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The Royal Canadian Navy Fleet: A Pathway to Decarbonisation

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In November 2020, the Treasury Board announced that the updated Government of Canada Greening Government Strategy (GGS) would include national safety and security operations as part of its 2050 net-zero emissions target.[1] While the safety/security fleet is exempt from having to achieve the 40% and 90% emissions reduction targets (below 2005 levels) set for 2025 and 2050 respectively, it is expected to develop decarbonisation plans that include "using more environmentally friendly technologies and low carbon fuels when available, affordable and operationally feasible" and to "adopt best practices to improve efficiency and reduce emissions and environmental impacts."[2]

In the fiscal year 2019-2020, the Department of National Defence (DND) aircraft, marine vessels and land vehicles emitted 706 kilo tonnes of carbon dioxide equivalent (kt CO_2 eq).[3] Marine vessels operated by the Royal Canadian Navy (RCN) emitted 17% of DND's total NSS emissions, or approximately 119 kt CO_2 eq, which is an increase of 9% when compared with the fiscal year 2005-2006 emissions.[4]

Notwithstanding that the government has directed that safety/security fleets will adopt greener technologies and practices, there are several other compelling reasons why the RCN should continue to strive to improve the energy efficiency and fuel efficiency of its vessels. These include improved operational efficiencies and reduced operational costs. Based on a review of current studies and existing literature on improving efficiency and reducing carbon emissions in both commercial shipping and naval ships, this paper argues that the RCN's best approach to realizing an efficient and environmentally sustainable fleet leading up to 2050 is to focus first and foremost on operational and procedural changes that will result in energy efficiency gains and fuel savings. Second, the RCN should capitalize on opportunities to introduce more efficient technologies into the fleet and, finally, once available, adopt the use of low-carbon drop-in fuels.

To understand the context surrounding the RCN's fleet decarbonisation journey, this paper begins with a description of the current fleet and the future ships that will be built under the National Shipbuilding Strategy (NSS) between now and 2050. It then proceeds to review past and current studies related to improving energy efficiency and reducing maritime greenhouse gas (GHG) emissions, concentrating predominantly on warships, but also considering commercial shipping when applicable. These studies are grouped into three categories, those that advocate for operational and/or procedural changes, those that consider new technologies, and those that look at the impact of adopting low-carbon drop-in fuel. In each case, the viability of applying changes into the RCN's current and future fleets and the estimated impact that the change could have is assessed.

Current and Future RCN Ships

The RCN is currently in a state of fleet renewal.[5] Existing vessels, the majority of which were built in the 1990s, are gradually being replaced over the next 30 years as part of the government's National Shipbuilding Strategy. The first of the new builds, Her Majesty's Canadian Ship (HMCS) *Harry DeWolf*, was commissioned in June 2021, with the other five Arctic and Offshore Patrol Vessels entering service over the next three years.[6] Construction of two new *Protecteur*-class Joint Support Ships is also underway with deliveries expected between 2024 and 2026.[7] Meanwhile, the Canadian Surface Combatant project is in the definition phase and is expected to deliver 15 ships that will replace the current *Halifax*-class frigates as well as the already decommissioned *Iroquois*-class destroyers between 2030 and 2050.[8] Data and information regarding the current vessels that make up the RCN's fleet are provided in Table 1 and a summary of future RCN vessels is provided in Table 2. The advanced age of the existing fleet combined with the advanced phases of the design and build of the future fleet will dictate what decarbonisation options are possible for the RCN.

Table 1. Current Fleet of RCN Ships and Submarines

Ship Class	Entry into Service	Number of Vessels	Standard Displacement (tonnes)	Propulsion Type
Halifax-class Multi-Role Patrol Frigates	1992 - 1996	12	4,770	Combined Diesel or Gas
Victoria-class Long-Range Patrol Submarine	1986 - 1993 (RN) 2000 - 2015 (RCN)	4	2,400	Diesel-Electric
Kingston-class Maritime Coastal Defence Vessel	1995 - 1998	12	970	Diesel-Electric
Orca-class Patrol Craft Training Vessel	2006 - 2008	8	210	Diesel

Sources: Canada, Department of National Defence (DND), "Halifax-class modernization and frigate life extension"; Royal Canadian Navy (RCN)/Navy-marine, "RCN Fleet Poster"; RCN, "Frigates - Tech Data"; RCN, "Her Majesty's Canadian Submarine Victoria (SSK 876)"; RCN, "Her Majesty's Canadian Submarine Windsor (SSK 877)"; RCN, "Her Majesty's Canadian Submarine Corner Brook (SSK 878)"; RCN, "Her Majesty's Canadian Submarine Chicoutimi (SSK 877[sic])"; RCN, "Victoria-class Capability"; Naval Technology, "Orca Class Patrol Craft Training (PCT) Vessels."

Table 2. Future Fleet of RCN Ships

Ship Class	Entry into Service	Number of Vessels	Standard Displacement (tonnes)	Propulsion Type
Harry DeWolf-class Arctic and Offshore Patrol Vessels	2021 - 2025	6	6,440	Diesel-Electric
Protecteur-class Joint Support Ship	2024 - 2026 (under review)	2	20,240	Diesel
Canadian Surface Combatant	2030 - 2050 (predicted)	15	7,800	Combined Diesel-Electric or Gas

Sources: Canada, DND, "Arctic and offshore patrol ships"; RCN, "RCN Fleet Poster"; RCN, "Arctic and Offshore Patrol Ships"; Canada, DND, "Joint support ship"; Naval Technology, "MAN wins engine contract for Canada's Joint Support Ships"; Canada, DND, "Canadian surface combatant"; RCN, "Canadian Surface Combatant Factsheet."

Operational and Procedural Changes

Operational measures such as slow steaming, route optimisation and just-in-time arrival have proven to have a meaningful impact on reducing GHG emissions in commercial shipping.[9] Between 2008 and 2015, it is estimated that the adoption of slow steaming reduced the CO_2 output and carbon intensity of commercial shipping by 30%.[10] Due to the nature of naval operations, which can require operating at a range of speeds and through all types of weather and sea states, the same overall reductions cannot reasonably be expected in naval vessels. However, a study conducted by Fraser Work, in which he monitored a *Halifax*-class frigate to determine energy and fuel use patterns, identified that in many instances the operators chose the gas turbine (GT) propulsion drive mode over the more economical propulsion diesel engine (PDE) drive mode even though the conditions for PDE use were satisfied.[11] Had the ship chosen the PDE over the GT, Work estimates that approximately 10% fuel savings could have been achieved.[12] Additionally, Work estimated that a further 25% of fuel savings could have been achieved had the ship reduced speed by 20%.[13] While not all RCN vessels have an economical drive mode option, they will all have an optimal fuel conservation speed, and Work's study has illustrated the potential fuel savings, and thus the potential reduction in GHG carbon emissions that can be achieved by choosing the most economical drive mode and the most economical steaming speed when operationally feasible.

In addition to reducing fuel used to propel the ship through the water, there is also a possibility to decrease fuel use by reducing the electrical load required to run the auxiliary systems onboard, such as the heating, ventilation and air conditioning (HVAC) system. In a study completed on a Spanish frigate, the load requirements of the auxiliary systems represented 59% of the ship's installed load and it was estimated that the HVAC represented between 18 and 57% of the total electrical consumption.[14] In Work's analysis of electrical energy consumed onboard HMCS *Vancouver*, he found that, on average, the HVAC consumed 25% of the overall electrical power requirement at sea and 19% when the ship was in port.[15] In his study, he noted that many of the temperature controls were not working properly and that many spaces onboard were being over-cooled to temperatures as low as 12 degrees Celsius, thus resulting in energy waste.[16] Although he was unable to quantify the wasted energy or potential savings, his observations suggest that there is an opportunity to improve the efficiency of the HVAC system through improved maintenance, monitoring and efficient operation of the system.

One way of implementing energy efficiency improvements onboard a ship is with a Ship Energy Efficiency Management Plan (SEEMP). The purpose of a SEEMP is to monitor and improve a ship's energy efficiency over its operational lifespan. SEEMPs have been mandatory for commercial shipping since 2013 but are not a requirement for warships.[17] Since the new Arctic and Offshore Patrol Vessels are being built to commercial ship standards, the vessels come with a SEEMP, which will require the RCN to monitor the ship's fuel and energy use and ultimately determine ways in which it can be reduced.[18] Adoption of a SEEMP for the other classes of vessels in the RCN could assist in monitoring and ultimately reducing fuel and energy consumption for the entire fleet.

Another way to improve the fuel efficiency of a ship is to ensure that the hull is free from biofouling (i.e., the accumulation of micro-organisms, plants, algae or animals on ship hulls). A hull that has accumulated biofouling will have increased frictional resistance, which in turn will decrease the efficiency of the propulsion engines and increase fuel consumption.[19] Compared to commercial ships, warships spend longer periods in port and are therefore more susceptible to hull fouling. In a study on the economic impact of hull fouling on naval ships, it was estimated that for a hull fouled with heavy slime, there is a 10% increase in fuel consumption relative to a hydraulically smooth hull condition, and when small hard fouling organisms are present, the fuel consumption increases by 20%.[20] Hull performance studies conducted on the *Halifax*-class frigates confirmed that the engine power output to achieve 15 knots through the water was 3,900 kilowatts for HMCS *Vancouver* the hull of which was 18% covered with hard fouling, compared to 3,000 kilowatts for HMCS *Calgary* the hull of which was covered with only 4% hard fouling. The requirement for increased engine power was even more dramatic at 20 knots, with *Vancouver* requiring 9,000 kilowatts, compared to 7,000 kilowatts for *Calgary*.[21]

One way to counter the effects of hull fouling is to conduct regular inspections and cleanings of the hull. Ship's hulls are routinely cleaned in drydock; however, RCN ships are only scheduled for routine drydocking every five years. To combat the effects of hull fouling in between scheduled drydocking, the hull must be cleaned while the ship is in the water. While these services exist, there are environmental concerns that need to be addressed, including biological effects resulting from microscopic fragments of anti-fouling paint containing copper and zinc that can be removed during the cleaning process.[22] Copper and zinc can bioaccumulate and be toxic to certain aquatic organisms such as phytoplankton.[23] As a result of environmental concerns linked to underwater hull cleaning, it is banned in certain ports, and there is a requirement to collect and properly dispose of the waste produced during the cleaning process in other ports.[24] Given the potential benefits of underwater hull cleaning, Public Works and Government Services Canada is currently seeking suppliers to provide hull cleaning and capture services to government vessels under a supply arrangement.[25] Once these services are available, it is recommended that the RCN develop a management plan that includes regular hull inspections and cleanings.

In summary, given the information available from current and past studies, it is estimated that the RCN could achieve meaningful fuel savings, and thus GHG emissions reductions, by implementing operational changes. These changes include consistently choosing the most efficient mode of propulsion and reducing speed when operationally feasible, implementing a biofouling management program that includes regular hull inspections and hull grooming, and optimizing the efficiency of the HVAC system onboard through regular maintenance and by ensuring that spaces are not being over-cooled. Ultimately, the adoption of a SEEMP for each class of ship in the RCN fleet would assist the RCN in identifying and implementing energy efficiency measures over the operational lifetime of the vessel.

Technological Solutions

Given the age of the RCN's existing fleet and the advanced stages of design and build of the future fleet, it is likely that any technical solutions to reducing GHG emissions and improving a ship's energy efficiency will be undertaken as part of a retrofit. To make informed decisions in this area, it is necessary to understand the specific fuel consumption of each propulsion engine and the specific energy requirements of each piece of equipment onboard. One way of doing this is by using an energy management system. The US Navy (USN) has adopted a Global Energy Information System (GENISYS) that combines a ship's existing data to provide clear links between fuel use data and mission and environmental data, such as sea state and current.[26] This energy management system allows personnel onboard not only to monitor real-time fuel and energy consumption but to make informed decisions based on the ship's mission and the environmental factors present in order to conduct efficient operations.[27] The USN's system also provides information to personnel ashore, thus allowing them to identify trends and problem areas.[28] Adoption of a similar energy management system for RCN ships would provide the data necessary to inform the operational changes recommended in the previous section, and could also be used to help inform decisions regarding expected energy and fuel savings resulting from future equipment upgrades.

In Work's energy and fuel usage study onboard HMCS *Vancouver*, 84% of the fuel consumed at sea was used by the propulsion system, and the remaining fuel was used by the electrical generation system.[29] These statistics indicate that optimising the efficiency of the propulsion system could provide significant fuel savings. One of the reasons that the more efficient PDE installed onboard the *Halifax*-class frigates is not used regularly, even when operationally feasible, is that it is often mechanically unavailable. Work reports that in 2015, *Vancouver*'s PDE was reported as being inoperable 88% of the time due to degraded components.[30] Additionally, the PDE is subject to a multitude of restrictions such as avoiding excessive manoeuvring and prolonged operations below 14 knots, needing to run at 17 knots for one hour every 24 hours to reduce carbon build-up, a speed restriction of 17 knots due to excessive stresses at high power, as well as sea state restrictions, all of which contribute to the reluctance to use the PDE even when it is available.[31] Given these issues, it is likely that significant fuel savings could be achieved by replacing the PDE with a more robust engine (i.e., more reliable and not as restrictive in its use). Additionally, the technology used in today's diesel engines results in a more efficient engine compared to what is currently installed on the *Halifax*-class frigates. For example, data collected by the Energy Efficiency Focus Group indicated that the replacement of the original MWM diesel generators with CAT diesel generators onboard HMCS *Calgary* has resulted in fuel savings of 0.05 litres per kilowatt-hour.[32] At the time of the data capture, the new generators had accumulated 522,170 kilowatt-hours indicating a fuel savings of over 26,000 litres of fuel. Similar savings could likely be achieved by replacing the PDE.

As previously indicated, a ship's HVAC is responsible for a large portion of the energy requirements onboard. In older warships, the HVAC system uses a constant-air volume (CAV) to deliver heating and cooling. While this type of system does have advantages in a warship, it usually applies a worst-case scenario cooling strategy to ensure the system can manage peak loads. Since the peak load scenario is relatively rare, the result is that the airflow onboard is higher than necessary in most scenarios resulting in wasted energy.[33] Based on simulations conducted using a USN *Arleigh Burke*-class destroyer (DDG-51), replacing the CAV HVAC system with a variable-air-volume (VAV) system predicted savings of 16% power, or 70 kilowatts of total fan power saved.[34] The cooling requirements for future surface combatants are expected to be an order of magnitude higher than for warships such as the *Halifax*-class frigates.[35] As such, optimisation of the HVAC system for the future fleet, particularly the Canadian Surface Combatants, using variable control technology is essential.

As the RCN transitions to its future fleet, new, more energy-efficient technology will be introduced, including diesel-electric propulsion in the Arctic and Offshore Patrol Vessels, and combined diesel-electrical or gas propulsion in the Canadian Surface Combatants. However, to achieve further decarbonization, the RCN will have to consider how it might incorporate energy capture and storage technology or renewable energy technology into the future fleet. Examples of energy capture and storage technology include fuel cells, lead-acid batteries and lithium batteries. Although batteries are a relatively mature technology, so far their use has only been proven on small vessels and submarines.[36] Challenges with implementing this technology on larger, deep sea-going vessels include weight and space requirements, and charge capacity.[37] However, this type of technology may prove appropriate for vessels such as the *Orca*-class Patrol Craft Training Vessels, which tend to conduct only day sails and therefore can frequently recharge batteries.

Fuel cells are another technology that shows potential for reducing marine vessel GHG emissions. Liquid hydrogen and/or oxygen fuel cell systems have been successfully employed on naval submarines; however, their use on warships is challenging due to fuel conditioning and processing requirements and the inability to store large quantities of hydrogen safely onboard. To further explain, there are safety concerns and space constraints associated with the bulk storage of hydrogen onboard. Therefore, the hydrogen used for fuels cells needs to be extracted from another type of fuel. Warships have strict rules regarding what types of fuels they can carry below decks due to the danger of fire/explosion. Theoretically, hydrogen can be extracted from naval distillate, the type of fuel that is currently used; however, impurities in the fuel can contaminate the fuel cells and degrade its performance.[38] Assuming that there will be a future replacement for the *Victoria*-class submarines, fuel cell technology may be a viable green option.

Renewable energy is energy that comes from renewable sources such as wind and solar. In commercial shipping, sails, kites and solar panels are examples of technology currently being used.[39] The use of these types of renewable energy sources is generally not considered viable on a warship due to a lack of free space onboard to place the system. However, one study indicates that solar-thermal systems may be viable on a military support vessel such as the RCN's Joint Support Ships, currently under construction.[40] The study concluded that by placing 23 solar thermal collectors on the compass deck of the Romanian Navy's military logistic support vessel savings of up to 25 kilograms of fuel per day or 0.2% could be achieved.[41]

Given the age of the RCN's existing fleet, and the advanced stages of design and build of the future fleet, the introduction of technological solutions to improve fuel efficiency and reduce GHG emissions will be limited. Despite this, research has shown that certain technological upgrades may be worth pursuing, including the installation of an energy management system, and upgrading older model engines such as the PDE on the *Halifax*-class. Additionally, technologies such as batteries, fuel cells and the use of renewable energy sources are progressing and may mature enough over the next couple of decades to be considered suitable for future application on naval vessels.

Low-carbon Drop-in Fuels

Another potential solution to reducing GHG emissions of naval vessels is by adopting cleaner-burning fuels. RCN vessels use F-76 naval distillate fuel, and the future fleet will also use F-76. Consequently, any future cleaner-burning fuel that the RCN adopts will need to be a 'drop-in' fuel, meaning that the existing systems and equipment onboard will not require modifications. Biodiesels, which are fuels derived from vegetable oils, animal fats or organic waste material, or biodiesel blends, are not considered appropriate as drop-in fuels because when exposed to seawater, the biodiesel becomes unstable and can result in water-separation issues and plugged filters.[42] Furthermore, biodiesel blends can result in lower fuel lubricity, which can have an impact on machinery such as fuel pumps that are dependent upon the lubrication characteristic of conventional fuel.[43]

Synthetic diesel blends of up to 50% are allowed under the North Atlantic Treaty Organization (NATO) standard for F-76 and updates have been proposed to the Canadian standard for naval distillate fuel that would also allow synthetic hydrocarbon blends.[44] One issue with synthetic fuels is that depending on how the fuel is processed, the carbon footprint can be quite large, thereby negating any reduction in carbon emissions gained from burning the fuel.[45]

To assist the federal safety and security departments in their future efforts to decarbonise, Treasury Board is engaging industry to determine the interest and capacity to provide drop-in, low-carbon-intensity fuels for the government's air and marine fleets. A low-carbon-intensity fuel emits fewer GHGs over its lifecycle than fossil fuels. The government is currently seeking drop-in synthetic fuel blends with a lifecycle carbon intensity that is at least 10% below the fossil-based fuel it is meant to replace.[46] Once lower-carbon-intensity synthetic blends that meet the applicable standards for F-76 become available, the RCN could realize significant GHG emissions by adopting these fuels. Although it is unclear at this time what the cost differences will be between the synthetic blends and conventional F-76, it is expected that the synthetic blends will have a higher upfront cost.

Conclusion

As the RCN transitions into the future, adopting greener practices, technologies and fuels will be required to meet government direction. However, these efforts can also contribute to more efficient and cost-effective operations. To realize an efficient and environmentally sustainable fleet, the RCN should focus on implementing operational and procedural changes that will result in energy efficiency gains and fuel savings. These changes will be the easiest to implement and have the potential for immediate impact.

With the introduction of the Canadian Surface Combatant not expected until 2030 and beyond, there will be requirements to upgrade equipment and systems on existing platforms. The RCN should capitalize on these opportunities to introduce more efficient technologies into the fleet.

Lastly, the RCN should prepare to adopt the use of low-carbon drop-in fuels once available.

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1. According to Canada's "Greening Government Strategy," this includes "aircraft, marine vessels and tactical land vehicles from National Defence, the Royal Canadian Mounted Police and the Canadian Coast Guard." Net-zero means "reducing GHG emissions from operations to as close to zero as possible and then balancing out any remaining emissions with an equivalent amount of carbon removal." Canada, "Greening Government Strategy: A Government of Canada Directive," available at https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/strategy.html.
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32. Energy Efficiency Focus Group, "EEFG Dashboard: Energy and Fuel Use Data for HMCS Calgary from 14 January 2016 to 29 November 2019," used with permission.
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