Green Vessel Design

Environmental best practices.

Environmental Protection IN THE AIR

by Mr. Brian W. King, P.E.
Vice President of Engineering
Elliott Bay Design Group

Mr. Ryan Roberts, P.E.
Naval Architect
Elliott Bay Design Group

Mr. Joseph Payne, P.E., LEED-AP
Senior Electrical Engineer
Elliott Bay Design Group

Ms. Christina Villiott, CPSM
Marketing Manager
Elliott Bay Design Group

Environmental issues are increasingly at the forefront of public awareness. The short- and long-term implications of pollution, global warming, ozone depletion, and other environmental issues are becoming major influences in public policy, regulation, and enforcement. This is particularly relevant to the marine community when you consider that roughly 70 percent of the earth's surface is covered with water, about 50 percent of the world's population lived within approximately 60 miles of a coastline as of 2002, and the trend is on the rise.[1]

The marine industry is currently in a position to help shape policy and public opinion and has an opportunity to demonstrate its commitment to responsible stewardship. Generally, shipment by water is inherently energy efficient. There is no "greener" mode of transportation for significant quantities of goods. For example, the carrying capacity of one barge equals that of 16 rail cars or 70 truck and trailer combinations. This translates into 514 ton-miles of fuel for barges, 202 ton-miles for rail cars and 59 ton-miles for truck-trailers.[2]

Even when you consider the ships themselves (as compared to buildings on land) you will find that ships are inherently green in many respects. Ships are built primarily from steel, a readily recyclable material. Most plumbing fixtures are "low-flow" to minimize the amount of onboard water tankage and/or water-making capacity. Energy use is also minimized due to space constraints. Unfortunately, these same vessel "pros" can also result in environmentally unfriendly practices. Hulls may be coated with anti-fouling paints that can reduce ship speed and thereby increase fuel consumption. In addition, a ship is a small seagoing community with ongoing industrial processes, many of which may involve or produce hazardous materials.

As naval architects and marine engineers, we have the opportunity to improve upon design practices and benefit the environment. These practices can be summarized into a few guiding principles for environmentally responsible design:

- Minimize use of hazardous materials and environmental contaminates.
- Maximize use of recycled and recyclable material.
- Minimize waste and scrap.
- Maximize use of rapidly renewable and regional materials.
- Minimize air emissions.
- Minimize energy use.
- Minimize discharges to water.

These principles are interdependent and not mutually exclusive to economic performance. In many cases they are the natural progression of regulations that have been refined through use and enforcement in the field.

Minimize Use of Hazardous Materials and Environmental Contaminates

Any discussion of hazardous materials and environmental contaminates first requires some clarification of the terminology. The two most widely accepted indicators of environmental impact are "global warming potential" (GWP) and "ozone-depleting potential"

(ODP). GWP is the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide. ODP is a number that refers to the amount of ozone depletion caused by a substance.

An ozone-depleting substance is a compound that contributes to stratospheric ozone depletion. Per the Montreal Protocol on Substances that Deplete the Ozone Layer, all CFCs and HCFCs (common refrigerants) are to be phased out by 2030. The Clean Air Act of 1990 has significant restrictions on the storage and handling of these refrigerants and other ozone-depleting substances, as well as strict requirements for the maintenance of equipment containing them, to limit the amount of leakage.

There are a number of programs that address the use and minimization of hazardous materials and containment. Per "Green Passport," an International Maritime Organization program, vessel owners are required to maintain accurate records of the potentially hazardous materials that went into the construction of their ships. The passport follows a ship through its lifespan and should accurately include any relevant modifications. This voluntary program is expected to become mandatory by 2010.[3]

IMO also addresses issues associated with ship and equipment recycling where it suggests identifying commonly used and potentially hazardous material (such as hydraulic fluid), and using less hazardous alternatives. The significant new alternatives policy is EPA's program to evaluate and regulate substitutes for ozone-depleting chemicals being phased out under the Clean Air Act. This program includes substitutes for refrigeration and air conditioning, cleaning solvents, fire suppression and explosion protection, adhesives, and coatings, all of which are critical to shipboard construction and operations.

Heating, ventilation, and air conditioning equipment offers an excellent area for improving a ship's environmental performance. Newer systems are available with a low refrigerant charge per ton of cooling capacity, as well as both low ODP and GWP. While some class society "clean" certifications permit an annual leakage rate of 10 percent, leakage of newer refrigeration systems can be as little as two percent, with a maximum of 10 percent released during final disposal and recycling of the refrigerant.

Minimizing use of volatile organic compounds (VOCs) is another key factor. VOCs are emitted as gases from certain solids or liquids and include a variety of chemicals, some of which may have short- and long-term adverse health effects. During ship construction and throughout a ship's life, use of low-VOC products can improve the air quality of the surrounding community, as well as the future occupants of the vessel. Today there are a number of low-VOC products on the market, such as paint and coatings, with many more in our future.

Maximize Use of Recycled and Recyclable Material

The environmental impact of a ship occurs in three distinct stages of its life: construction, operation, and disposal. There are many ways in which green considerations can be applied during vessel design, which will translate to improvements in both the construction and operation of a vessel throughout its lifecycle, and provide for a greener and more cost-effective recycling at the end of the ship's lifespan.

Using the maximum amount of recycled and recyclable materials possible is one approach to green design. Steel and aluminum used for ship construction are readily recyclable materials, but improvement in recycling is necessary for many other materials throughout the ship. A key consideration is the design and installation of systems that prevent non-recyclable and/or hazardous materials from contaminating recyclable material. This applies to insulating materials, as well as interior bulkhead systems and flooring systems.

Minimize Waste and Scrap

Much of the waste generated during construction can be reduced with careful production planning, weight control, and greater reliance upon detailed design and computer lofting of structure and piping systems. Frequently, the first step in vessel design is a study of hull size and form, propulsion/power configurations, and materials to determine the best approach to an owner's needs. Further design development involves optimizing structure, systems, and hull form for reduced energy use and production.

To accomplish this analytic approach, state-of-the-art tools such as finite element analysis and computational fluid dynamics are used. At the pre-production and production stages of design, computer lofting is extensively used to plan for almost all of the structure of the ship and increasingly in piping and wireways. When comprehensively applied, weight and waste will be minimized with the added benefit of reduced production labor.

Over the life cycle of a ship, reduction of waste generated during construction is a one-time event. However, the waste built into the ship is detrimental throughout its operational life, with a cumulative effect on fuel efficiency.

Maximize Use of Rapidly Renewable and Regional Materials

Rapidly renewable materials are generally defined as having a natural replacement cycle of less than 10 years. Rapidly renewable products such as bamboo, linoleum, cork, poplar, and wool are less of a burden on our environment. Wool carpeting is already a standard for marine applications due to its inherent low-smoke characteristics. As another example, rapidly renewable wood products can directly replace hardwoods in almost every application, where feasible, with minimal or no cost increases.

Utilizing regional materials significantly reduces the energy required for their transport. This should include locally recycled material, regardless of its original production location.

Minimize Air Emissions

Diesel engines that power a majority of the world's fleet are responsible for carbon dioxide, sulfuric and nitrous oxides, smoke and particulate emissions, noise, and sensible heat leaving the stack. Positive change toward minimizing air emissions can lead to substantial environmental improvement. Areas for emission-minimizing opportunities include hull form optimization, speed considerations, diesel choices, and use of alternative fuels.

The conventional displacement hull, which makes up the majority of documented ships operating in the United States today, requires power that is exponentially proportional to speed, so reducing the resistance and power required can significantly lower both the size of the prime movers and the amount of fuel burned.

Figure 1 shows a typical speed-power curve for a modern 235-foot offshore support vessel. The horsepower is based on sea trial data with a service life and sea margin of 10 percent added. To upgrade a vessel from a top speed of 12.0 kt to 12.5 kt requires a power increase of 1550 hp, or 38 percent! If the 12.5-knot service speed were chosen, the next size larger engine would be required.

With this larger power plant comes an associated increase in fuel used, lubrication oil consumption, and harmful emissions. For a 500-nm run, the faster vessel would arrive only one hour and 40 minutes earlier. It is apparent that there must be an extremely strong case for high speeds to justify the inherent costs to the environment, the initial cost of the engines, and the fuel and operating costs.

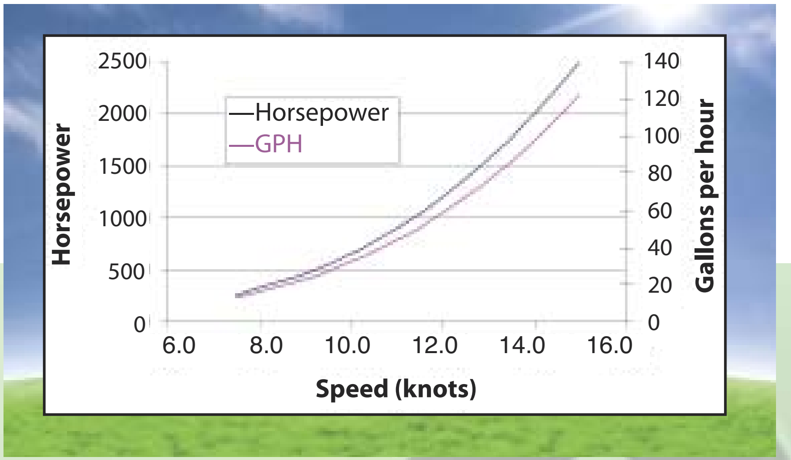

Figure 1: Powering penalty for increased speed. Graphic courtesy of Elliott Bay Design Group.

With an appropriate operating speed selected, optimizing the hull form for lowest resistance may mean spending an extra $20,000-$100,000 during the design stage. While this may seem a steep price to pay up front, in reality it can easily result in a life cycle cost savings of several orders of magnitude greater than the initial outlay, along with a tremendous decrease in harmful pollutants and greenhouse gases.

Designing diesel engines and ships to utilize dual fuel can also result in lower emissions. Converting engines to burn either standard diesel and fuel oils or liquefied natural gas (LNG) has been standard for large LNG carriers for some years now, but smaller-, medium-, and higher-speed marine diesels are now being modified to be dual fuel as well. In regions where there is an adequate gas supply, this is an attractive option. Natural gas also has fewer emissions compared to diesel.

This option can be designed from the beginning or reasonably retrofitted to existing vessels. LNG fuel systems do require 65 percent more storage volume, so this option may only be viable for ships with sufficient space for the additional fuel system. The barrier to wider use of LNG or compressed natural gas is not the engines or the design of the vessels to support the fuel systems, but rather the shoreside infrastructure to support distribution and refueling.

Simply using alternate fuels can greatly benefit the environment. The most obvious is the use of low sulfur fuel oils, although there is a price increase. While there is ongoing investigation to determine the impact of low sulfur diesel and ultra-low sulfur diesel (ULSD) on marine diesel engines, many operators are already beginning to use them to troubleshoot problems before the EPA requires ULSD use in 2015. Biodiesel offers a unique opportunity to eliminate sulfur dioxide emissions completely. Currently, most marine diesels are certified only for blends with up to 20 percent biodiesel, which is used in place of standard distillate.

All current and pending MARPOL and EPA regulations focus on the reduction of nitrogen oxides and other emissions and particulates. The regulations also have the unfortunate side effect of increasing CO_2 emissions, which is not currently recognized as an air pollutant by the EPA. The amount of CO_2 emissions for engines using diesel and fuel oils directly correlates with the amount of fuel they use. Beginning with the MARPOL Annex XI and each successive tier of EPA marine engine emissions regulations, engine fuel efficiency has decreased by one or more percentage points, thus proportionately increasing their carbon dioxide emissions. This trend of reduced fuel efficiency and increased CO_2 emissions will continue with the introduction of EPA Tier III and Tier IV. With Tier IV, CO_2 emissions will significantly increase due to the overall reduction of fuel efficiency caused by active regeneration required for the particulate filters, pumping requirements of selective catalytic reduction systems, and the added weight of the equipment, fuel, and urea[4] that the vessels must carry.

Figure 2: The harbor tug "ship docking module" design being adapted for hybrid drive. Photo courtesy of Elliott Bay Design Group.

Biodiesel can be substituted for fossil fuel and, in theory, can be carbon-neutral. That is, the release of carbon dioxide from the production and use of biodiesel would be no more than the release at the end of the plant's lifecycle. It is estimated that the use of biodiesel will produce 68 percent fewer greenhouse gas emissions than using regular diesel.[5] Biodiesel also offers the added benefit of moderately reducing dependence on foreign oil sources.

Current generation biodiesel is produced mostly from soy and canola crops and thus competes with the food uses of these crops. The crops devoted to the production of biodiesel compete for arable land that may be used for food production, and may contribute to deforestation. Next-generation biofuels to be developed from algae and other non-food crop resources will alleviate many of these concerns. Technical challenges remain with the large-scale production of biofuels from non-food resources, so they are not yet commercially available in significant quantities.

Hybrid drives use a combination of diesel-electric generator power and the stored energy from batteries to provide the electrical power required to drive propulsion motors (Figure 2). The use of hybrid drive technology has the potential to reduce the installed prime mover size and the resulting emissions. This is, however, dependent upon a suitable peak load operational profile. One example of a hybrid drive would be the use of a battery bank to provide the high-power, short-duration "pulse" required for bow thruster operation. The battery weight and volume, as well as the potential hazardous material created, must also be considered. Except in some very unique waterborne transportation applications, hybrid drives do not produce the levels of fuel efficiency gain seen in wheeled transportation.

More so than ever in the past, one thing is clear—ships must be designed to be adaptable to changing fuel types, and vessel systems will become increasingly complex to accommodate fuel storage and handling and emissions systems.

Minimize Energy Use

As noted, air emissions are highly dependent upon the energy efficiency of the vessel. An often-overlooked aspect of the design is the location and placement of the appendages, such as the rudder, bilge keels, keel coolers, etc. If not aligned to the water flow over the hull, they can increase the drag by a surprising amount.

Several modifications can be made to fleets in service to increase efficiency and decrease fuel consumption, such as a stern flap or wedge. These devices are essentially built-up plates that are fitted at the stern with a depth and angle determined by the flow characteristics at the most common operating speed for a given time/speed profile. A flexible but more expensive option is installing moveable trim tabs or vertical interceptors that serve the same purpose, but reduce motion as well. Powering savings between three and eight percent are not uncommon with this technology.[6]

Increased hull and compartment insulation is another significant energy saver.[7] HVAC requirements are typically the single largest electrical load on ships and are the primary driver for sizing service generators. With the current high costs of fuel, the payback for better insulation can be measured in months, not years.

Just as important as the selection of thermal insulating material is its installation. Inherent in traditional steel and aluminum ship construction is the potential for thermal short circuits—heat conduction through thermally conductive aluminum or steel from inside surfaces to outside surfaces. Thermal short circuits occur at joiner bulkhead-to-hull stiffener attachments, through windows and doors and their frames, through duct and piping penetrations, and generally through compressed or nonexistent insulation. A great deal of energy is lost, translating to increased fuel consumption and exhaust emissions.

To maintain interior air quality, 20 percent or more of conditioned ventilation air is typically exchanged with fresh air from the outside. While this improves interior air quality, it also represents lost energy used to heat or cool the air. Much of this energy can be regained by installing fresh air heat exchangers, which heat or cool the incoming fresh air using the waste conditioned air it is replacing. The installation of fresh air heat exchangers is now a common practice in land-side building construction but has yet to be adopted as a standard practice in ship design. A well-designed system, in combination with tight construction to reduce other leak paths, can improve the efficiency of a ship's HVAC system by as much as 10-15 percent.

On smaller ships, the installed generation capacity also can be reduced by utilizing parallel switchgear on systems not traditionally designed for parallel operation. Many operators of small ships shy away from parallel operation, thinking the system too complex for the small crew. Modern electronics, however, make parallel operation an extremely simple, reliable option, as well as a space, cost, and fuel saver. All marine regulations require that in the event of the loss of one generator, the remaining generator(s) are to be capable of supplying all critical loads and minimal habitability loads. Without parallel operation, this usually results in two generators, each of which must be capable of supplying the worst-case electrical load. Given that ships rarely see a worst-case condition, the operating generator set is usually operating at less than optimum load. Utilizing three smaller sets, sized such that any two would supply the worst-case load, would result in less total installed capacity and permit the on-line unit(s) to operate at a more fuel-efficient loading.

Much energy from fuel is lost as heat through the engine exhaust or for engine cooling. The typical heat balance of a vessel with high-speed diesel engines for propulsion is shown in figure 3.

The ship designer can recover some of this lost energy by utilizing jacket water heat recovery to produce fresh water or for accommodation heating. Exhaust heat can

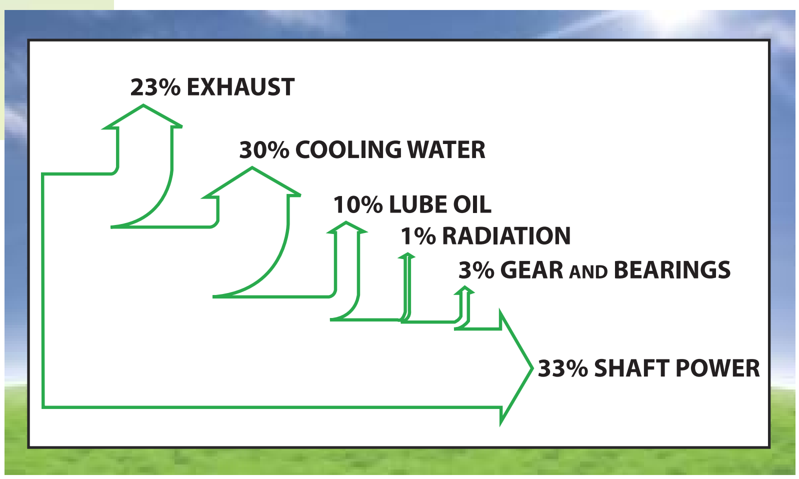

Figure 3: Typical heat balance of a vessel with high-speed diesel engines. Graphic courtesy of Elliott Bay Design Group.

be recovered and converted to steam through exhaust boilers for heating or for use in small steam turbo generators. In some ships, fuel efficiency gains can approach 10 percent.[8] Heat recovery is especially suited to ships that spend most of their time at transit speeds with the engines at or near their rated power. Opportunities for exhaust heat recovery will no longer be available when EPA Tier IV regulations are implemented; keeping the exhaust hot will be required for selective catalytic reduction and particulate filters.

Minimize Discharges to Water

Obviously, minimizing discharge into the water is a key guiding principle in environmental design. Ships such as large petroleum tankers and barges have been subject to the IMO, MARPOL, and OPA 90 double-hull regulations for some time, but smaller vessels have generally been exempted if they carry less than 500 cubic meters of fuel or have a damaged outflow less than a given criteria. Regardless of the size of the ship, placing oil tanks away from the side and bottom shell greatly reduces the probability of an oil spill in the event of grounding or collision.

An increasing number of ship owners are setting an ambitious and laudable goal of operating their ships to approach zero overboard discharge of waste. Achieving this goal requires a complex number of shipboard procedures and installed systems to either minimize the production of all types of waste and then process it for onboard reuse, or reduce and compact it for storage and shoreside recycling.

Past recent challenges have successfully addressed the elimination of oily waste discharge. The current challenge is the processing and total onboard recycling of black and gray water or treatment such that the overboard discharge is sterile water with no residual toxins. The future challenge will be treating ballast water to eliminate the transference of invasive species, again with no residual toxins. In each case, ship design and operation is evolving and adapting to suit these challenges.

Moving Forward

The greatest opportunity to achieve the greenest—as well as the most cost-effective—ship is in the early design phases of an acquisition program. Closely scrutinizing the ship's requirements and designing to them with a view to maximizing efficiencies is paramount to develop a vessel for best environmental practice. For ships already in operation, select design efficiencies and improvements can bring substantial benefit through greener technologies.

As designers, it is our goal to improve upon these practices and thereby benefit the environment and vessel owners and operators. It is very much the role of the designers—or, rather, their obligation—to our industry to introduce leading-edge best practices that will shape the future and health of our maritime environment.

About the authors:

Mr. Brian King, vice president of engineering at Elliott Bay Design Group, is a licensed professional engineer of mechanical engineering and marine engineering/naval architecture. He holds a B.S. in marine engineering from the U.S. Merchant Marine Academy and is a licensed U.S. Coast Guard chief engineer of motor and gas turbine ships, unrestricted, and a U.S. Coast Guard third assistant engineer steam vessels, unrestricted.

Mr. Joseph Payne, senior electrical engineer at Elliott Bay Design Group, is a licensed professional engineer, electrical engineering, and a LEED (Leadership in Energy & Environmental Design)-accredited professional. He holds a B.S. in electrical engineering from the University of Missouri, is a graduate of the Naval War College, and serves as an engineering duty officer captain in the naval reserve.

Mr. Ryan Roberts is a staff naval architect with Elliott Bay Design Group and a licensed professional engineer in naval architecture/marine engineering. He attended the Florida Institute of Technology, where he received his bachelor's degree in ocean engineering in 2000.

Ms. Christina Villiott is the marketing manager with Elliott Bay Design Group. She holds a bachelor of arts in marine education from Fairhaven College at Western Washington University and is a certified professional services marketer.

Endnotes:

1. U.N. "Atlas of the Oceans," based on studies between 1990-1995.
2. "Environmental Advantages of Inland Barge Transportation," U.S. Department of Transportation, Maritime Administration.
3. IMO Resolution 962, Ship Recycling.
4. Urea is essentially a liquid, non-hazardous form of ammonia that is injected into the exhaust gas stream as part of the selective catalytic reduction process for reduction of NOx emissions.
5. National Geographic, October 2007, Volume 212, number 4, page 54.

6a. Dominic Cusanelli and Christopher D. Barry, "Stern Flap Performance on 110 ft Patrol Boat *Staten Island*," Naval Surface Warfare Center.

6b. Dominic S. Cusanelli and Liam O'Connell, "U.S. Coast Guard Island Class 110 WPB: Stern Flap Evaluation and Selection," Naval Surface Warfare Center.

7. Gordon Hart, "Ship Configurations: Insulation Design and Application," Insulation Outlook (NIA, Nov 2004).
8. Anders Hultqvist, "A Ship Owner's View of Engine Choice and Emissions," operational experience of the container ship *Emma Maersk* using main engine exhaust gas boiler and steam turbine to generate ship's power. Presented at Lloyd's Marine Engineering Forum, London, September 2007.