Appendix C

Current and Advanced Technologies for the Ship Breaking/Recycling Industry

Report No. MA-ENV-820-96003-C
Contract No. DTMA91-93-C-00004

U.S. Department of Transportation

Maritime Administration

July 1997

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EXECUTIVE SUMMARY

The domestic ship breaking/recycling industry is presently small with a few recyclers relying on hulls of former U.S. Navy warships to stay in business. On average, 55,000 tons of these ships are scrapped yearly at a few sites along the nation's coasts, using simple cutting torches and metal shears. Navy ships represent a small part of the 80 million ton per year national scrap steel recycling industry. While an additional 360,000 tons per year of U.S.-flagged commercial ships are scrapped each year, until recently all have been exported overseas, where scrap prices are higher, ship recyclers are unburdened by strong environmental regulation, and labor is inexpensive.

The practice of exporting U.S. ships for recycling has changed, however. Prohibited levels of polychlorinated biphenyls (PCBs) in plastic and rubber materials have been found in Navy and Maritime Administration ships (References 4 and 5), and it is likely that PCBs are present in all U.S. ships. The U.S. Environmental Protection Agency (EPA) has already banned the export of Navy and Maritime Administration ships for recycling, in keeping with the U.S. prohibition on export of PCBs (Reference 3), and may soon do so for all U.S. ships. This forces more ships to be recycled here, but the PCBs and other hazardous materials will further add to the cost of recycling, seriously affecting the profits of the industry (Reference 6).

Foreign nations are not silent on the question of environmental problems with old ships. Recently, the Indian Government has expressed concerns with hazardous materials in old ships that are being brought in for recycling. International attention to the problems of trade in hazardous materials continues to grow, as evidenced by the ratification by 93 nations (the United States is not among them) of the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal, which places strong restrictions on the practice (Reference 2).

In this light, this report summarizes the technology presently employed in the domestic ship breaking/recycling industry, reviews examples of new and developmental technologies for their potential to help the industry, and presents a notional idea of a fully modern domestic ship breaking/recycling yard that employs appropriate current and new technologies to recycle ships while properly handling the wastes. The yard would incorporate large, modern shears, conveyors to move metal, shredders and separators, modern hand-held cutting tools, modern waste processing facilities, integrated market planning, and most important, a single set of environmental rules and regulations that put forth a cohesive and effective, but not excessive, environmental control, monitoring, and reporting scheme.

To select the appropriate technologies and develop the needed regulatory scheme, it is recommended that a demonstration project be established. The technologies and the regulatory approaches that prove successful in this demonstration project could be made available for utilization by the metal recycling industry. This could influence the technological and regulatory development of other industries as well.

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APPENDIX C

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LEGAL NOTICE

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1.0 INTRODUCTION

This and the other reports in this series (References 1, 2, 3, 4, 5, 6, and 7) provide technical, environmental, and cost/benefit evaluation of ship breaking/recycling technologies in the United States. The purpose of the project is to provide to the U.S. Department of Transportation Maritime Administration (MARAD):

- A survey of environmental problems encountered when breaking typical MARAD vessels, accomplished through appropriate testing and analysis of candidate ships;
- A survey of currently available and advanced technologies for effective removal, handling, and disposal of hazardous materials resulting from ship breaking/recycling;
- A survey of current federal, state and local environmental laws and regulations applicable to ship breaking/recycling;
- A baseline economic case for cost-effective ship breaking/recycling in the United States; and
- An environmental assessment for government ship breaking/recycling in the United States that satisfies the National Environmental Policy Act (NEPA).

This report addresses the second of these items, describing current technologies used for recycling ships in the United States and in some foreign countries, and describing and evaluating available new and advanced technologies which might be employed to improve the domestic ship breaking/recycling process.

Information in this report was gathered from interviews with persons in 11 U.S. firms involved in metals recycling, including several who are or were ship recyclers. The three most active firms were visited. Additional information was obtained and reviewed from over 30 product development organizations and manufacturers engaged in the development of innovative technologies that may have application to ship breaking/recycling. Appendix 1 contains a list of organizations and manufacturers that were interviewed or visited, and whose literature was reviewed.

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2.0 BACKGROUND

2.1 THE RECYCLING PROCESS

Ship breaking/recycling (also called shipbreaking or ship scrapping) produces several grades and types of scrap metal, some reusable components such as galley equipment and diesel engines, and, on occasion, artifacts such as portholes for the consumer market. The process can be thought of as having three distinct elements: the recovery of materials, the sale of materials, and waste management.

2.1.1 Recovery of Materials

The recovery of materials, i.e., cutting the ship apart, can be done with the ship either afloat or in a drydock. Drydocks, which are expensive and more profitably engaged in ship construction or repair, are not used unless necessary. Surface ships are often recycled afloat, since much of the ship's structure is well above the waterline and the hulk can be kept afloat as the work proceeds.

Recycling afloat begins with removal of fuel and other liquids and the removal of the ship's propeller(s) (to make it easier to pull the hulk ashore as scrapping proceeds). The interior of the ship is stripped of small articles that will fit through hatches. The uppermost decks (the superstructure) and systems are cut off first, using cutting torches, saws and shears (discussed in Chapter 3), followed by the main and lower decks. Large, reusable components are removed as they are made accessible. As the weight of the structure and machinery is removed, the remaining hulk floats higher and higher until nothing but the lowest regions of the hull remain afloat. This is then pulled ashore and cut up. Figure 1 illustrates the recycling process.

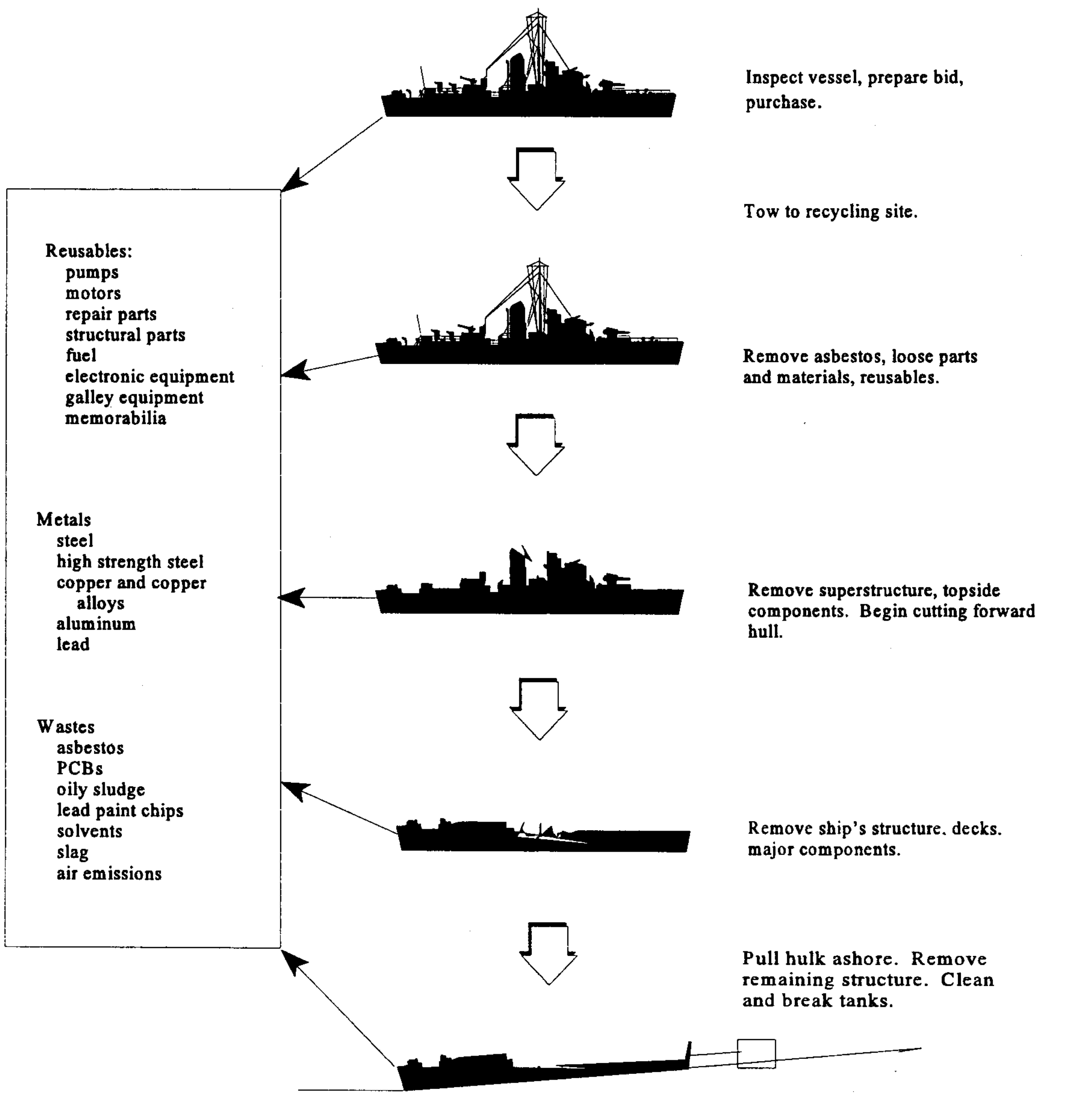
Submarines are recycled at Puget Sound Naval Shipyard (PSNS) in drydocks. The ships are opened circumferentially (and at other suitable locations in the hull), and components and structure are removed as the hull is cut apart. The process, which is a special case, will not be covered here in detail but is described fully in U.S. Naval Nuclear Powered Submarine Inactivation, Disposal, and Recycling, March 1995, (Reference 8).

2.1.2 Sale of Materials

Scrap metal, principally steel, is the primary economic resource in recyclable vessels. Metals are sorted by grade and composition and sold to smelters or to scrap metal brokers. Some recyclers operate mini-mills where the metals are remelted and formed into new products.[1]

[1] Personal communication, MSCL Inc. (Burritt) and Schnitzer Industries (Zelenka), June 15, 1995.

Figure 1
Ship Recycling Sequence



Some components are resold for service elsewhere. Reusable materials and equipment are sold directly with little or no refurbishment at the recycling yard.[2] Ship propulsion machinery that is certified to be in conformance with the requirements of a recognized classification society, such as the American Bureau of Shipping, may be resold at a premium price for use in other ships if not obsolete or worn out. (Uncertified machinery is usually sold as scrap metal.)

Other than small craft and barges that are uneconomical to export, only U.S. Navy warships and submarines have been domestically recycled in recent years. After removal and disposal of the reactor compartments, the U.S. Navy has recycled the remains of up to 20 submarines per year, producing up to 30,000 tons of iron and steel scrap and another 14,000 tons of assorted metal scrap such as lead, copper and aluminum. Navy surface ship sales to domestic scrappers have averaged about 55,000 tons per year since 1990, representing about 30,000 tons of iron and steel scrap and 25,000 tons of other metals.[3]

From 1990 to 1995, an average of about 360,000 tons of U.S. commercial ships were sold yearly for scrap, all overseas. Of this, about 250,000 tons were privately owned ships and the balance, MARAD ships. Had all of the commercial ships been scrapped in the United States, they would have represented from 1 to 2% of the domestic iron and steel scrap market.

The value of the metals recovered from ships varies with the market price. Copper and copper alloys, for example, represent a small fraction of the total weight of the metals recovered from a ship, but return a large fraction of the revenue because of their high value.[4] Table 1 lists the approximate relative value of the metals and reusable components recovered from recycling U.S. Navy destroyers and submarines.

These issues are discussed in detail in Maritime Administration, Report MA-ENV-820-96003-F, *The Markets, Cost and Benefits of Ship Breaking/Recycling in the United States*, July 1997.

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[2] Personal communication, MSCL Inc. (Rushworth) and Wilmington Resources Inc. (Tomlinson), October 5, 1995.

[3] Courtesy of Mr. Glen A. Clark, Naval Sea Systems Command, March 29, 1996.

[4] The *Iron Age Scrap Price Bulletin*, March 25, 1996, cites scrap prices for iron and steel scrap ranging from $15 to $202 per ton depending on scrap quality, dimensions, and location. The dealer's price for copper is cited as $0.82 per pound ($1837 per ton).

increasingly expensive environmental requirements.[10] Since that time, nearly all domestic commercial ships have been exported overseas for recycling, and the remaining domestic recyclers have been left with small vessels, barges, oil rigs, and former U.S. Navy and other government vessels that, for reasons of security, potential military value, or government policy, must be scrapped in the United States.[11] Nine organizations in the United States—eight private firms and one government yard—remain active in the recycling of Navy vessels.[12]

The practice of exporting ships overseas may be changing, however, because of environmental problems. Beginning in 1989, the U.S. Navy began finding that many nonmetallic materials such as gaskets, electric cables, and rubber parts in Navy warships contained PCBs at concentrations in excess of the amount the U.S. Environmental Protection Agency (EPA) allows in domestic or overseas commerce.[13] Similar materials have been found in U.S. Coast Guard ships, and References 4 and 5 confirm their presence in three typical old MARAD ships. This discovery has recently brought a halt to the export of MARAD vessels for recycling. Eventually this may provide additional hulls to domestic recyclers, but as of this writing, MARAD has not yet decided the future course of its ship disposal program.

2.3 FOREIGN SHIP BREAKING/RECYCLING

The focus of this report and the others in this series is the domestic U.S. ship breaking/recycling industry. However, foreign competition is partly responsible for the decline of the industry.

In past years, ship breaking/recycling firms in Asia have bought most of the U.S. ships destined for recycling.[14] Many Asian countries need a source of metals for their developing industries but are burdened with old, inefficient steel production plants. As shown in Table 2, for example, many steel plants in India use more than twice the amount of energy to produce a ton of steel from iron ore as do modern plants in developed countries.

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[10] From *New Steel Magazine*, February 1995.

[11] Borsecnik, *Scrap Processing and Recycling Magazine*, May/June 1995, pp. 63.

[12] Puget Sound Naval Shipyard, Bremerton WA; Seawitch Salvage Co. Inc., Baltimore MD; Wilmington Resources Inc., Wilmington NC (recently re-formed under the name Sigma Recycling); The Best Group, Brownsville, TX; Transforma Marine, Brownsville, TX; International Shipbreaking, Brownsville, TX; Saber Steel, Brownsville, TX; Northern Marine, Portland, OR; and Peck Iron and Metal, Richmond, VA are active as of this writing. New firms often are formed when recycling opportunities arise. Other naval shipyards perform partial recycling of some Navy submarines prior to final recycling at PSNS.

[13] Generally, levels of PCBs at or above 50 parts per million by weight in any liquid or solid (40 CFR 761).

[14] Borsecnik, *Scrap Processing and Recycling Magazine*, May/June 1995.

Table 2. Comparison of Energy Requirements for the Production of Steel from Ore

Country	Average Gigacalories Consumed per Ton of Steel Produced
Japan	4.01
Germany	5.20
Korea (Pohang plant)	5.21
United States	6.00
India (Bhilai plant)	8.90
India (Bokaro plant)	10.81
India (Pourkela plant)	11.12
India (Durgaphur plant)	11.45

Source: World Resources Institute, *World Resources, 1994-1995*, Oxford University Press 1994.

Asian ship breaking/recycling firms have several advantages:

- A ship is a very competitive source of scrap. An old freighter containing 8,000 tons of recyclable steel and 1,000 tons of other recyclable metals might be purchased for about $800,000 ($90 per ton) and towed to Alang, India (a large shipbreaking site) for an additional $500,000—a total of $1.3 million. For about the same price, an Indian importer would be able to purchase and import 8,000 tons of processed scrap steel, with no copper or other valuable metals.[15]

- Labor to break the ship is inexpensive, no more than $3 per day (at current exchange rates) in India, compared to about $112 per day in pay, benefits, tax and other burdens for a U.S. counterpart.

- There are lower costs for protection of the environment and worker safety. The standards are not as stringent as those in the United States, as discussed in Reference 2.

[15] Estimates courtesy of Wilmington Resources, Wilmington, NC; and Jacobson Metal Company, Chesapeake, VA.

- There are large demands for rerolled products such as concrete reinforcing bar made directly from plate steel recovered from vessels.[16]

- Despite working conditions that most U.S. workers and employers would find unsatisfactory and even illegal, ship breaking/recycling provides employment opportunities in countries where unemployment is high.

2.4 CONCLUSIONS

The low scrap prices in the early 1980s, together with escalating environmental requirements, forced out much of the domestic ship breaking/recycling business. Scrap prices recently have risen[17] while, at the same time, environmental problems have restricted export of MARAD ships. These new trends suggest that the industry may recover, particularly if cost-effective solutions to environmental problems can be developed and new technologies can be employed to overcome high labor costs.

[16] Ibid.

[17] The U.S. Geological Survey Mines FaxBack for Iron and Steel scrap reports that the U.S. average price for No. 1 heavy melt scrap has risen from $83.88 per ton in 1992 to $130.00 per ton in 1995.

3.0 CURRENT TECHNOLOGY AND PROCESSES USED FOR DOMESTIC SHIP BREAKING/RECYCLING

3.1 GENERAL

The key technologies and technical processes currently used for ship breaking/recycling are discussed below. All of the technologies that are described are available from a number of competing manufacturers. The report focuses on the technical aspects of ship breaking/recycling that may be notably improved by a new technology. Background technology, such as electric power production and distribution, is not assessed.

The report is organized to follow a ship through the recycling process, from arrival and initial preparation for metal cutting to final disposition of the wastes.

3.2 CUT-LINE PREPARATION AND CLEANING OF SURFACES

Many interior surfaces in ships are coated with insulating materials and layers of paint and insulation adhesives. These materials must be removed before cuts are made in order to avoid fires, the formation of toxic combustion products, and the release of insulation dust.

During recycling of Navy surface ships, manual removal of thermal insulation and combustible materials in the way of cut lines is sufficient. However, the interior surfaces of submarines are often coated with layers of anti-sweat insulation, adhesives, paint, and sound dampening materials that not only are flammable but also are contaminated with PCBs that form highly toxic dioxin and furan fumes when heated.[1] Therefore, very thorough cleaning is performed before cutting.

Having tried solvents, needle guns, scrapers, grinders and many other methods, Puget Sound Naval Shipyard has found grit blasting to be the most effective. Many different grits have been tried, including minerals, steel shot, and steel grit. The most effective is steel grit. Sand and mineral grits are the least expensive per pound and are efficient cleaners but they degrade to dust during one use, add to the waste volume, and may expose workers to harmful sand or mineral dust. Steel shot is dangerous for workers to walk on and tends to peen surfaces and entrap contaminants rather than cut cleanly to bare metal.[2] Table 3 compares the characteristics of some grits that were tried.

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[1] Dioxin and furan compounds are both extremely toxic products of the incomplete combustion of many chlorine-containing organic materials, particularly PCBs.

[2] Personal communication, MSCL Inc. (MacKinnon) and PSNS (Kelly), September 20, 1995.

Table 3. Comparison of Blasting Grits

Grit	$/lb	# Cycles	Safety
Sand	0.01	1	Dust Hazard
Black Beauty	0.42	1	Dust Hazard
Steel Shot	0.48	>10	Slip Hazard
Steel Grit	0.50	>10	-----

Steel grit blasting is also used to clean parts that are coated with PCB paints or residues before they are cut or remelted.

Steel grit is suitable for use in closed loop systems. The used grit and debris are fed as they are generated to a recovery system where the debris is separated and the grit returned to the blast gun. The system reduces the volume of grit needed and the volume of waste to be disposed of, and precludes the need for a separate system for separation of grit from the waste. A typical system is illustrated in Figure 2.[3]

Typical systems will blast 60 to 250 square feet per hour, depending on the nozzle size and the amount of air provided. A system that feeds four blasting nozzles costs about $20,000 and will last at least 20 years. There is no required periodic maintenance other than blast tip replacement.

3.3 SECTIONING AND LIFTING

The steps to reduce a ship that is several hundred feet long to small pieces, suitable for remelting furnaces, must be carefully planned to minimize cost. The number and size of the pieces that can be cut from a ship, the number and capacity of cranes and forklifts available to move them off the ship to processing stations elsewhere in the yard, the capabilities of the processing stations to cut up and sort the metals, and the capacity of the rail car or truck loading systems must all be coordinated so that the materials flow smoothly through the process with minimum labor and without delays along the way. Each recycler must decide how best to coordinate his or her process. Labor pay rates afloat and ashore, crane capacities, the availability of laydown areas where further cutting can be performed, the vessel size, railroad siding capacity, and many other factors affect the decisions. One recycler has found it most economical to section ships into large pieces weighing up to 30 tons and move them ashore for further reduction, sorting, staging

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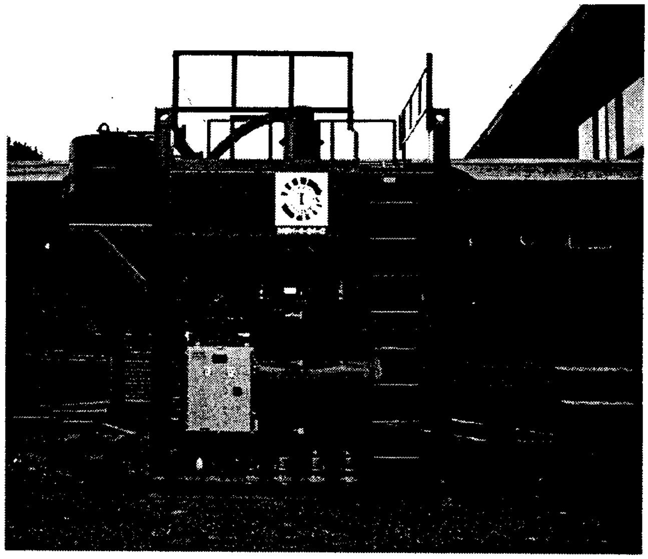
[3] Courtesy of Safe Systems Inc., Kent, Washington.

Figure 2. Mobile Steel Grit Blasting System



and rail car loading.[4] Another cuts the ship directly into small pieces aboard t available space on the hulk for sorting and staging.[5] A third found that cuttin about 20 tons permitted large forklifts to perform many of the movements, rel the process theretofore caused by the limited speed of the overhead crane syst

A wide variety of heavy lift equipment can be employed. Railroad cranes, mc cranes, forklift trucks, and loaders are available from many domestic and fore

3.4 METAL CUTTING

Metals are cut with a variety of torches, saws, and shears. Oxygen-fuel torche types of steel operate on the principle that iron, when sufficiently hot, reacts v oxygen, releasing heat that forms molten oxides and melts the metal itself. Ele arc cutters generate temperatures high enough to liquefy almost any metal and excess oxygen in the manner of oxygen-fuel torches. Mechanical cutters such operate on the same principle as household saws and scissors, but on a larger s the torches, saws, and shears that are currently in use at domestic ship recycle turn.

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[4] Personal communication, MSCL Inc. (Rushworth) and Wilmington Resources Inc. (Tomlin

[5] Personal communication, MSCL Inc. (Shaw and Burritt) and Seawitch Salvage Company, I

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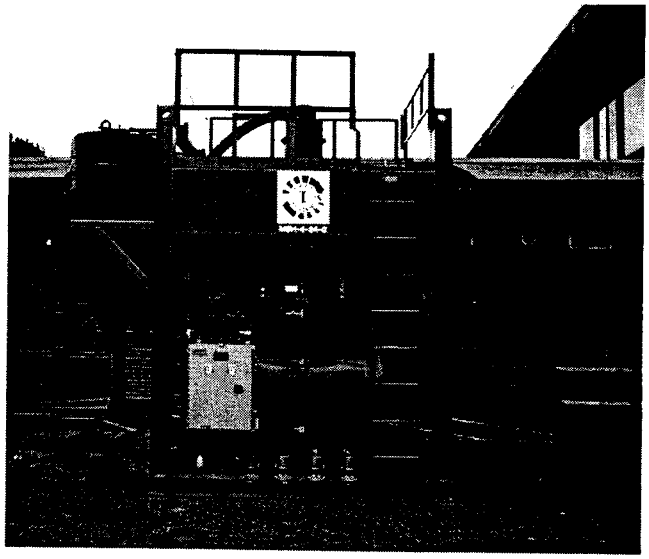

and rail car loading.[4] Another cuts the ship directly into small pieces aboard the ship and uses available space on the hulk for sorting and staging.[5] A third found that cutting pieces limited to about 20 tons permitted large forklifts to perform many of the movements, relieving a choke in the process theretofore caused by the limited speed of the overhead crane systems.[6]

A wide variety of heavy lift equipment can be employed. Railroad cranes, mobile (crawler) cranes, forklift trucks, and loaders are available from many domestic and foreign manufacturers.

3.4 METAL CUTTING

Metals are cut with a variety of torches, saws, and shears. Oxygen-fuel torches used on many types of steel operate on the principle that iron, when sufficiently hot, reacts vigorously with oxygen, releasing heat that forms molten oxides and melts the metal itself. Electric arc or plasma arc cutters generate temperatures high enough to liquefy almost any metal and also can employ excess oxygen in the manner of oxygen-fuel torches. Mechanical cutters such as saws and shears operate on the same principle as household saws and scissors, but on a larger scale. Examples of the torches, saws, and shears that are currently in use at domestic ship recyclers are discussed in turn.

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[4] Personal communication, MSCL Inc. (Rushworth) and Wilmington Resources Inc. (Tomlinson), October 5, 1995.

[5] Personal communication, MSCL Inc. (Shaw and Burritt) and Seawitch Salvage Company, Inc. (Ellis), July 19, 1995.

[6] Personal communication, MSCL Inc. (MacKinnon) and PSNS (Kelly), September 20, 1995.

3.4.1 Oxygen-Fuel Torches[7]

Modern oxygen-fuel cutting torches are the tool of choice for cutting steel. Torches burn a wide variety of fuel including acetylene, propane, butane, fuel gas, natural gas, and MAPP® (methoxyacetylene dipropane) and use either oxygen or liquid air as the oxidizer and "cutting gas" that serves to burn (oxidize) iron along the cut line. Oxygen-fuel torches operate with a flame temperature of 3,500° to 4,000°F and flame velocities of 290 to 425 feet per second. When cutting steel, the torch flame heats the cut line to red-hot temperatures (about 1400°F). Excess oxygen is then injected into the flame to chemically react with iron, form molten iron oxide (that melts at a lower temperature than steel) and blow the molten mass away from the cut line (the kerf). Cutting speeds for 3/4-inch steel range from 17 to 26 inches per minute depending on the fuel, oxidizer and torch tip chosen.

The technology of oxygen-fuel cutting torches is highly developed. Dozens of different styles of torches and torch tips are available depending on the type and supply pressure of the fuel and oxidizer, the thickness of metal to be cut, and the environment where the work is done. For very thick metal, separate long hollow tubes (lances) are used to feed oxygen to the kerf, which is heated by a separate torch. Figure 3 illustrates typical torch tip configuration, and Figure 4 a typical oxygen-fuel cutting torch.

Figure 3. Typical Oxygen-Fuel Cutting Torch Tip Configuration

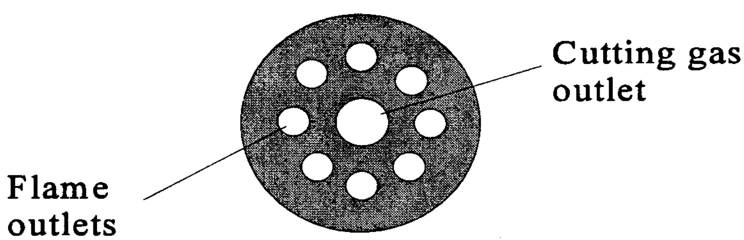
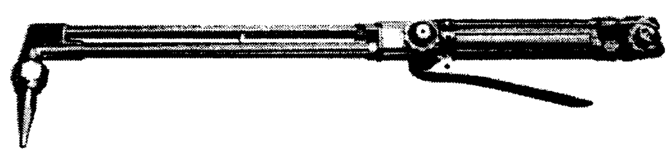


Figure 4. Typical Oxygen-Fuel Cutting Torch



[7] Much of the information in this section is from Althouse et al., *Modern Welding*, the Goodheart-Willcox Company, Inc., 1988.

Acetylene and propane are popular fuels. Table 4 compares the key features of an acetylene and propane torch system.[8] Although propane torches cut more slowly than acetylene torches because propane does not burn as hot, propane is much less expensive and is the fuel of choice in most modern domestic ship breaking/recycling yards. PSNS has found that MAPP® gas, which burns almost as hot as acetylene, is best for cutting the thick steel of submarine hulls.

Table 4. Oxyacetylene and Oxypropane Torch Characteristics

	Acetylene	Propane
System Purchase	$350 to 600	$350 to 600
Fuel Cost (per hour of operation)	$6.00	$3.20
½ Steel Cutting Rate	20-24 in/min	18-22 in/min

Acetylene torches cannot be operated continuously as can propane or MAPP® torches. Acetylene gas is dissolved in acetone, and when withdrawn from the cylinder, the acetone chills, acetylene pressure gradually falls, and within an hour the gas pressure is too low for the torch. An hour's wait will warm the cylinder and restore pressure, but work is delayed. A large manifold acetylene system can overcome this problem, but the higher fuel cost of acetylene has driven the industry to propane.

Both liquid and compressed oxygen are used to provide oxygen to oxygen-fuel torches.

Torch cutting releases large amounts of metal fumes and smoke to the atmosphere. Under present environmental and safety rules, it is not heavily restricted; however, recent changes in the Clean Air Act, discussed in References 2 and 3 may lead to increased restrictions on such emissions.

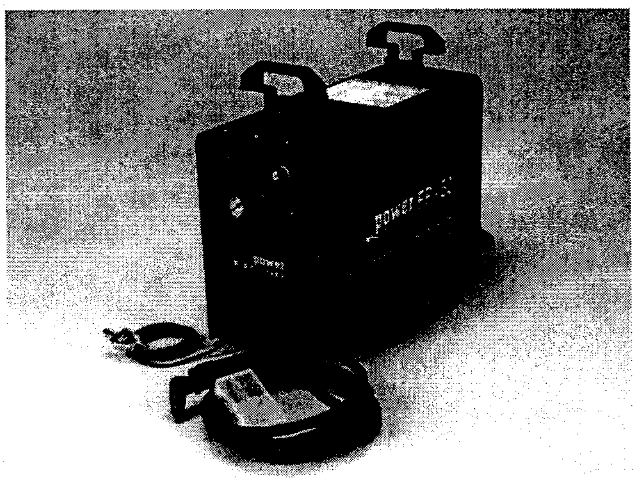
Oxygen-fuel torches are effective for cutting steel. Metals that form oxides that do not melt at a temperature less than the base metal, such as copper nickel, are difficult to cut with these torches. With practice, an operator can learn to manipulate the torch to blow away molten metal and blow off oxide deposits as they form and successfully cut such metals, but the process is slow. Also, powdered iron or aluminum can be fed to the kerf through special torches to react with the oxygen and form desirable low-melting oxides; however, these systems suffer from frequent clogging of the tip orifice through which the powdered metal is injected. These and other adaptations of the oxygen-fuel torch system have been developed to cut nearly any metal, but the cutting rates are often slow, and other cutting methods, such as plasma arc torches or saws, are normally used instead.

[8] Courtesy of Victor Equipment Company, Denton Texas.

3.4.2 Electric Arc Torches

Electric arc torches generate heat for melting metal by the discharge of electric arcs. Two different approaches are used: 1) an electric arc is struck between the metal to be cut and an electrode in the torch handle generating heat in the metal, or 2) an electric arc is struck inside the torch head and heats a "shield gas" to extremely high temperatures, forming a plasma which jets from the torch handle and heats the metal to be cut. In some applications, the latter approach adds an arc between the torch handle and the metal being cut, combining both principles. Electric arc torches can generate extremely high temperatures and can melt and cut almost any metal. A typical plasma arc cutting system, employing air as the cutting gas, is illustrated in Figure 5.

Figure 5. Air Plasma Arc Torch System



Automatic electric arc torches used for cutting metals in production lines can be optimized to cut very rapidly: up to 140 inches per minute on 0.25-inch-thick steel. Manual torches are much slower than oxygen fuel torches in typical ship breaking/recycling environments, cutting at rates of no more than 10 inches per minute. However, they are able to cut any metal with equal ease. A cutting gas is required to blow away the molten metal, and air is often used. Oxygen will speed the cutting rate of steel by the same iron-oxygen reaction that occurs with an oxygen-fuel torch, but both air and oxygen attack the electrode, shortening its life. Electrode life can be prolonged by using argon for the cutting gas, but cutting of steel is slower and argon itself is more expensive. Carbon electrodes are often used, but hafnium is coming into use with air and oxygen gas. Tungsten is often used with inert cutting gas.

A plasma-arc torch system costs from $10,000 to $15,000 and consumes from 9 to 17 kilowatt-hours of electric energy per hour. At a cost of about $0.07 per kilowatt hour (Virginia Power), a plasma-arc torch will consume up to $1.20 per hour of electricity.

Aside from a slow cutting rate, there are other limitations inherent in plasma arc systems:

- High voltage DC (direct current) provided to the electrodes suffers from pronounced I^2R losses (electric resistance heating) if the cables are over 15 feet long.

- The torch handle must be held at a constant, nearly perpendicular angle with respect to the surface of the metal being cut and for this reason is difficult to use on the corners and curves that are frequently encountered in ship breaking/recycling.

3.4.3 Underwater Cutting

Underwater cutting is sometimes required to remove propellers and propeller shaft supporting structures so that a ship can be more easily pulled ashore during the terminal stages of recycling. Underwater cutting systems use the same principles described above, except that the kerf is "shielded" by high-volume air blankets to keep water momentarily away. Oxygen-fuel underwater torches often use MAPP® gas because it can be delivered at a higher pressure than acetylene (to overcome the back pressure of the water) and burns hotter than propane.

3.4.4 Metal Cutting Saws

A variety of electric power metal cutting saws are available, including those with circular and reciprocating blades. Both types are capable of cutting nonferrous metals up to 2 inches thick at rates ranging from 36 inches per minute for 1/4-inch-thick metal to 20 inches per minute for 1-inch metal. Saw drivers cost from $200 to $1000 each, run on 110 or 220 volt AC power and last indefinitely with care.[9] Blades must be replaced every few weeks of use but are inexpensive, ranging up to $40 each. Saws can be used only on nonferrous metals. Frictional heating of the cutting edge of the blade on ferrous metals will cause oxidation of iron, very high temperatures, and instant destruction of the blade.

3.4.5 Shears

Large industrial shears, some specifically designed for ship breaking/recycling, can quickly reduce large metal parts to small dimensions, suitable for a remelting furnace, with less labor than torch or saw cutting. There are dozens of different sizes of stationary and mobile shears available, and some ship recyclers use them. Stationary shears range in size from devices suitable to cut up small pipes and tubing to very large machines capable of shearing sections of hull plate up to 13 feet wide and 29 feet long. Mobile shears, mounted on tractor crawlers, powerful enough to shear plating and structure directly from ships, are used at some recyclers. Large shears have cutting rates measured in tens of feet per minute, compared to inches per minute for torches. Some large stationary shears include pre-compression or "boxing" devices which can compress irregular objects and metal debris into a log-shaped mass before cutting.

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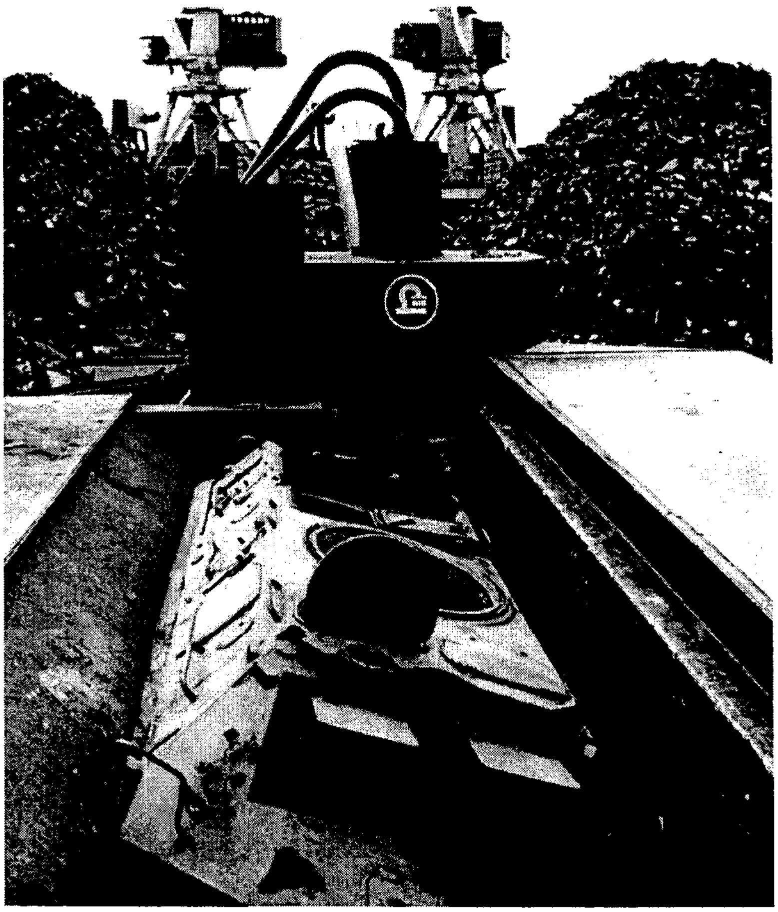
[9] Courtesy of American Carbide Saw Co., Hatboro, PA.

Figure 6 illustrates a large stationary shear.

Figure 6. Stationary Boxing Shear Ready to Box and Shear An Armored Personnel Carrier Cabin



The thickness, toughness, and dimensions of the metal to be sheared, the required cutting rate, and the product dimensions are important for selecting the correct machine for the service. Table 5 shows the capabilities of a range of large stationary machines suitable for shearing steel plate.[10]

[10] Harris Waste Management Group, Inc., *ABS Shears*.

Table 5. Typical Stationary Shear Capacity and Dimensions

Model	1	2	3	4
Shear Force (tons)	500	550	803	1016
Cuts/min	4.5	3.5	4	4
Production Rate (tons/hr)	13	13	18	22
Horsepower	100	100	200	300
Gross Weight (tons)	80	98	110	177
Height	16'8"	20'11"	20'6"	21'9"
Width	15'11"	18'3"	18'5"	21'5"
Length	54'3"	48'4"	49'4"	62'10"

PSNS has experimented with mobile shears for cutting up submarine hulls in drydocks. Because of the extraordinarily thick and hard metals in submarines, very high cutting pressures were required, sometimes creating high velocity projectiles from the cut steel, endangering workers in the drydock. Also the shears were cumbersome and slow when operating within the confines of a drydock. PSNS concluded that they are unsuitable and no longer uses them[11]; however, other recyclers have used them successfully on surface vessels.[12]

3.5 SHREDDING AND SEPARATING

Recyclable metal that is intermixed with useless nonmetallic material can be recovered for reuse by using shredders and separators. Shredders and separators are rarely if ever used to process hull and structural metals from ships because these products are usually recovered in large pieces, free of significant nonmetallic material. However, shipboard electric cables (about 75% by weight copper) are often shredded for recovery of the copper by recyclers specializing in this process. Recyclers of automobiles, white goods, and other small waste objects consisting of complex mixtures of metals and nonmetallic materials also use shredders and separators.

Shredders first reduce the parts to a gravel-like mixture of metal particles and nonmetal "fluff." Shredders operate on a number of different principles. Some use spinning blades, much like home garbage grinders, while others have flails that literally beat the feedstock to particles. Hundreds of different shredders are available, ranging from machines with dimensions of a few feet, designed for shredding tires and other small objects, to massive machines capable of

[11] Personal communication, MSCL Inc. (Rushworth) and PSNS (Shipley), October 12, 1995.

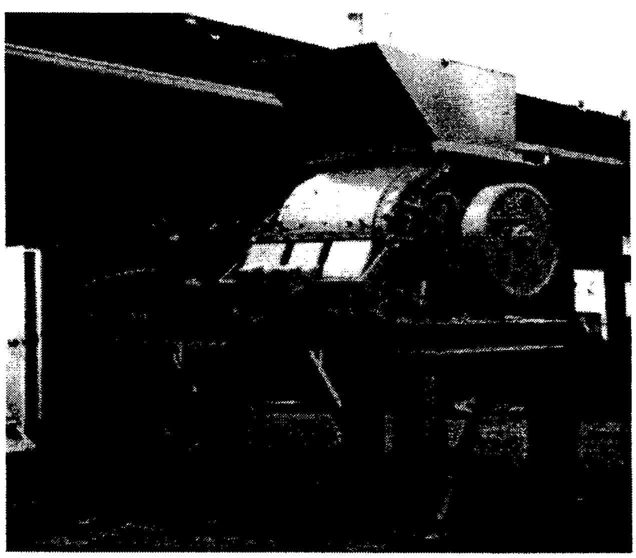
[12] Both Wilmington Resources and Jacobson Metals report the successful use of mobile shears to cut apart surface vessels. Note that Jacobson has not recycled ships recently but has used mobile shears on large barges.

shredding automobiles. Table 6 lists the properties of one manufacturer's series of shredders designed for shredding aluminum and other soft scrap, and Figure 7 illustrates a typical small shredder.[13]

Table 6. Shredder Capacity

Model	Feed Opening Length (in)	Feed Opening Width (in)	Horsepower	Shredder Head Weight (lbs)	Capacity (lbs/hour)
1	28	17	Up to 25	3900	Up to 2,500
2	36	25	Up to 40	5200	Up to 8,000
3	51	25	Up to 60	9000	Up to 9,000
4	50	35	Up to 150	16500	Up to 2,000
5	54	40	Up to 300	23500	Up to 4,000
6	64	40	Up to 300	28000	Up to 8,000
7	72	52	Up to 400	36000	Up to 12,000
8	95	52	Up to 600	40000	Up to 16,000
9	105	72	Up to 800	55000	Up to 28,000

Figure 7. Small Shredder



[13] Courtesy of Counselor Engineering, Hudson, Ohio.

After the shredding, the metals are separated from the fluff by several means. Magnetic separators are often used for separation of steel. Air flotation separator columns, which lift fluff free of the heavier metals, and shaker tables work well where the shredded metal is much heavier than the fluff. To select the right shredding and separating equipment, the recycler considers the dimensions of the feedstock, the toughness and composition of the metals and nonmetals in the scrap, the desired purity of the shredded product, and the cost of competing systems. In most recycling yards, shredders and separating equipment are arranged in series with conveyor belts and air lifts to move materials through the process in a continuous stream.

Periodic maintenance on shredders and separators includes replacement of shredder cutter blades and conveyor belts every few months.

Some shredder feedstock contains hazardous materials, such as asbestos or PCBs, that may be difficult to contain and effectively separate from the metals during the shredding and separation process. Regulating agencies require special licensing of shredding operations to ensure that such hazards are properly controlled during shredding and separation and that the metals and fluff are properly managed thereafter.[14] For a discussion of the regulations that may apply to shredding and other ship breaking/recycling operations, see References 2 and 3.

3.6 MINI-MILLS

At least one major U.S. metals recycler, though not presently active in ship breaking/recycling, operates small steel mills (mini-mills) close to scrap operations.[15] This reduces transportation costs for scrap and provides another source of profit for the firm. Waste processing technologies may also improve the profitability of domestic recyclers. These are discussed in Chapter 5.

3.7 OCCUPATIONAL SAFETY AND HEALTH TECHNOLOGY

Ship breaking/recycling is a heavy industry subject to the safety and health requirements of all heavy industry in the United States. The applicable statutes, rules and regulations are discussed in References 2 and 3. These rules and regulations require the use of specific personnel safety equipment, depending on the circumstance faced by the worker. For example, to reduce injuries from falling and moving objects, rigid helmets (hard hats) and hard-toed shoes are required in most areas of a ship breaking/recycling yard. Also, workers using cutting torches must often wear leather welder's gloves and protective suits (to protect from spatter) and welder's helmets (to protect the eyes). Asbestos workers must wear full-body protective suits, head covers, and air breathing masks to ensure that workers neither breathe nor come in bodily contact with asbestos dust.

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[14] H.E.L.P.E.R. Inc of Madison, SD has been working with EPA to be licensed to shred PCB-contaminated electric cable from the U.S. Navy.

[15] Personal communication, MSCL Inc. (Burritt) and Schnitzer Industries (Zelenka), June 15, 1995.

There are many administrative health and safety protections afforded workers. They must be fully informed about workplace hazards. They have rights and responsibilities to report problems and conform to the rules. All these requirements are laid out in applicable rules, but none is unique to the industry or has unique applications. However, there are some new technologies which could be used to reduce the hazards. More extensive use of large shears would reduce generation of the metal fumes that accompany oxygen-fuel torch cutting and worker exposure to this hazard. Several new technologies which could mitigate worker exposure concerns are discussed in Chapter 5.

3.8 EQUIPPING A BREAKING/RECYCLING YARD

Ship breaking/recycling can be performed almost anyplace where there is water deep enough to bring a ship near shore. Some ship breakers/recyclers have used nothing more than a beach, and others, a fully equipped shipyard. The type and amount of new equipment needed to begin ship breaking/recycling at any particular location will be influenced by facilities and equipment already at the site, the type of ship being scrapped, the market requirements for the scrap, and many other variables. Therefore, no single list of equipment will be correct for each circumstance. However, Table 7 provides a rough estimate of the value of the equipment needed for a yard capable of ship breaking/recycling 10 ships per year. The list assumes that a site is available with buildings, a place to pull ships ashore, but little else. The assumptions are:

- Ship breaking/recycling will be done afloat,
- Rail and road transportation services are available,
- There are adequate buildings for offices, storage of reusable equipment, artifacts, and materials but there is no lifting equipment,
- There is a slip with adequate water depth that enables mobile cranes to lift materials off and there is an area to pull the remaining hulk ashore as material is removed, and
- New equipment will be purchased.

Ship breaking/recycling in drydocks or constructing transportation facilities, buildings or a slip would add to the cost of outfitting a site, whereas purchase of used equipment would substantially reduce the cost.

Table 7. National List of Equipment for a Ship Breaking/Recycling Yard

Type of Equipment	Number	Unit Price	Total Cost
150 ton Crawler Crane	2	$395,000	$790,000
50 ton Crawler Crane	1	258,000	258,000
100 ft reach Hydraulic Counterbalancing Crane	2	600,000	1,200,000
140 Ton Mobile Shears	1	165,000	165,000
50 Ton Mobile Shears	1	95,000	95,000
Front End Loader	2	100,000	200,000
2,200 ton Automatic Baler-Shear	1	3,850,000	3,850,000
1,000 ton Automatic Baler Shear	1	1,400,000	1,400,000
20-Ton Fork Lift	3	45,000	135,000
125 cfm Air Compressor	3	30,000	90,000
Personnel Safety Equipment	20 sets	80,000	80,000
Plate Scale	1	10,000	10,000
Oil/Fuel/Grease Truck	1	25,000	25,000
Scrap Dump Truck	3	125,000	375,000
Winch	2	15,000	30,000
Diaphragm Air Pump	5	2,000	10,000
Fork Lift	10	3,000	30,000
Grit Blast System	3	75,000	225,000
Misc. Tools	1	35,000	35,000
		Total	$9,003,000