	4	4	5	2	3	N/A
4: Cmd/surv	5	7	5	1	2	N/A
5: Aux	12	11	15	15	15	N/A
6: Outfitting	8	8	10	6	10	1
7: Armament	7	7	4	2	1	8
Margin	4	—	—	4	—	—

[a]Averages for CVs are based on the new weight system data for *Forrestal* and *Kitty Hawk*. New-system weight breakdowns are not available for the older carriers.

Merchant Ship Data[15,16,17]

Our information on recyclables from merchant ships is from recycling yards in India and estimates made by MARAD for domestic recycling of merchant ships. No actual return data are available from the U.S. recycling industry for small merchant ships. Table B.8 shows the data from Indian recycling. Note that the scrap species are different than those discussed above in that steel is largely recovered as reroll plate: steel plates that are rerolled into new sheet metal products without first being remelted. This is a common practice in Asia but nearly unheard-of in the United States. The nonferrous metals shown in Table B.8 are nearly all copper and copper alloys. Very small amounts of aluminum are also occasionally recovered from merchant ships. The information in the table represents average recovery results from the recycling of approximately 1,700 ships of all kinds at Alang, India, over more than 10 years.

Indian ship recyclers recycle all but about 3 percent of the as-received ship. The difference between this figure and those in Table B.8 represents the amount of a ship's original as-built LSW that is lost to corrosion during its service life. These figures appear in Table B.8's Weight Lost column.

Table B.8

Recoverable Materials Weight Data from Indian Recyclers (percentage of LSW)

Type of Vessel	Reroll Scrap	Melting Scrap	Cast Iron	Non–ferrous Metals	Machinery	Furniture and Misc.	Weight Lost
General cargo	56-70	10	2-5	1	4-8	5	9-15
Bulk carrier	61-71	8-10	2-3	1	2-5	1-5	10-16
Ore carrier	62-69	10	3	1	3-5	5	10-16
Passenger	44-58	10	5	1-2	10-15	5-7	11-17
Oil tanker	72-81	5-7	2-3	1-2	1-2	1-2	10-12
Ore/bulk oil carrier	66-75	8-10	3	1	1-6	1-2	10-13
Naval ships	53-67	10	2-6	1-2	4-6	1-2	15-22
Container ship	63-67	10	3-4	1	5	5	10-13
Fishing vessel	47-67	10	3-8	1-2	2-10	5	12-18
Average	64	9	4	1	5	4	13

[15]Ferrous Scrap Committee, Ministry of Steel, Government of India, *Comprehensive Environmental Impact Assessment and Environmental Management Plan,* August 1997.

[16]Ferrous Scrap Committee, Ministry of Steel, Government of India, *Shipbreaking in India, A Roadmap for Future Development*, undated (circa spring 1999).

[17]MARAD, *The Markets, Cost and Benefits of Ship Breaking/Recycling in the United States*, Report MA-ENV-820-96003-E, January 1997.

The MARAD estimates are for the amount of recoverable scrap species from standard types of MARAD-design merchant ships. These estimates are shown in Table B.9

Table B.9

MARAD Estimates of Recoverable Materials from U.S. Merchant Ships

Scrap Species	Percentage of LSW
Ferrous	93.5
Copper and copper alloys	1
Waste	5.5

ESTIMATING THE AMOUNT OF RECYCLABLE SCRAP SPECIES AND WASTE FROM LSW DATA

By synthesizing the data above, we developed reasonable estimates of both the percentage of scrap metals that can be recovered and the waste produced during recycling. All are expressed as a recovery index in percentage of LSW.

The data above suggest that there are some differences in the recovery rates for different types of ships. We thus decided to classify Navy and U.S. Coast Guard ships in nine categories and MARAD merchant ships in one category:

- Navy and USCG ships
    1. Surface combatants (SC)
    2. Surface combatants with aluminum deckhouses (SCA)
    3. Aircraft carriers (CV)
    4. Battleships (BB)
    5. Submarines (SUB)
    6. Amphibious warfare (AMP)
    7. Auxiliaries (AUX)
    8. Mine warfare (MINE)
    9. Other (OTH)
- MARAD merchant ships (including all other miscellaneous ships)

We used the ship types identified in Appendix A, Table A.1 under Ship Type. For Navy ships, the ship type is one of the nine abbreviations listed above. All USCG vessels are listed as OTH, as are all Navy craft and dry-docks. For MARAD merchant ships and miscellaneous ships, we used the specific MARAD ship type designation (such as T2-S or C3-S-33b), or PRVT if there was no MARAD designation for the ship, or country of origin if there was no other type information available from MARAD.

The available information on waste generation comes from NAVSEA data for submarine recycling (9 percent), the Indian recycling shown in Table B.8 (13 percent), and the MARAD data shown in Table B.9 (5.5 percent). We chose to use the average of these data (9 percent) for the waste generated in recycling all ship types shown in Appendix A, Table A.2.

The recovery indices developed for the scrap species and waste involved in recycling the different types of ships are given in Table B.10. Details on the indices of the various ship types are provided below. These indices were used to determine the scrap metal value of the different types of ships. We assumed that all battleships would become museums and thus did not include them in our working inventory.

Table B.10

Recovery Indices for Ship Types

	Ferrous	Aluminum	Copper and Copper Alloys	Lead	Waste
Surface combatants	79	4	4	4	9
Aircraft carriers	85	1	1	4	9
Submarines	53	1	8	29	9
Amphibious warfare	85	1	1	4	9
Auxiliaries	85	1	1	4	9
Mine warfare	Nil	Nil	Nil	Nil	Nil
Merchant ships	90	0	1	0	9
Other ships	90	0	1	0	9

Surface Combatants

For ferrous scrap weight, we used the sum of the ESWBS weight groups 1, 2, 5, and 7 in Table B.7 averaged over the table's three types of surface combatants adjusted for aluminum and waste generation. We also adjusted the ferrous index to float as necessary to make the sum of all fractions equal to 100. Regarding aluminum, we were advised by NAVSEA that all surface combatants listed in Table A.2 as derived from the *Forrest Sherman* (DD931 Class) employed aluminum deckhouses. *Forrest Sherman* was built in 1955, and only five of the 70 surface combatants in Table A.2 were built before 1955. We concluded that it was adequate to treat all of this class as post-1955 ships and thus applied the aluminum index (4) to all of them. The NAVSEA data, as shown in Table B.1, were used for indices for aluminum (4), copper and copper alloys (4), and lead (4).

Aircraft Carriers

For the CV ferrous index, we used the sum of the Naval Institute Press data in Table B.7 for ESWBS groups 1, 2, 5, and 7, floated as necessary to make the total index equal to 100. This gives a ferrous index of 85. The aluminum estimate for carriers in Table B.1, the *Forrestal*, is surprisingly small (0.01 percent). In most modern warships, aluminum is used for interior joinerwork bulkheads, doors and doorframes, deck plates, and many other services—the goal being to reduce the vessel's overall weight. We estimated that an aluminum index of 1 is adequate to represent these sources. For copper and copper alloys, we used the NAVSEA estimate of 1 percent. We believe this is reasonable for aircraft carriers because their steel hull and structures are truly massive, including armor plate and multiple side protection systems. This mass of steel diminishes the fraction of their total displacement devoted to nonferrous materials. For lead, the average of the data in Table B.1 (4 percent) was used; for waste, 9 percent was used, as before.

Submarines

For submarines, we used the rounded NAVSEA data from Table B.1. This approach may be subject to notable error because nuclear and conventional submarines are very different vessels. However, the nuclear submarine data were the only data available. Because the number of conventional submarines awaiting disposal is small, any errors have little influence on the total recoverable metals represented by the inactive fleet.

Amphibious Warfare and Auxiliaries

For ferrous scrap for amphibious warfare ships, we used the sum of ESWBS weight groups 1, 2, 5, and 7 for these ships in Tables B.6 and B.7, floated as necessary to make the total index equal to 100. Amphibious warfare ships carry large numbers of U.S. Marines. Aluminum is used in these ships in the same manner and extent as in heavily manned aircraft carriers. Therefore, we chose an index of 1 for this specie. Copper and copper alloys were estimated from the ESWBS weight information in Tables B.2 through B.4 and Table B.6. In Tables B.2 through B.4, the sums of the propulsion and electrical ESWBS groups range from 17 to 27 percent of LSW, whereas in Table B.6 these categories add to only 8 percent for amphibious warfare ships. This reflects the smaller propulsion and electrical systems found in amphibious warfare ships compared with surface combatants. We concluded that a copper and copper alloys index of about one-third that of surface combatants, or 1, is appropriate. For lead, we used the same index used for surface combatants.

For Naval auxiliary ships, there are no weight data on which to base recovery fractions. However, we know that many if not all Naval auxiliary ships identified by the Navy or MARAD as being to a Navy design would have been constructed in accordance with "General Specifications for Ships of the United States Navy,"[18] which means standard Navy design practices, such as the use of copper alloys in seawater systems and lead ballasting, would have been employed. Also, as is evident in Appendix A, Table A.1, Navy auxiliaries have power densities in the 100s of tons per shaft horsepower, comparable to Navy amphibious ships. (Warships have power densities in the tens of tons per shaft horsepower.) Based on this evidence, we concluded that the recovery fraction for amphibious ships is also appropriate for Naval auxiliaries.

Mine Warfare

Mine warfare ships are constructed of wood or nonmetallic hulls and nonmagnetic interior equipment made from metals such as copper and certain stainless steels. Their recovery indices are therefore very different from those of a warship or Naval auxiliary.

As of this writing, several of the mine warfare ships recently in the Navy inventory have been disposed of. And in Appendix A, Table A.2, only six such vessels remain, totaling only 4,404 tons of LSW. This constitutes less than 0.2 percent of the total LSW of the ships in Table A.2. We thus decided not include to material recovery from mine warfare ships in this analysis.

Other Ships and Merchant Ships

We treated all other vessels and all merchant ships (including miscellaneous ships) the same. While this may be incorrect for specialized small vessels such as patrol craft and tugboats, there are so few of these and their total LSW is so small (less than 1 percent of the total LSW of the disposal candidates in the analysis) that the error introduced is equally small. Table B.8 shows the recovery of materials during recycling of ships in India. For the average merchant ship, about 82 percent of its LSW is recovered as ferrous species, 1 percent as nonferrous species (mostly copper and alloys), and 4 percent as reusable furnishings. Thirteen percent is lost as waste, and 10 percent of that 13 percent represents corrosion loss relative to as-built LSW. Most of the 4 percent of the LSW that is reusable furnishings is items such as old furniture, window glass, door frames, and floor coverings—items reusable in India but not in the United States and thus that would become waste. As for the MARAD waste estimate, it

[18] NAVSEA S9AAO-AA-SSPN-010/GEN-SPEC, 1983 Edition.

is low compared to other information. We used an overall average figure of 9 percent for waste among all types of ships.

Compared to the Indian data in Table B.8, the MARAD information in Table B.9 shows the same copper and copper alloys recovery (1 percent), no notable aluminum or lead recovery, and proportionally more ferrous scrap (93.5 percent). We concluded that for other ships and MARAD merchant ships, the MARAD metal recovery data are appropriate except that steel recovery was reduced to accommodate the higher waste estimate.

RECOVERY OF MARKETABLE COMPONENTS AND ARTIFACTS

The MARAD information also notes that about 10 percent of the total market value of a scrap ship is in the resale of reusable equipment such as fire pumps and motors, galley equipment, bollards, anchors and anchor chain, and artifacts such as hatch covers (from Liberty ships, made into furniture). In estimating the total value of a ship, this source of revenue is included by dividing the total scrap metal value by 0.9—i.e., ($ value of scrap metal) ÷ 0.9 = ($ total recoverable value of a ship).

SUMMARY OF RECOVERY INDICES

Indices for recyclable materials and waste recovery were developed for the Navy and MARAD vessels in Appendix A, Table A.2, using Navy and MARAD documentation and published literature. These indices, shown in Table B.10, were then used to determine the scrap metal values for recycled ships.

THE VALUE OF SCRAP METAL[19]

The values used for the calculations are shown in Table B.11 in dollars per long ton and, for all but steel, dollars per pound. After applying these prices to the recoverable scrap metal fractions of each type of ship and dividing by 0.9 to account for the value of equipment sold for continued use, we found that for domestic recycling the average Navy ship has a recovery value of $88 per long ton and the average merchant ship has a recovery value of $64 per long ton. These are average values based on recent prices for scrap metals. The prices for all metals are near their decade-long low. If prices go up, the recovery value of a ship could double; if they continue to decline, recovery value could drop even further. Table B.12 summarizes the average recoverable value from Navy and

[19]Appendix D addresses scrap prices in detail.

Table B.11

Average Value of Recovered Scrap Species

	Steel	Aluminum	Copper and Copper Alloys	Lead
$/long ton	53	725	972	213
$/pound	N/A	0.324	0.434	0.095

Table B.12

Average Recoverable Value of Ships in Domestic Recycling

	Weighted Avg. $/Ton	
Material	Navy Ships	Merchant and Other Ships
Steel	44	48
Aluminum	11	0
Copper and copper alloys	16	10
Lead	8	0
Total scrap metal	79	58
Equipment	9	6
Total	88	64

merchant ships based on the selected scrap prices. The totals do not add because of rounding.

SUMMARY AND CONCLUSIONS

Steel is the dominant scrap species in recycling Navy and MARAD ships, so the market value of scrap steel, presently at a low level, is the major determinant of a ship's value. For Navy ships, copper, aluminum, and lead are important contributors to value. In merchant ships, however, steel is the single dominant species, the value of copper is more modest (about 16 percent of steel value), and there is no aluminum or lead of note. The total estimated average value of the recoverable species from recycling is $88 per long ton for a Navy ship and $64 per long ton for a merchant ship, and each of these values vary by as much as ±50 percent in as little as a year.