REGIONAL CLASS RESEARCH VESSEL DESIGN

Green Ship Initiatives

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Executive Summary

The purpose of this report is to discuss green ship initiatives in the design of the Regional Class Research Vessel (RCRV) that can reduce energy use and improve environmental performance.

A number of green ship alternatives were examined in the areas of the hull, propulsion system, auxiliary systems, pollution control, and outfitting. The options that were evaluated were considered in conjunction with the mission profiles of the vessel. Table 1 summarizes the considered alternatives that were incorporated in the design. Each of these alternatives and the basis of benefit(s) are discussed in detail in the report.

Table 1 Green ship incorporated alternatives

Green Ship Alternative	Benefit/Rationale
Hull	
Hull form optimization	15% reduction in resistance
Hull coating-hard coating with frequent in water cleaning	No biocide toxin release
Propulsion	
Variable speed generators	Estimated 5-15% reduction in fuel consumption
Permanent magnet alternators and motors	Increased motor efficiency
Wake adapted propellers	Increased propeller efficiency, decreased underwater radiated noise
Twin propeller pods	Increased propulsive efficiency
Electrical System	
VFD pumps and fans	Electrical savings, possible noise attenuation concern
Premium efficiency motors	3-10% electrical savings
LED Lighting	Lower energy use, higher upfront cost
Auxiliary Systems	
Waste heat recovery	Provides heat for HVAC, water makers, and domestic hot water. ~350 kW electrical savings
Climate control – waste heat heating	Can replace electric heat for large heaters, 70+ kW electrical savings
Novec 1230 fire suppression	Minimum application of greenhouse gas
Non-ozone depleting refrigerants	Minimize environmental damage
Pollution Control	
Biologic MSD	Clean effluent
5 PPM OWS	Minimize oil discharge
Fuel overflow system	Minimize risk of accidental fuel oil discharge

Green Ship Alternative	Benefit/Rationale
Environmentally acceptable lubricants	Minimize impact of accidental oil discharge
Minimize underwater radiated noise	Minimize noise pollution
Ballast water treatment system	Required, reduces spread of invasive species
EPA Tier 4 engines	Reduce engine air emissions
Solid waste storage	No incinerator air emissions
Outfitting	
3" minimum insulation	Reduce heat loss/gain
Sustainably sourced, environmental friendly materials	Minimize environmental impact

Additional technologies were examined throughout this process. For example, biodiesel was considered as an alternate fuel. While it does not have a direct impact on the design of the vessel, it does present operational issues. It would be possible to use biodiesel in the vessel.

Table 2 lists the alternatives that have not been incorporated into the design.

Table 2 Green ship alternatives - not recommended for incorporation

Green Ship Alternative	Rational
Propulsion	
Battery hybrid	Minimal benefit with variable speed generators. Adds cost & weight.
Alternative fuels, LNG	Integration of LNG system incompatible with vessel design
Electrical System	
Solar system	Minimal benefit with available installation area
Auxiliary Systems	
Climate control – air/air heat exchangers	Impractical due to space constraints, may offer benefit if feasible
Climate control – heat pump	Less efficient than waste heat heating, equivalent to chiller A/C

Hull

Hull Form Optimization

Within the constraints imposed by the dimensional, arrangement, and stability requirements of the vessel, the hull lines have been optimized to minimize the resistance of the hull. This reduces the power necessary to propel the ship resulting in reduced fuel consumption, emissions, and operating cost. Glosten's subcontractor, FutureShip, used a proprietary potential flow computational fluid dynamics (CFD) computer program code to optimize the hull form and propeller locations for resistance and powering. The optimization balanced the need to provide clean flow over the transducers with the desire to reduce the power required to propel the hull at cruise speed.

The optimization resulted in a 15.8% reduction in the required thrust at the cruising speed compared to the base hull form developed in the design refresh. This reduction in thrust results in a fuel savings of approximately 4,500 gallons over a 5,400 nm range based on calm water powering calculations. This equates to a reduction of approximately 50 tons of CO_2 over this distance, based on CO_2 emissions from diesel fuel data from the US Energy Information Administration.

Hull Coatings

Traditionally, anti-fouling paints have been used to control the growth of organisms on the hull. The growth of these organisms has two negative impacts. The first is that the growth contributes to hull roughness and increases hull resistance. The second is that those organisms can be transferred as invasive aquatic species.

Historically, the means for controlling growth was to use paint with a heavy metal or biocide that kills organisms when they try to attach to the hull. The problem with these coatings is that the toxicity is not limited to the hull itself, but leaches out of the paint and enters the environment. The use of tributyltin (TBT), an especially effective but toxic form of biocide, was phased out beginning with the ratification of the *International Convention on the Control of Harmful Antifouling Systems on Ships* (Reference 3). Most biocide antifouling paints are currently copper based; however, there are non-copper alternatives.

Another class of antifouling paint is foul release paint. Foul release paints do not contain a biocide. They work by creating a slippery, low friction surface to which fouling organisms have difficulty attaching. When the vessel is traveling at speed, the fouling organisms are washed off the surface. Foul release coatings do not inhibit growth while stationary, however, and require speeds of at least 10-12 knots to release.

Paint manufacturers have suggested that foul release coatings can result in fuel savings of 5 - 9% for typical large merchant vessels due to the reduction in resistance due to fouling compared to traditional non-TBT antifouling paints. However, these studies were conducted for vessels operating at higher speeds than the RCRV. Foul release coatings are three to four times more expensive than traditional non-TBT antifouling paints, and are less durable in terms of abrasion resistance (i.e. more susceptible to damage).

The current recommended practice is that the entire hull, including all niche areas, be coated with a long-lasting, hard hull coating. These coatings can be routinely cleaned without releasing toxins into the water. Paints such as glass-flake vinylester resins are one type of coating. The potential downside of these paints is that in-the-water cleanings are required on a more frequent basis. According to various manufacturers, these coatings can reduce fuel consumption by up to 5%.

With regard to the transfer of invasive species, it is also imperative that seachests be designed with hinged and/or easily removable gratings for easy cleaning access. These areas may accumulate a large amount of biological growth that could be unintentionally transferred between ports if left uncleaned.

Specifications for these coatings will be developed to be in accordance with IMO *2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize Invasive Aquatic Species Transfer* (Reference 4).

Propulsion System

Propulsion System Architecture

The propulsion system will be an integrated diesel-electric system. Electrical power for both propulsion and ship service power will be generated by multiple diesel generator sets operating on a common bus. The use of multiple generator sets not only provides redundancy in the electrical plant, but also flexibility. Generators can be brought online and offline to match the power demands. This allows the power management system to operate the generators nearer to their peak efficiency points than could be achieved with fewer, larger engines.

The design will utilize three generators producing 835 ekW each. With load cases requiring from 600 to 1,900 ekW, the power management system will have significant flexibility for matching the electrical load to the efficient operating points for the engines.

Variable Speed Diesel Generators

Variable speed diesel generators will be utilized in the vessel design. Variable speed generators produce constant voltage AC power at a variable frequency. The system includes rectifiers to produce DC power, feeding into a common DC bus. Because the power from the generators is converted to constant voltage DC, the alternator does not need to maintain a constant synchronous speed as is required for maintaining the frequency in parallel operation of synchronous AC generators.

The DC power is then converted to clean AC power with power conversion equipment. The larger motor loads can be fed directly from the power conversion equipment eliminating the need for phase shifting transformers and additional electrical drive equipment. 60 Hz AC power is fed to a 480 VAC Ship's Service switchboard serving the smaller motor loads and house loads. With advances in digital electronics, the conversions between AC and DC power happen far more efficiently than in the past.

The ability to vary the speed of the diesel generator allows a much broader fuel map for the engines than is available in a constant speed engine. This allows the engine's control system to select an operating point for both speed and power that maximizes the efficiency of the engine and reduces fuel consumption. A 5-15% reduction in fuel consumption may be possible depending on the operating profile of the vessel. This also results in reduced air emissions and because engine maintenance intervals are determined by fuel consumption, this extends engine overhaul intervals thereby reducing lifetime operating costs. The benefit of the variable speed generation can be seen in the specific fuel consumption comparison shown in Figure 1.

The largest benefit comes when operating below 50% loading, because this is an area where constant speed generators are very inefficient.

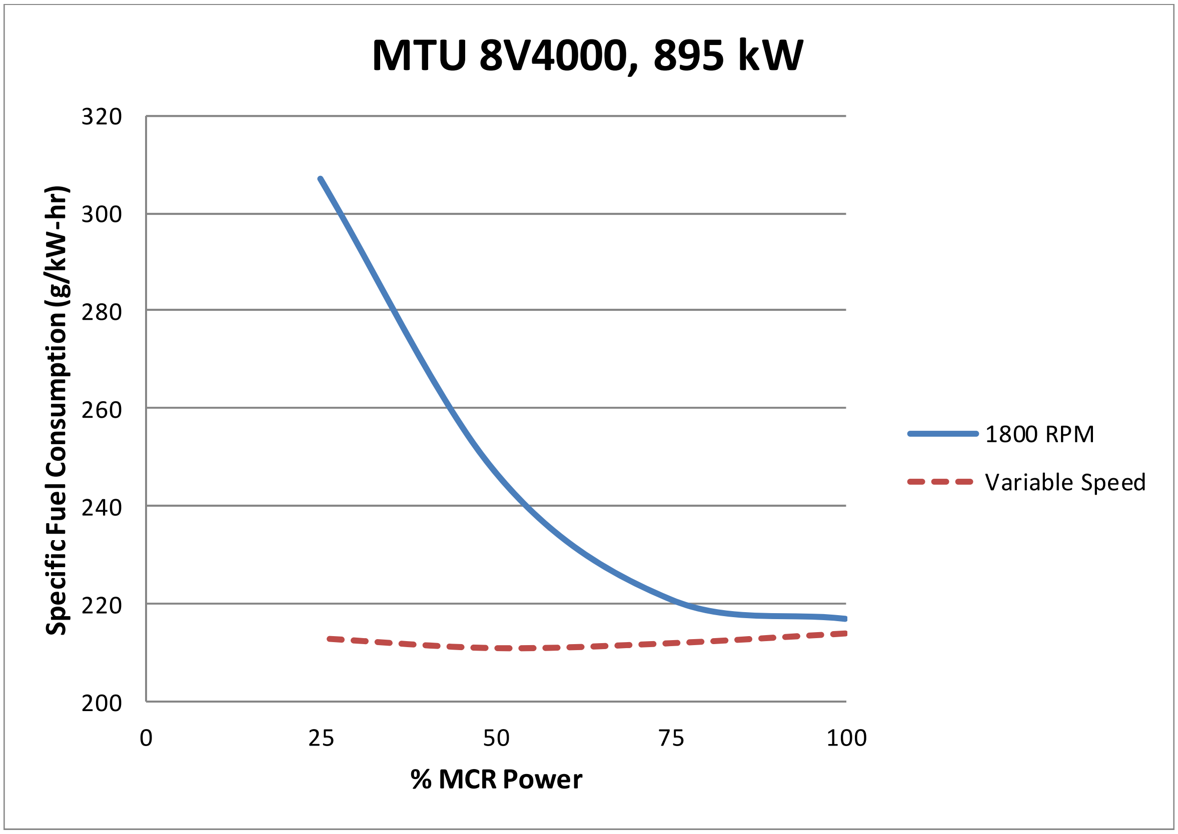

Figure 1 **Fuel consumption comparison**

Variable speed generators (VSGs) are a recent development in the marine industry. They do, however, have a history in industrial applications and are now being extended into marine applications. Further development and adoption of marinized VSG technology for ship electrical power generation will continue within the next few years.

Permanent Magnet Alternators and Motors

Permanent magnet (PM) AC alternators and motors are inherently more efficient than conventional induction machines due to elimination of rotor conductor losses, lower resistance windings, and "flatter" efficiency curves. Due to their synchronous operation, PM motors offer more precise speed control. PM motors provide higher power density due to the higher magnetic flux as compared with induction machines. Finally, PM motors generally operate at a cooler temperature, resulting in longer bearing and insulation life. Similar advantages are also seen in PM alternators.

It is recommended that PM motors be used for the propulsion motors and bow thruster motors, if available. Additionally, it is recommended that PM alternators be used in the generator sets, if available.

Wake-Adapted Propellers

Wake surveys from CFD and physical model testing will be used to develop wake-adapted propellers for the vessel. Through this process, the propeller design can be tuned to the vessel's specific wake characteristics. The advantages of wake-adapted propellers include both reduction of underwater radiated noise and increased propeller efficiency. Wake-adapted propeller efficiency gains of 2-3% over stock propellers are common.

Twin Propeller Drives

The selected propulsors for the vessel are Z-drives with twin propellers. Having two propellers results in lower pressure loading on the propeller blades compared to a single propeller delivering the same thrust. This reduced pressure has a twofold advantage by reducing propeller noise and increasing propeller efficiency. It is difficult to characterize precisely the efficiency increase without significant analysis because it is highly dependent on the propeller design and the vessel's wake. However, Schottel suggested that a 10% increase in efficiency of a twin-propeller pusher/puller type z-drive may possible compared to a single propeller pusher type unit.

Battery Hybrid Plant

Recently, battery hybrid technology has been used in harbor tugs and other types of vessels with some success. The technology for this type of system on ships is continually evolving, especially for the batteries. The use of the hybrid approach allows fixed speed engines to be run at efficient power levels even if the demand for power is not present, with the excess power going to charge the batteries. Battery power can then be utilized to supplement diesel power once the batteries are charged. This is typically used for vessels with short duration peak loads (i.e. peak shaving) such as harbor tugs, or it is used for high transitional power demands such as time between generator failure and a subsequent generator coming on-line (critical dynamic positioning applications such as a drill ship). A hybrid plant can also be effective for extended loitering periods at very low power levels. Such peak shaving or loitering applications are not expected to be representative of the RCRV's anticipated operational profile.

Reference 10 gives a summary estimate of the operational scenarios of the *R/V Sharp* over an average operating year. The results have been tabulated in Figure 2. Reference 16 summarizes the calculations of the expected electrical plant loads for the RCRV for similar operating profiles to those of the *R/V Sharp*. Calculations show that variable frequency generators will be operating at near optimal values for the entire operational profile (see Figure 1 and Table 3). This will negate the primary peak shaving benefits of hybrid power as well as the loitering case benefits. Consequently, the benefits of a battery solution would not be fully realized for this application. The design does not incorporate a battery hybrid propulsion plant as it would also add unnecessary cost and weight.

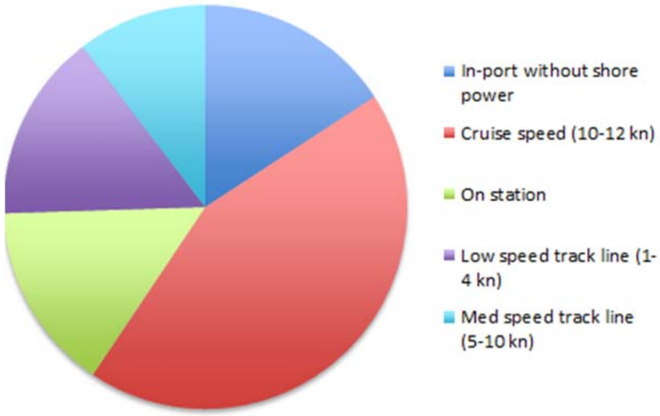

Figure 2 ***R/V Sharp*** **average annual operations estimate**

Table 3 Relative fuel consumption of various operational scenarios

Operational Scenario	Load (kW)	No. Gensets Operating	Generator Load (% MCR)	% Optimal Fuel Consumption
In port without shore power	323	1	37%	98%
Cruise speed (10-12 kts)	1367	2	79%	98%
On station	866	2	51%	100%
Low speed track line (1-4 kts)	1093.5	2	61%	99%
Med speed track line (5-10 kts)	1321	2	77%	98%

Although a fixed hybrid battery plant is not recommended for RCRV, the possibility of a mobile "battery power van" could be explored. The battery power van would be intended to provide temporary ship service power in lieu of diesel generators for limited duration scientific studies that require zero emissions. At this point it is unlikely that the power density achievable in a battery power van would be high enough to provide propulsion power.

Alternate Fuels

LNG

The use of alternate fuels such as liquefied natural gas (LNG) is being explored by the marine community as a way to reduce nitrous oxide (NO_x) and sulfur oxide (SO_x) emissions, and meet regulatory mandated emission levels. LNG has the added advantage of presently being significantly less expensive in the US than ultralow sulfur diesel fuel. However, there are significant challenges that make the use of LNG on the RCRV not feasible at this point in time. These include LNG availability, tankage/volumetric limitations and tank arrangement constraints.

While LNG is becoming more available as a shoreside vehicle fuel, the availability of marine bunkering facilities for LNG is still very limited. Most LNG-fueled vessels, with the exception of LNG carriers, are bunkered from trucks or dedicated shore facilities that are resupplied by trucks. At this time, most of the world's ports do not have LNG readily available. Because the RCRV will not have a set trade route, the limited availability of LNG would making refueling planning for LNG much more difficult, and might result in additional regional restrictions for vessel operations.

The tankage requirements for LNG are typically two to three times larger than for diesel fuel tanks. There are three reasons for this: one, the volumetric energy density of LNG is two-thirds that of diesel fuel; two, LNG as a liquid is stored under pressure, requiring cylindrically-shaped tanks rather than hull tanks; and three, LNG is cryogenic and requires insulated tanks, further restricting potential tank locations. Consequently, it is difficult to locate and integrate LNG tanks efficiently into the hull.

Coupled with the LNG tank sizing issue is the tank location issue. The location of LNG fuel tanks below accommodations spaces is not currently accepted by the USCG. This would require that LNG tanks be located either below the aft working deck or on or above the open deck (Main Deck or 01 Deck). Locating the fuel tanks in any of these locations would severely limit the scientific capability of the vessel and are not deemed practical.

Consequently, it is not recommended that LNG be considered as a fuel for the RCRV.

Biodiesel

Biodiesel is another alternative fuel that has been used primarily on a trial basis in the commercial marine industry. In general, specialized equipment is not required for use of biodiesel and many major diesel engine manufacturers have accepted the use of biodiesel blends up to 20% (B20) provided that it meets the manufacturer's fuel specifications.

There are some drawbacks to the use of biodiesel for a marine fuel. The US Maritime Administration (MARAD) discussed the use of biodiesel in the US marine industry in a study published in 2010 (Reference 11). In the study, the limited availability of biodiesel at marine bunkering facilities was cited as a concern as was inconsistent quality, fuel instability, plugging of filtration equipment, and hose and seal material incompatibility. Additionally, the study noted that some reduction in power, 3% for B20, is associated with the use of biodiesel.

Glosten conducted a trial on the use of biodiesel on several ferries with Washington State Ferries. During the transition from petroleum diesel to biodiesel, significant plugging of fuel filters and purifiers was experienced as biodiesel released deposits left from petroleum diesel in the fuel system. Additional plugging of filters and purifiers due to microorganism growth necessitated the addition of biocides to the biodiesel. After a transition period, problems were resolved and B20 was successfully used. Washington State Ferries continues to use B5 (5% biodiesel) in their vessels, but has discontinued the use of B20 primarily due to cost concerns.

If a reliable supply of high quality biodiesel can be secured, it may be viable as a blended fuel up to B20. However, fuel stability concerns would need to be addressed and fuel planning would need to ensure that fuel turnover rates are high enough to avoid aging-related fuel stability problems. Additionally, switching between petroleum diesel and biodiesel could be a cause for concern with filter and purifier plugging.

Electrical System

Pumps and Fans

Pumps and fans are typically sized for the maximum demand in a worst case scenario (i.e. the "design day"). The day to day demands in typical operation are significantly less than the design day worst case. Variable frequency drives (VFD) can be used to allow turndown of large fan and pump motors for operation when the full design capacity is not required. Power consumed by a pump or fan follows the affinity law:

$$P = P_0 \times \left(\frac{n}{n_0} \right)^3$$

where P is the power consumed by the pump or fan, and n is the RPM.

Thus, for example, a 25% reduction in the speed of a pump results in a 58% reduction in the power demand. The turndown of the pumps and fans can either be manual or automatic.

Large pumps that run continuously are good candidates for VFDs. For example, the seawater pumps could be set up for a temperature controlled operation in which they are turned down when the cooling demand decreases, thus preventing the use of unnecessary energy in pumping high volumes of seawater.

The use of VFDs does add some cost to the motor and control equipment and adds additional complication to the pump or fan controls, especially if automatic controls are used. Additional controls and sensors add additional failure modes and maintenance items. The efficiency gains need to be thoughtfully balanced against the added cost and complication.

Two additional concerns with using VFDs are electrical system harmonics and vibration/noise control. Specialized electrical cabling, controls and motors need to be used with VFDs to ensure the motors operate properly and do not induce harmonic distortion to the ship's electrical system. Secondly, attention must be given to the noise attenuation of the equipment. Typically, structure borne noise is mitigated through the application of resilient mounts for equipment. These mounts are tuned based on the excitation frequency of the equipment. When a VFD is installed, the excitation frequency of the equipment varies, increasing the complexity of noise mitigation.

VFDs are worth considering for the larger pumps and fans that run for extended periods of time. The design will incorporate VFDs on the chilled water pumps, waste heater recovery pumps, and several of the larger air handlers and ventilation fans. These are all equipment that typically have large motors sized for worst case peak demands, but that are often operated with significantly reduced demand.

Electric Motor Efficiency

Typically electric motors come in three different efficiency ratings: standard, EPAct compliant, and NEMA premium. Figure 3 shows a comparison of the average efficiencies for the various types of electric motors.

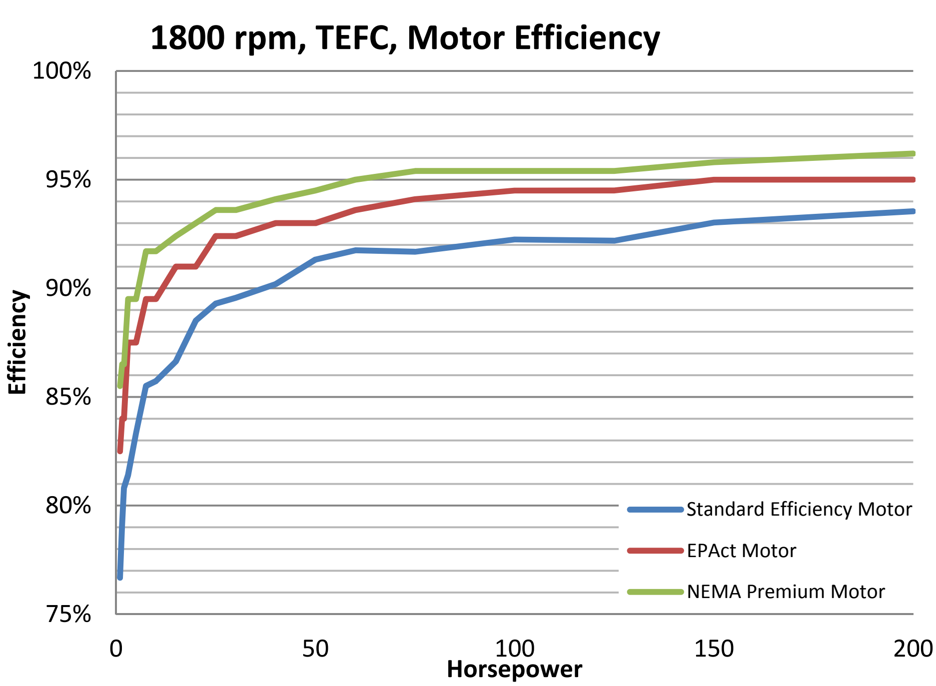

Figure 3 Example motor efficiencies

Since electric motor capital cost increases with increased efficiency, selection of motor type should be based on anticipated frequency use. Motors in equipment that is run frequently or for extended periods of time are recommended to be premium efficiency motors.

Lighting Systems

Light Emitting Diodes

Traditionally, the interior lighting on commercial vessels has been fluorescent light fixtures. Fluorescent lighting is low cost, has low energy use, and has bulbs and fixtures that are readily available. There have, however, been recent significant advances in commercial marine quality LED lighting systems.

Typical LEDs offer better directional control of light when compared to fluorescent lighting, which increases the coefficient of utilization (CU) value by ~30%. The fixtures themselves are slightly more efficient, but not significantly. Lamp efficiency of fluorescents is approximately 72-90 lumens/watt, whereas LEDs are on the range of 75 - 98 lumens/watt. However, because of the increased CU values, fewer LED fixtures would be required. (Note that the fluorescent lamp used as a base is a 4', T8 type tube. LED "lamps" are commonly a module with an array of small LEDs. LED tube lamps, intended to replace a fluorescent lamp in an existing fixture, are manufactured. One [from LED Global Systems] was used for some comparisons in this study.)

The life of an LED light operated at a temperature of 25°C is around 90,000 hours. In the machinery spaces, which are closer to a temperature of 45°C, the life drops to around 60,000 hours. In comparison, a fluorescent lamp has a typical life of 20,000 hours in either temperature scenario.

LED lights typically have a lower startup time (instant on) and, as such, could be a better match for use with more advanced (motion detection/occupancy) type controls, as well as being a better match for cold spaces where the startup time of fluorescents lags.

Currently, LED fixtures (with lamps) are 2-2.5 times the cost of fluorescent fixtures, while the LED lamps (linear T-8 replacement tubes) are approximately 8-10 times the cost of fluorescent lamps. In LED fixtures with an array, the replacement cost is approximately 18 times that of fluorescent lamps. However, these costs should continue to decline as the LED technology and market continue to develop. Further consideration and monitoring of this technology is recommended as the cost benefit analysis will likely change over the next few years.

One concern regarding fluorescent lamps that is not a problem with LEDs is the disposal of the lamp, and the effects of the mercury used in the lamp. About 4 mg of mercury is in each fluorescent lamp. Mercury is slowly absorbed in the lamp's glass, phosphor, and tube electrodes, over the lamp life, so that there is very little mercury remaining at the end of the life. The lamps should be recycled, where the remaining mercury is reclaimed for reuse. Mercury is a neurotoxin, but, unless the lamp is broken, poses no known environmental or health threat. Special cleanup procedures are recommended should any fluorescent lamp be broken.

LED fixtures appear to be a viable substitute for linear fluorescent lights, with the exception of capital costs. While more expensive initially, LEDs use less power, overall, than fluorescent fixtures, resulting in less fuel burned, and less CO_2 release. The service life of

LEDs (~6.8-10.3 years) versus fluorescent lamps (~2.3 years) makes them attractive from a maintenance standpoint, however, the cost of maintenance is less with the fluorescents. For specific applications, such as in cold spaces or in spaces where optical fatigue could be an issue, LEDs should be considered.

Lighting Controls

Motion-sensing light switches have been incorporated to turn off lights where they may otherwise be left on while a space is unattended.

Solar Power

Solar power systems have been discussed over the course of the RCRV development. The space available for installing solar panels is limited because most of the deck area on the vessel is designated for science work, walkways, or maintenance and access. The practical available area for solar panels is about half of the Pilothouse top, or 400 square feet. Currently available commercial solar panels can produce a maximum of about 16 W/ft^2 with direct sunlight. Under average conditions, however, the output is more likely to be around 8-10 W/ft^2. Based on 5 hours of full sunlight per day (average for California), the solar panels could generate about 18 kW-hrs per day, or enough power to run nine typical 2×40 W fluorescent light fixtures. Integrating the solar system into the ship's power system is likely to cause more complication than it is worth for the minimal power output of the panels. Additionally, combatting icing on the panels if the vessel is operating in icing conditions may be difficult without damaging the solar panels. It is not recommended to use solar panels on the RCRV except perhaps as an alternative for batteries for some standalone scientific sensors.

Auxiliary Systems

Waste Heat Recovery

Typically diesel engines are about 40% efficient. This means 60% of an engine's output (or 1.5x the output brake horsepower) is lost as heat to the engine exhaust, engine jacket (cooling) water, and ambient air. Waste heat from diesel engines can readily be recovered and used for a variety of services including potable water generation, domestic hot water heating, and/or climate control heating. An evaluation of the heat available for recovery is included in Reference 14.

A waste heat recovery system would consist of jacket water to hot water heat exchangers for each main diesel engine that would transfer the heat from the engine jacket water to a secondary waste heat system used to supply the evaporators, HVAC system heating coils and domestic hot water heat exchanger. The use of waste heat for the services mentioned would reduce the electrical power or diesel fired heater demands that would otherwise be required for those services.

The downside to a waste heat recovery system is that it adds additional piping, pumps, heat exchangers, and system controls. This increases the weight, complexity, cost, and maintenance of the vessel's auxiliary systems. However, the increased capital cost is quickly offset by reduced electrical demand.

The amount of waste heat that is rejected by the main diesel generators is significant. In fact, a single diesel generator providing only ship service power has enough recoverable waste heat to meet over 95% of the maximum demand of a water maker and all the HVAC heaters for the -4°F design day. Under this condition, the diesel-fired water heater would provide the additional 5% of heat required, and potable water heaters would revert to their electric heating elements. With two generators online, the waste heat available exceeds the combined demand for water making, HVAC heating, and potable water heating. In total, this replaces approximately 485 kW of electrical heating with recovered waste heat that would otherwise be dumped to the sea. For this reason, a waste heat recovery system has been incorporated into the vessel design.

Heating System Design

The selection of the vessel's heating system considers the tradeoff of an all-electric heating option versus hot water heating using a combination of waste heat and a diesel fired water heater. Because of the losses associated with using electrical power generated with diesel generator sets, a diesel water heater can be substantially more efficient than electric heat (up to 2 times more efficient). Additionally, a hot water heating system can be readily integrated with the waste heat recovery system. The primary downside to hot water heating is that it requires additional piping systems; this increases installation cost and maintenance, and requires more space than electric heat.

Because sufficient waste heat is available, a traditional chilled water plant for cooling and a waste heat hot water system for heating is the preferred design solution. It is, however, only practical to use the hot water heating system for the large preheaters in the air handling units and for larger unit and duct heaters. A hot water heating system distributed to all the small terminal heaters throughout the vessel would require too large a piping system to be practical. Therefore, it is recommended that the smaller heaters be electric.

Fire Suppression

Several options exist for fixed fire suppression for machinery spaces, including carbon dioxide (CO_2), chemical agent (FM-200, Novec 1230), and inert gas (Inergen, i3). All of these systems have advantages and disadvantages. Carbon dioxide is the least expensive, has no ozone depletion potential, and a global warming potential (GWP) of one. However, CO_2 at the concentration required for fire suppression is lethal. Because of this, CO_2 is not recommended.

Alternative chemical agent and inert gas systems are safe to use in manned spaces and have varying cost, size, and environmental impacts. Inert gas systems use various blends of inert atmospheric gases to reduce the oxygen level of the space below that required for combustion of most materials, but high enough that it is breathable. These gasses have no greenhouse gas content or ozone depleting potential. However, inert gas systems require more space than the chemical agent systems.

Both chemical agent systems investigated have no ozone depletion potential. FM-200 is a hydrofluorocarbon (HFC), with a GWP of 3220 and an atmospheric lifetime of 34.2 years. Novec 1230 has a GWP of 0.54 (less than CO_2), and persists in the atmosphere for only 5 days. Novec 1230 is slightly more expensive and requires slightly more agent than FM-200. Based on these considerations, Novec 1230 has been selected as the fire suppression agent.

Refrigeration Systems

The air conditioning machinery and refrigeration machinery will use EPA approved, non-ozone depleting refrigerants. Due to their different temperature ranges, it is likely that the air conditioning and refrigeration machinery will need different refrigerants.

Climate Control (HVAC) Systems

Because of the large deckhouse and accommodations on the RCRV, the vessel will have a significant HVAC system. There may be opportunities to increase the energy efficiency of the HVAC system. However, there are significant space constraints due to the limited space available and large size of energy efficient system components (see below). This limits the practicality of some of the high efficiency HVAC system technologies.

Air-to-Air Heat Exchangers

An example HVAC component with a potential for energy saving is heat recovery air-to-air heat exchangers. These heat exchangers use the exhausted air to precondition the outdoor makeup air. In the cooling season, this would cool the makeup air, and in the heating season, it would preheat the makeup air. This would reduce the cooling and heating demands for the makeup air. The air-to-air heat exchangers can be up to 85% efficient. These systems are used effectively shore side and on large cruise ships. These components tend to be large, typically doubling the size of the air handlers, and successful integration into the HVAC systems on the RCRV with the available space limitations is not possible.

Heat Pumps

Another HVAC system that has been explored is a heat pump which can be used for both heating and cooling. On a ship, a heat pump would need to use the seawater or a freshwater loop as the heat source/sink. Two marine HVAC vendors that were contacted suggested that a heat pump was not a very common marine installation and would not be their recommended system for this vessel.

The primary concerns raised by both vendors contacted by Glosten were that, because the vessel may occasionally operate in cold or ice bound waters, the heat pump may not be able to extract sufficient heat from the seawater heat source during the most severe heating conditions and may experience freeze ups. These concerns could necessitate a backup heating system with added cost, weight, and complexity.

Another concern was the added complexity and maintenance of heat pump refrigeration systems that operate continuously in both the heating and the cooling seasons. Refrigeration systems tend to require significant maintenance and repair. Additionally, a heat pump system cannot provide simultaneous heating and cooling in different zones of the ship. This can be a problem because the pilothouse often requires air conditioning well before other spaces due to its high solar load.

Pollution Control

Marine Sanitation Device

The current regulation governing the discharge of sewage at sea is Annex IV of MARPOL (Reference 1). While the United States is not a party to Annex IV, a vessel operating on international voyages is subject to foreign port state action if it does not comply with Annex IV. It is anticipated that as the RCRV will be engaged in foreign voyages, the MSD will comply with the requirements of Annex IV at the minimum. This requires that the MSD be certified to IMO MEPC 159(55) (Reference 12).

The Piranha system marine sanitation device is being considered for this vessel. The Piranha system uses biological treatment to break down sewage. The effluent from the process is clean water that exceeds the EPA reuse requirements.

Oil Discharge

Oily Water Separators

The primary regulation governing the discharge of oil is MARPOL Annex I, which limits oil discharge to concentration of 15 ppm or less. However, oil discharges of less than 5 ppm are currently required for vessels operating in Canadian inland water, including the Great Lakes. It is reasonable to expect that 5 ppm discharge limits may be expanded to additional areas as environmental laws become increasingly restrictive. There are numerous oily water separators (OWS) available that meet the MARPOL requirements. There are also several OWSs on the market that can exceed the current requirements and produce effluent with less than 5 ppm.

To achieve the lower discharge oil content, 5 ppm certified OWSs generally require additional separation equipment, which adds somewhat to the size and cost of the unit. However, given that the RCRV may be operating in sensitive areas, to the design will use the best available technology with a 5 ppm OWS.

Fuel Tank Venting and Overflow

The fuel tanks will be fitted with an overflow system to prevent spillage during bunkering and fuel transfer operations. Containments or drip pans will be required under oil system equipment to contain any leaked oil.

Lubrication Systems

Environmental acceptable lubricants (EAL) should be used where technically feasible for all oil-to-sea interfaces or where a lubricant has a reasonable potential for being washed into the sea. These applications include hydraulic oil and lubricants for deck machinery, wire lubricants, and thruster lubricants. EALs as defined in Reference 9 are lubricants that are biodegradable, minimally toxic, and are not bioaccumulative.

Noise Pollution

Underwater noise generated by vessels, while not a regulated source of pollution, has increasingly gained attention as causing disturbance and harm to marine life. The RCRV design will minimize sources of underwater radiated noise to the greatest extent practicable in order to meet stringent underwater radiated noise criteria. Reduction of noise will be achieved through selection and maintenance of equipment, resilient mounting for large rotating machinery, and wake adapted propellers.

Ballast Water Treatment System

Under 33 CFR§151 (Reference 13), new vessels are required to meet restricted ballast water discharge criteria. To meet these criteria, a ballast water treatment system (BWTS) will be required. Ballast water treatment systems are still a developing technology. The three main types of these systems are filtration/UV, filtration/ozone, and chlorination (usually electrochlorination).

Under current regulations, ballast water treatment systems for vessels operating in the US are required to be USCG type approved. There are several systems with IMO type approval; however, none have USCG type approval to date. Temporarily, the USCG will accept some BWTSs that have been approved by another flag state as Alternate Management Systems (AMS). A system installed under AMS may only be used for five years after the discharge standard compliance date for the vessel. After that period, the system must be USCG approved or replaced with a USCG approved system. Further complicating the selection of a BWTS is that many of the systems are sized for larger vessels with more ballast throughput.

It is likely that by the time the RCRV is built, one or more systems will have received USCG type approval. However, which systems will receive USCG type approval is currently an unknown. A review of the available BWTS technologies should be conducted at each design cycle to determine the most suitable system for this vessel based on current technologies, system sizing, and type approval status.

Air Emissions

The main diesel generator engines will be EPA Tier 4 compliant. EPA Tier 4 encompasses the highest level of reduction of regulated air emissions under the EPA's current multi-tier standards for marine diesel engines. The Tier 4 emissions regulations for engines of the size and type used on the RCRV will enter into effect in 2017.

Because the regulations are not currently in force, engine manufactures have not fully developed the emissions treatment systems. However, it is expected that exhaust after treatment with selective catalytic reduction (SCR) using aqueous urea and special catalysts will be used. This technology is currently used in both land based diesel engine applications and in some marine applications with larger engines. The vessel design accounts for use of this technology. However further development is required as the details of the SCR systems evolve during the lead up to the entry into force of the regulations.

Solid Waste

Solid waste will be compacted and stored in bales aboard the vessel. Solid waste with food contamination will be compacted into bales and refrigerated for storage. This eliminates the air emissions associated with garbage incineration. Stored waste can be offloaded in port for proper disposal ashore. A region-based waste management plan will need to be developed by each operator with a goal of reducing waste generated onboard, separating recyclables and garbage, and properly disposing of waste.

Outfitting

Insulation

Additional insulation on exterior surfaces of air conditioned or heated spaces can be considered to reduce heating and cooling loads. The tradeoff of additional insulation is added weight and cost. It is suggested in Reference 5 to use a minimum of 3" of insulation with a 1.5" beam wrap. The use of insulating coatings should be considered in areas where fiber insulation cannot practically be used and thermal or acoustic insulation is beneficial.

Materials

Consideration should be given to the use of sustainably sourced and environmentally friendly materials in the outfitting of the vessel. In particular, the use of low VOC coatings, adhesives, and floor coverings is recommended where a suitable product is available.

Certification and Class Notations

There are a number of voluntary environmental certifications, class notations, and stewardship programs available to ship owners and operators, ranging from vessel-specific to organizational in scope. For the most part, these notations and certifications recommend and standardize best practices for energy efficiency and for reduced emissions and waste streams. Monitoring and benchmarking are typical requirements for participation. Some, such as ABS ENVIRO/ENVIRO+ notation, also have some specific vessel design considerations. Much of the green ship design alternatives discussed in this report could be documented and recognized under these programs. While these certifications and notations do not necessarily produce any additional functional environmental performance improvements, they can be a useful tool for assessing and analyzing environmental performance, and can be useful in community outreach.

The downside of many of these certifications is that that they can require significant administrative cost and burden to the vessel operator and the ship's crew, that in and of itself does not provide additional environmental benefit, only documentation. ABS ENVIRO/ENVIRO+ is one such program that does have significant administrative requirements that would add non-trivial overhead costs to construction and operation of the vessel.

OSU has explored other voluntary certifications with less administrative burden. Two such programs that OSU intends to pursue are the Environmental Ship Index (ESI) and Green Marine.

ESI is a program for reducing and managing air pollution and CO_2 emissions. Vessels are assigned a score based on their emissions which is automatically calculated and maintained without significant cost to the owner. Port and other parties may offer incentives to participants based on the ESI score.

Green Marine is a certification program recognizing continuous environmental performance improvement. Ratings are given in ballast water, air emissions, bilge water, and garbage management. Participation in this program does have annual membership fees and requires self-evaluation and publication of results with biennial external audits. This program requires participation of all vessels within a class.

Conclusions

During the Design Refresh, many green ship initiatives aimed at reducing the environmental footprint of the RCRV have been considered and evaluated for their benefits and costs. Of the initiatives considered, a considerable number have been implemented in the design. These include initiatives to reduce energy consumption such as waste heat recovery, hull and propeller optimization, and VFD controls; and initiatives to reduce pollution such as using a best available oily water separator, ballast water management system, and exhaust after treatment system. The overall result is a vessel design that goes well beyond the regulatory minimums for protection of the environment and for human habitability.