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Life cycle assessment of ships

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ABSTRACT: The paper gives an overview of the main issues of Life Cycle Assessment (LCA) of a product. The types and main components of LCA are briefly discussed. The holistic approach of LCA of any product is outlined. The main categories of Environmental Impact Assessment (EIA) are highlighted. The modern approach of ship Design for Environment is presented. The LCA of ships is addressed to clarify energy consumption and environmental impacts. Particular emphasis is placed on the methods commonly used to reduce energy consumption and environmental impacts over the three stages of ship construction, ship operation and ship scrapping. The rationalization of materials used in shipbuilding and ship scrapping is emphasized. The solid waste management hierarchy is presented. The importance of using LCA to determine the environmental performance of ships is highlighted.

1 INTRODUCTION

Over the past 20 years, environmental issues have gained greater public interest and recognition. Particular emphasis is placed on the increasing problems of greenhouse gases that threaten to change the climate and the increasing consumption of chemicals that reduce the ozone layer. Also, the public is now becoming more aware than ever that the consumption of manufactured products and the daily services and activities of our society adversely affect supplies of natural resources and the quality of the environment.

Environmental protection requires the development and application of methods to identify and reduce the adverse environmental effects of human services and activities. There is now a growing awareness of the need to radically decrease waste streams from production and consumption processes. This awareness has not only brought about the implementation of improvements in the currently used production processes but has also led to increased circulation of materials. Industry has not always been able to make use of all reusable materials, as collection of materials for reuse has not always been an efficient and successful process. Recycling is a means of reducing waste streams and accordingly reducing the demand for waste treatment. The objective of an efficient material production and recycling scheme should not only be to just recycle but also to minimize the resource utilization and associated emissions of all streams of materials in the production cycle.

Life Cycle Assessment (LCA) of a product is used to identify, evaluate and minimize energy consumption and environmental impacts holistically, across the entire life of the product. LCA is, therefore, a systematic way of examining the environmental impacts of a product throughout its life cycle, from raw materials extraction through the processing, transport, use and finally product disposal. LCA is sometimes called a "cradle-to-grave" assessment. LCA could be used also to assist companies to identify and assess opportunities to realize cost savings by making better design and more environmentally friendly products, more effective use of available resources and improving waste management systems.

2 BASIC CONCEPT OF LCA

LCA adopts a holistic approach by analyzing the entire life cycle of a product from raw materials extraction and acquisition, materials processing and manufacture, material transportation, product fabrication, transportation, distribution, operation, consumption, maintenance, repair and finally product disposal/scrapping.

The solid waste management hierarchy of a product disposal system includes waste prevention, waste minimization at source, reuse, recover, repair, recycle, incineration (with or without energy recovery) and landfill. Figure 1 shows the input and output of any industrial process, including energy demand and environmental impacts. Figure 2 shows the demand of energy and environmental impact of the material extraction industry.

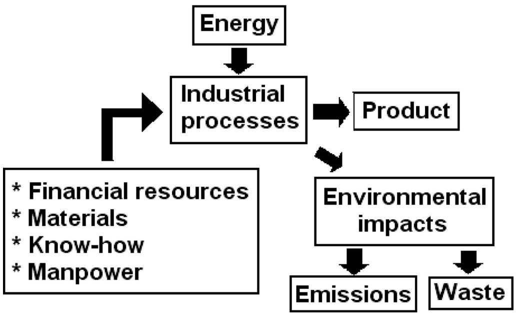

Figure 1. Input/output of any industrial processes.

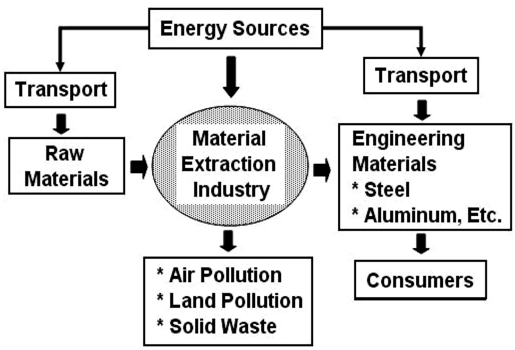

Figure 2. Energy and environment of pre-production stage.

3 MAIN COMPONENTS OF LCA

The main elements of LCA of a product are shown in Figure 3. The main objectives of LCA are:

– Minimization of energy consumption
– Minimization of environmental impacts
– Rationalization of material used.

The main components of a product Life Cycle Assessment are given below.

3.1 *Inventory analysis*

It is the identification and quantification of energy and resources used and environmental releases to air, water and land for all the processes within the system boundary. The results generate an inventory of the environmental burdens. The system boundaries includes the main production sequence (extraction of raw materials up to and including final product disposal), handling and transport operations, production and use of fuels, generation of energy (electricity and heat, including fuel production) and disposal of all process wastes.

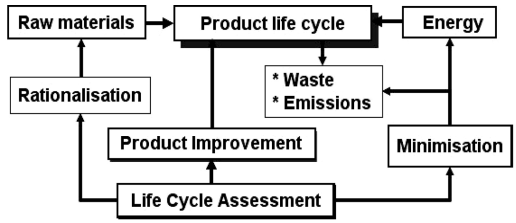

Figure 3. Main concept of LCA of a product.

3.2 *Environmental impact assessment (EIA)*

Environmental impact assessment (EIA) is the technical qualitative and quantitative characterization and assessment of the consequences on the environment. The impact analysis addresses ecological and human health consequences and resource depletion and could be divided into three sub-phases:

- Classification: sorting of parameters into environmental effect categories.
- Characterization: calculation of the potential contribution of the environmental loading to each effect category.
- Valuation: assessment of the total environmental impact of the product life cycle.

The main elements to be considered in an EIA are:

- Resources: energy, water, and land.
- Human health: toxicological impacts, non-toxicological impacts, etc.
- Global warming: GHG emissions.
- Depletion of stratospheric ozone: widespread use of CFC.
- Acidification.
- Habitat alterations and impacts on biological diversity.
- Risk assessment: environmental hazards, health hazards, etc.

3.3 *Improvement analysis*

It is the evaluation and implementation of opportunities to reduce environmental burdens. This could be achieved by the efficient use of natural and man-made materials and in a cost effective manner, better measurement of environmental impacts, minimization of consumption and management of wastes by recycling/reuse of waste as a raw material, using clean technologies, polluting less, cleaning up the pollution, using risk assessment and management. Therefore, LCA could be defined and categorized as follows:

Conceptually: LCA is a process guiding the selection of options for design and improvement. Qualitatively: LCA is an assessment of key environmental burdens or releases at the different stages of the life cycle of a product.

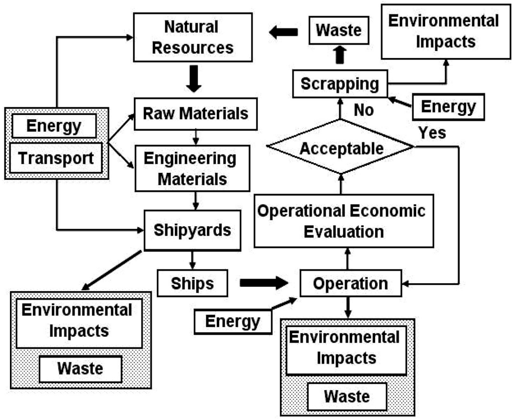

Figure 4. Ship life cycle.

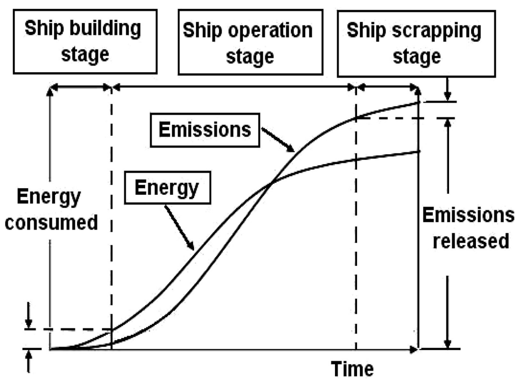

Figure 5. Cumulative energy and emissions.

Methodologically: LCA is a quantitative inventory of environmental burdens or releases, evaluating the impacts of those burdens or releases and considering alternatives to improve environmental performance.

4 LCA OF SHIPS

LCA of ships should assess rational use of construction and outfitting materials, energy consumption and environmental impacts in all stages of ship design, construction, outfitting, operation, maintenance & repair, and finally in ship scrapping. Figure 4 shows the energy demand an environmental impacts over the life cycle of a ship. Figure 5 shows the cumulative energy consumption and emissions released over a ship's life cycle. Figure 6 shows the material and energy input and the waste and emissions output of a shipyard.

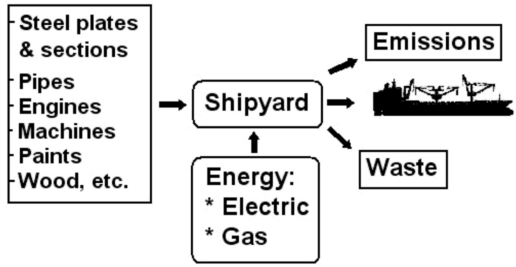

Figure 6. Input/output of a shipyard.

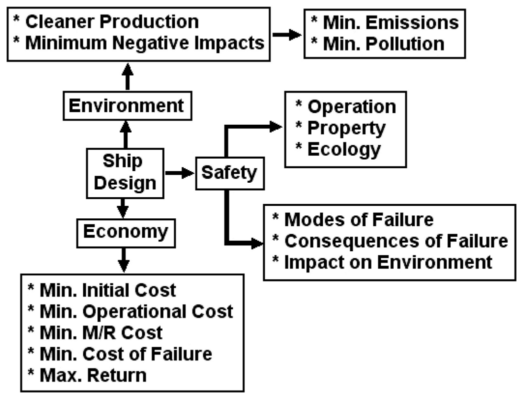

Figure 7. Rational design approach.

4.1 *Environmental dimensions in ship design*

The environmental dimension in ship design should be an integral part of a rational approach to ship design, see Figure 7. This approach is sometimes called ship design for environment (DFE) which should make safety, economy, energy efficiency, environmental performance and ship disposal an integral part of the ship design process.

The holistic approach of ship design should satisfy the following main issues:

- IMO and other international conventions
- Statutory requirements
- Classification society requirements
- National and international safety requirements
- Performance requirements
- Rational use of materials
- Minimization of energy consumption
- Ensuring cleaner production
- Minimization of environmental impacts
- Minimization of solid waste
- Minimization of demolition problems

4.2 *Rational use of materials*

The main materials commonly used in the shipbuilding industry, which require rationalization, are: steel plates and sections, welding coils and rods, castings, forged parts, timber, paintings, etc. The rational use of these materials should not only reduce energy consumption and the negative environmental impacts but should also have positive economic gains. The minimization of the negative environmental impacts and wastes in ship construction could be achieved by the efficient use of ship construction materials, welding rods, paints, etc. The emissions of welding electrodes over its life cycle are given in Table 1 (ESAB 1997).

4.3 *Environmental impact of ship production*

The energy used in ship production could be divided into direct and indirect energies. The indirect energy used in the shipbuilding industry is used for the manufacture and production of the following main items: steel plates and sections, main and auxiliary engines, equipment, fittings, welding coils and electrodes, paints, etc. The energy demand in all processes of ship steel production is shown in Figure 8.

The direct energy required for ship construction is used for handling and transport (raw materials, fabricated sections and blocks), fabrication processes (cutting, forming, welding), assembly of steel plates and sections, construction of 2D and 3D blocks, erection and assembly of blocks on berth or in dock, outfitting operations, tests and trials, see figure 9. Energy demands and emissions for welding and forming operations of steel plates are shown in Figures 10 and 11.

In all fusion welding processes, sufficient energy is required to produce local melting. During welding operations, welders are exposed to welding fumes. Welding current, arc voltage and welding speed are the most decisive variables affecting energy input to a welded joint. The required energy or input power is given by:

$$H_i = f.EI/V$$

Where: H_i = Energy input, J/mm
f = Heat transfer efficiency, less than 1.0
E = Arc voltage, volts
I = Welding current, amps
V = Welding speed, mm/sec

Table 1. Life cycle impact of welding electrodes.

Items of LCA	CO_2 (%)	NO_x (%)	Particles (%)
Raw materials	84	59	24
Production	7	6	1
Transport	6	23	1
Use	3	12	74
Total	100	100	100

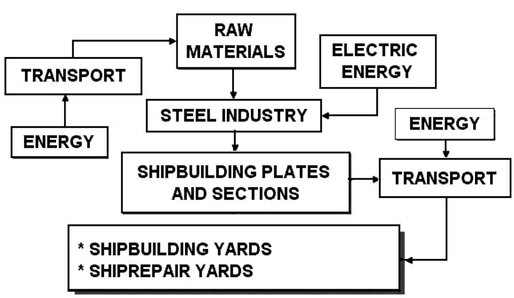

Figure 8. Energy demand for the production of ship steel.

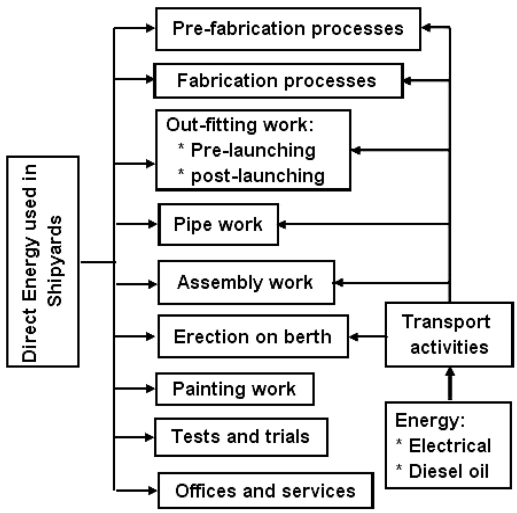

Figure 9. Demand for direct energy in shipyards.

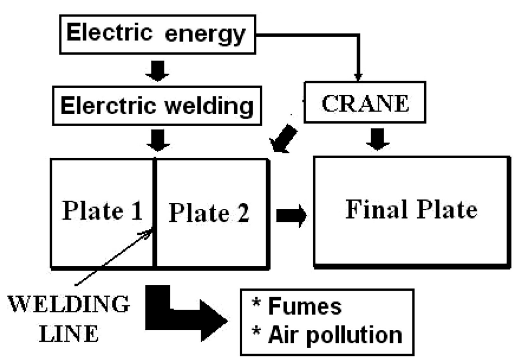

Figure 10. Energy demands for plate welding.

The principle of the line heating method is shown in Figure 12. Acetylene is normally used for providing the required heat energy and CO_2 is the main polluting gas emitted. Assuming complete combustion of acetylene, the amount of emitted CO_2 could be estimated using the reaction equation for complete combustion as given by:

$$C_2H_2 + 2.5\ O_2 \Longrightarrow 2\ CO_2 + H_2O$$

As an example, the amount of emitted CO_2 to form a steel plate of length 6.0 m, breadth 2.0 m and thickness 16 mm to a radius of curvature 3.0 m using 6 heating lines is 12.1 kg.

Figure 13 shows energy demand and emissions for gas cutting of steel plates. The total heat input for gas cutting is given by (Glizmanenko 1965): Total heat input = heat input for pre-heating (17%) + heat input for combustion of iron and impurities (37%) + heat input for slag (22%) + heat losses with waste gases, radiation and unused Oxygen (24%).

The energy demand and emissions for pipe work and frame bending are shown in Figures 16 and 17.

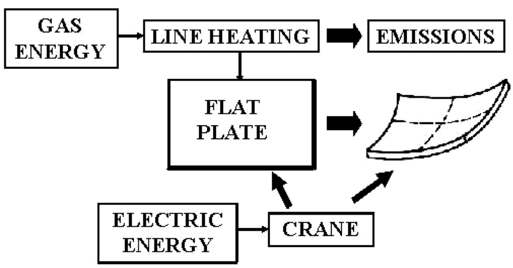

Figure 11. Energy demand of line heating method.

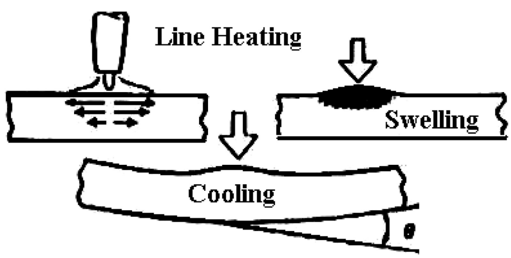

Figure 12. Principle of line heating method.

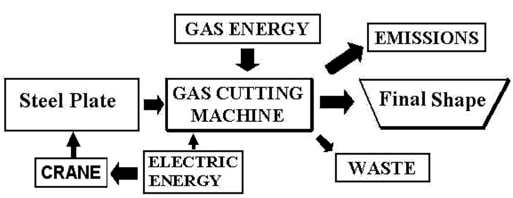

Figure 13. Energy and emissions of gas cutting.

4.4 *Measures of energy saving in ship construction*

The measures commonly taken at the design stage to improve energy efficiency of ship construction are: reduction of hull steel weight, use of alternative materials and reduction of weight and power requirements of engines, machines, equipment and fittings.

The main measures commonly taken at the fabrication stage to improve energy efficiency are: rationalization of inter-process transportation and material handling, improvement of bending and forming

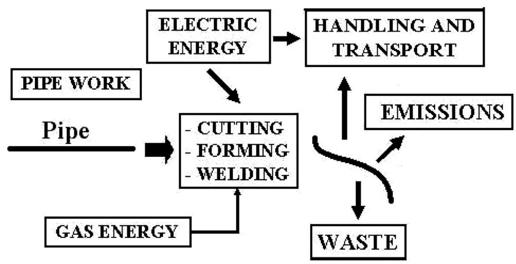

Figure 14. Energy and emissions of pipe work.

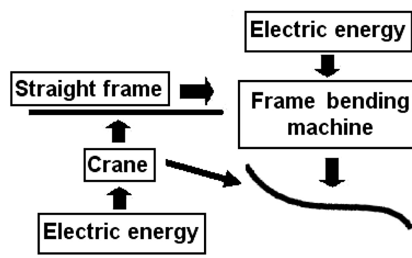

Figure 15. Energy demand for frame bending.

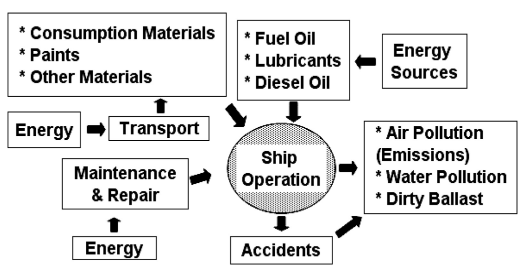

Figure 16. Energy and environment in ship operation.

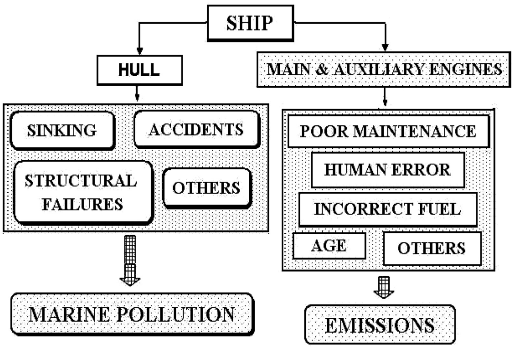

Figure 17. Environmental impacts of ship operation.

operations (2D and 3D forming) using press forming instead of line heating methods, using large sizes of steel plates, particularly plate width, improving welding operations, improving accuracy of edge preparation, minimization of welding lengths, maximization of down-hand welding, minimization of cutting lengths of steel plates, widespread use of computer-aided marking and cutting, minimization of scrap and waste by the efficient use of plate nesting and minimization of rework.

4.5 *Environmental impacts of ship operation*

Oceans are essential parts of the global life support system. They influence the climate and provide food and other resources for our growing world population. However, oceans are under increasing environmental stress from shipping operations.

The energy demand and environmental impacts of ship operation are shown in Figure 16. With regard to energy consumption, ships require less energy to carry a given tonnage of cargo over a given distance than all other means of transport. The environmental impacts of ship operation should be considered for both modes of operation at sea and in ports. The main causes of marine pollution and emissions are shown in Figure 17. The environmental impacts should be also considered for both conditions of normal ship operation and when a ship experiences major structural failures or an accident. The main causes of ship structural failures are aging, hull degradation, human error, accidents, etc. The causes and environmental consequences of tanker accidents are shown in Figure 18.

Marine transport contributes to the world's NO_x production. Minimization of the negative environmental impacts during sea operation require reduction of exhaust gas emissions (CO_2, NO_x, SO_x, particulate), sewage treatment, treatment of contamination of ballast water, handling/control of garbage by efficient stowage/incineration, reduction of the harmful impact

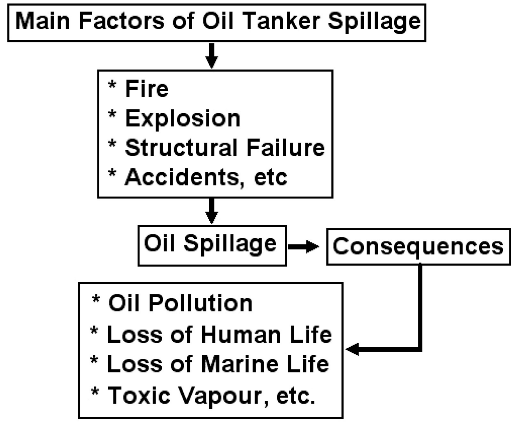

Figure 18. Environmental impact of tanker accidents.

on marine life induced by underwater coatings and antifouling paints, reduction of fouling at sea chests, etc.

4.6 *Ship design aspects affecting energy-efficiency of ship operation*

Improving energy efficiency of ship operation could be fulfilled by improving ship routing, optimum design of hull shape, maximization of volumetric and deadweight cargo capacity, using efficient propulsion system, minimization of propulsion power for the required ship speed, rational selection of the percentage of sea margin, improving rudder design, maximum use of the heat energy of exhaust gases, etc. Over-estimation of the percentage of sea margin could lead to unnecessary increase of the installed power of the main engines. This will have deleterious effects not only on the economy of ship operation but will also have increased negative environmental impacts.

4.7 *Environmental impact of ship scrapping*

Ship scrapping is becoming an important industry in several countries as the number of ships that has to go out of service is increasing significantly every year. For ship owners, the decision to scrap a ship, continue operation or convert to a different trade requires condition assessment and economic evaluation. Because of the increasing costs of acquiring a new ship, some ship owners have extended the life of some of their ships by upgrading either hull, machinery or both. Extending a ship's life is a positive attitude to protect our natural resources. Figure 19 shows a decision making strategy based on the condition assessment of the ship. The results of the condition assessment of hull and machinery should help ship-owners to take the right decision whether to up-grade and continue operation or to scrap the ship.

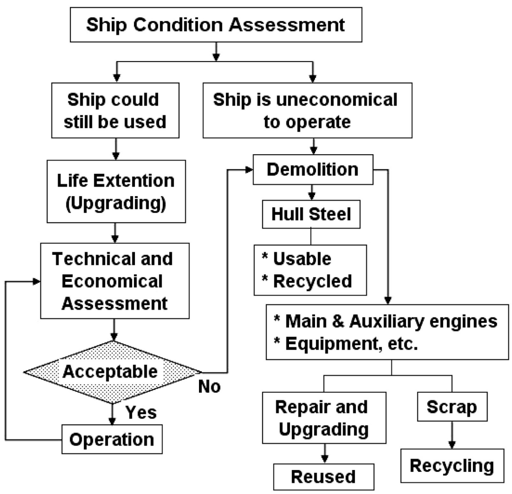

Figure 19. Decision making of ship waste management.

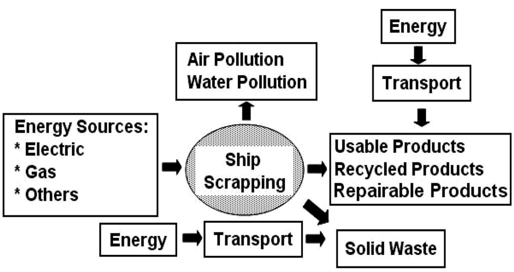

Figure 20. Energy and environment in ship demolition stage.

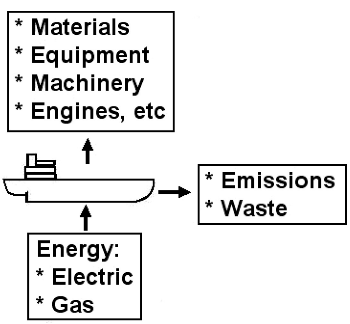

Figure 21. Input/output of ship scrapping.

The energy demand and environmental releases of ship scrapping is shown in Figure 20. Ship scrapping products could be divided into, see Figures 21 and 22:

- Usable materials, equipment, machinery, etc.
- Repairable engines, machinery, equipment, etc.

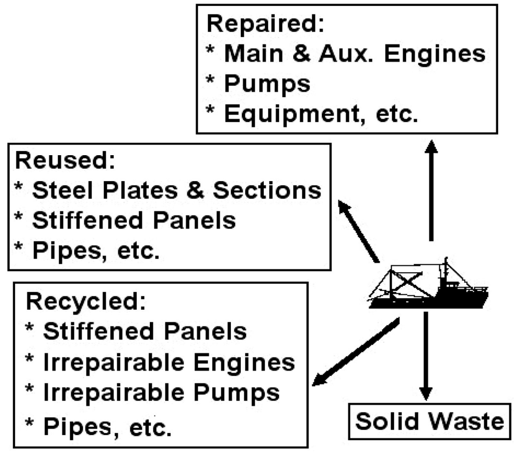

Figure 22. Output of ship scrapping.

- Recycled materials, equipment, engines, etc.
- Waste

The outcome of ship scrapping includes:

- Ferrous materials: steel plates & sections, pipes stiffened panels, cast iron, cast steel, etc.
- Non-ferrous materials: copper, brass, bronze, aluminum, zinc, etc.
- Non-metallic materials
- Equipment: electric, navigation, electronic, communication, etc.
- Machinery: cranes, winches, motors, pumps, etc. – Engines: main and auxiliary.

Environmental performance of ship scrapping could be improved by the development of a ship scrapping management system. The system should aim at:

- Maximizing reuse, recover and repair of materials, fittings equipment, machinery, engines, etc.
- Minimizing wastes and recycled materials, machinery, equipment, engines, etc.
- Minimizing energy consumption and the negative environmental impacts.

Waste management in ship scrapping should not only have significant economic opportunities but should also have positive impact on environmental protection.

5 CONCLUSIONS

The main conclusions drawn up from this paper are:

- Life Cycle Assessment of ships could be used to assist shipbuilding and ship repair companies to identify, quantify and assess opportunities to minimize energy consumption, control/reduce negative environmental impacts and to realize cost savings by making more effective use of available resources.

- LCA could be used effectively for comparing optional production schemes with regard to energy efficiency and environmental performance.
- Ship safety, economy, energy efficiency, environmental performance and ship scrapping should be integrated into a holistic ship design process.
- The rational use of shipbuilding materials should not only reduce the negative environmental impacts and energy consumption but should also have positive economic gains.
- The highest proportion of energy consumption and environmental impacts are expected to result from ship operation. Much effort is therefore needed to improve ship energy efficiency and environmental performance of ship operation.
- Waste management in ship scrapping should not only have significant economic opportunities but should also have positive impact on environmental performance.

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