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**EMERGING PROPULSION SYSTEM: TECHNOLOGIES FOR A GREENER FLEET**

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# EMERGING PROPULSION SYSTEM: TECHNOLOGIES FOR A GREENER FLEET

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## AIM

1. The Defence Environmental Strategy calls for a shift from simply managing environmental requirements to effectively integrating a through life approach in support of a sustainable modern military[1]. The stated strategic vision is for the Department of National Defence (DND) and the Canadian Armed Forces (CAF) to be recognized as leaders who are contributing to the sustainable development goals of Canada through the effective and innovative integration of environmental considerations in support of the Defence mandate[2]. The Royal Canadian Navy's (RCN) largest contribution to climate change are emissions from the ships' propulsion systems. Efficiencies must be found in propulsion systems in terms of through life costs and impact to the environment to produce efficient prime movers. The aim of this service paper is to assess what is the most promising emerging technology in terms of "greening" the propulsion systems for the fleet.

## INTRODUCTION

2. Before the invention of mechanical methods of propulsion in the late 19$^{th}$ century, sea power could be achieved without harming the environment. Prime movers have evolved significantly over the past century. From their dependence on coal to Distillate Fuel Oil (DFO), once the world's navies realized the performance benefits of fossil fuels, they never looked back. However, with the International Maritime Organization (IMO) now reporting that Maritime transport is responsible for approximately 2.5% of the world's total greenhouse gas emissions[3], the Marine Engine Regulations are only getting more restrictive[4]. As a matter of fact, the most recent MARPOL regulations are such that no Diesel engine can meet the current standard on its own without the additional use of ancillary systems such as intake filters and exhaust scrubbers[5].

3. The current RCN fleet is exempt from these most recent regulations given that these revised stricter rules only apply to new or refurbished ships that were built after 2013[6]. Ships being constructed by the National Shipbuilding Strategy (NSS) including the Arctic Offshore Patrol Ship (AOPS), the Joint Support Ship (JSS), and the Canadian Surface Combatant (CSC) are all expected to comply. Therefore, the current plan for Canadian ships under construction will utilize hybrid diesel electric plants that are able to meet current environmental regulations. However, if the RCN wants to be recognized as a leader in the field, as envisioned in the Defence Environmental Strategy, it must look beyond the current environmental standards and find new innovative ways to improve how it does its business. This service paper will assess promising emerging technologies and how they could be leveraged to simultaneously meet RCN needs and future environmental policy. The most promising technologies that will be discussed in this paper are solar sails, rotor sails, biofuel, hydrogen fuel cells and small modular reactors.

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[1] Defence Environmental Stragegy, p. 7
[2] Ibid.
[3] European Commission. "Reducing Emissions From The Shipping Sector". 2016.
[4] MARPOL Annex VI, Chapter 4
[5] Ibid.
[6] Ibid.

**DISCUSSION**

4. The first emerging technology is the solar sail[7]. Designed with cargo ships in mind, the hybrid propulsion design offers a two-pronged approach to energy savings by attempting to capture both solar and wind energy to augment a traditional marine engine. Before factoring in energy savings, it is important to acknowledge that all theoretical data for this technology is done at cruise speeds typically at or below 15 knots. The potential energy savings attributed to this technology would significantly diminish if a warship were to ramp up to higher speeds. In fact, the sails would not only hinder a warship's ability to go faster through additional resistance, but it would also reduce the ship's manoeuverability and increase the ship's electromagnetic signature. Additionally, the significant upper deck space required to fit this technology is extremely prohibitive to allow sufficient space for typical naval capabilities such as weapons and sensors. Naval requirements aside, solar sail trials have reported up to 30% energy savings at low transit speeds[8]. From a through life environmental impact perspective, it is also extremely important to consider the quantities of rare earth minerals, as well as significant amounts of coal and energy required in the manufacturing process of these panels[9]. Furthermore, the maritime environment can significantly reduce the lifespan and efficiency of a solar panel and the placement of the panel to better harness wind energy also reduce the overall efficiency of the photoelectric cells. While at first glance, this technology seems extremely attractive, there are too many reasons it would not be desired on a warship.

5. The second emerging technology is the rotor sail[10]. This technology would be an improvement on the solar sail because it does not require quite as much upper deck space, it does not have as much dependency on rare earth materials and fossil-fuels in the manufacturing process, and it would not provide as much resistance at higher speeds. This said, this technology was also conceived with cargo shipping in mind. The height and weight of rotor sails would provide challenges to heavy maneuvering and significant additional ballast weight would have to be added near the ship's keel to ensure adequate stability. The rotor sails would also negatively impact the ship's electromagnetic signature and would provide blind spots in weapons and sensors' functional arcs of operation. Rotor sails have been successfully implemented in commercial fleets and report typical fuel savings in the order of 15%[11]. One advantage of rotor sails is that their function does not depend on what direction the wind is coming from. For optimal efficiency, the only limitation to navigation is to not sail directly towards or away from the wind to prevent the rotor sail columns from obstructing each other. Although this technology would be too prohibitive in a combat platform, its use in an auxiliary ship could be fathomable.

6. The third emerging technology is the use of engines that can burn biofuels in conjunction with traditional naval fuels[12]. Unlike the two previous options, this option does not require any compromise in naval capability and performance. Biofuel engines are currently able to burn up to 10% biomass blended with DFO and the US navy thinks this ratio could theoretically, in time,

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[7] Eco Marine Power. "Energysail". 2021.
[8] Ibid.
[9] Troszak, Thomas Anthony. "burn coal and trees to make solar panels" 2019.
[10] Casey, Tina. "Wind Power Returns". 2019.
[11] Ibid.
[12] Associated Press. "biofuel-powered aircraft carriers". 2016.

become closer to 50%[13]. Some biofuel reactors are also designed to double as an incinerator to provide ships with an additional capability to manage solid waste onboard. Unfortunately, although biofuel is currently considered by many environmental groups to be a green technology, there is increasing debate on its viability as a renewable technology given its dependence on fossil fuels in the manufacturing process and on the inefficiencies of using living organisms as a renewable fuel source[14]. For biofuel to be truly considered a renewable resource, the total energy dependencies of the supply chain to create the fuel must be taken into consideration. The US Navy's new biofuel ships are designed to utilize beef fat as its biological component[15]. In his critique of biofuel as a renewable resource, Mr. Jeff Gibbs argues that simply burning fossil fuels directly has less total impact to the environment than raising living organisms to be converted to act as fuel[16]. While the American Navy is aggressively pursuing biofuel as a form of renewable green energy, an evidence based through life analysis of the viability of this fuel source is required. Although biofuel may have viable applications in the future, current iterations still produce significant greenhouse gases and the dependency on fossil fuels remains.

7. The fourth emerging technology is the use of hydrogen powered ships. The concept of using hydrogen as a fuel source is not new and practical prototypes utilizing hydrogen fuel cells in other fields have been around for decades. The most significant challenge related to Hydrogen as an energy source is its volatility. In fact, its energy density is almost triple that of diesel[17]. While this is a good thing as far as potential energy is concerned, it adds significant challenges with regards to safe storage and handling procedures which are extremely important factors for sea going vessels. The safest form of storage created to date are fuel cells, which may work well for land applications, but create significant challenges for refuelling at sea. What is currently considered to be the best approach to replenishing hydrogen fuel cells at sea is the use of a steam methane reforming system[18]. In this system, both methane and methanol can be converted to hydrogen at temperatures ranging from 150 to 350 degrees Celsius. The drawback of doing this is that in this process, carbon dioxide emissions are unavoidable. This can be somewhat mitigated using carbon capture and storage (CCS) systems. Although this technology is still in its theoretical stage, it is technically feasible to utilize this technology to reduce carbon dioxide emissions by 65%[19]. The space required to store such a system would be considerable which would be a limiting factor for smaller warships, but the potential benefits cannot be ignored. If this technology's concept were to be proven, it would provide significant improvements to greenhouse gas emissions without limiting available naval capabilities. Additionally, fuel cells without the methane/methanol replenishing systems remains a viable option for smaller auxiliary ships that only operate in the littorals who make more frequent port visits.

8. The fifth and final technology that will be discussed is the use of Small Modular Reactors (SMR). Due to their long history of naval operation, nuclear reactors can hardly be considered an emerging technology. However, reactor size, has until recently been a limiting factor in what type of ships could be fitted with such a capability. Nuclear marine propulsion was one of the

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[13] Associated Press. "biofuel-powered aircraft carriers". 2016.
[14] Gibbs, Jeff. "Planet of the Humans". 2020.
[15] Associated Press. "biofuel-powered aircraft carriers". 2016.
[16] Gibbs, Jeff. "Planet of the Humans". 2020.
[17] Lee, Hyunyong et Al. "On-Board Methane and Methanol Reforming Systems". 2020.
[18] Ibid.
[19] Ibid.

first applications of nuclear energy with USS Nautilus, a nuclear-powered submarine, first going to sea in 1955[20]. The World Nuclear Association estimates that there are currently over 160 naval crafts, which consist mostly of aircraft carriers and large submarines, operating with nuclear reactors[21]. The game changer that makes nuclear reactors worth a new look is the emerging trend towards SMRs[22]. These SMRs are currently being built in sizes ranging from 70MW to 300MW. This range of reactor sizes is ideal for most of the RCN's major warships. They are the only emerging technology that is completely free of greenhouse gas emissions, it offers no sacrifices to traditional naval capabilities and even offers many potential gains in terms of speed, range, and sustainability. Seventy years of nuclear reactor data demonstrate that nuclear reactors provide a safe, secure, and clean propulsion option[23]. The emergence of SMRs could now offer these benefits to smaller warships. From a through life perspective, if Canada were to leverage one of many Canadian Industry SMRs in development, such as the CANDU SMR technology being developed by SNC-Lavalin[24], this propulsion solution could provide significant value proposition and industrial benefits at the national level. The Ministry of Natural Resources has already launched an action plan to utilize SMRs in a pan-Canadian effort to place Canada as a strategic leader in the energy sector[25]. However, DND, the CAF, and the RCN are not currently listed among the many potential stakeholders in their plan. This is not surprising considering that the current Defence Energy and Environment Strategy makes no specific mention of seeking greener propulsion systems for the future fleet[26]. However, if the Defense sector were to present itself as a high interest, high influence stakeholder, it could help shape the solution space for the future given the influence the procurement budgets can have on Value Proposition.

## CONCLUSION

9. The marine sector's contributions to climate change are being increasingly scrutinized by international organizations. This creates a unique opportunity for DND, the CAF, and the RCN to rise-up and dare to fulfill the Defence Environmental Strategic vision and become recognized as a world leader through the effective and innovative integration of environmental considerations in support of the Defence mandate. This service paper discussed five emerging technologies that are being considered, tested, or applied in the marine sector to provide environmental benefits to propulsion systems. The first two technologies; solar sails and rotor sails, while appropriate for commercial cargo ship applications, would be widely inappropriate for naval combat operations. The next two technologies; biofuel, and hydrogen fuel cells, offer theoretical gains in energy efficiency without sacrificing naval combat capability. These technologies could have niche uses for some future ships yet remain mostly unproven and contain potential pitfalls. The final technology that was considered is the new smaller iteration of a technology with a proven track record. The emergence of SMRs as a viable solution for marine propulsion on a wider range of ships could be the opportunity that Canada needs to step forward as a key contributor to present viable solutions to climate change on the world stage. However, implementing this technology would not be a short-term solution. It would require a

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[20] Lee, Hyunyong et Al. "On-Board Methane and Methanol Reforming Systems". 2020.
[21] World Nuclear Association. "Nuclear-Powered Ships". 2020.
[22] Hirdaris, S.E. et Al. "SMR technology for merchant marine propulsion". 2014.
[23] IAEA, "losses at sea involving radioactive material". 2001
[24] SNC-Lavalin. "Nuclear". 2021.
[25] Ministry of Natural Resources. "SMR Action Plan". 2021.
[26] National Defence. "Defence Energy and Environment Strategy". 2020.

significant strategic investment and the development of many key partnerships. This being said, if this route were to be considered as a viable long-term strategic engagement, it could fundamentally change the face of the RCN and Canadian Industry.

**RECOMMENDATION**

10. It is recommended for DND to recognize within its Defence Energy and Environment Strategy that marine propulsion systems are a key area that offers many potential opportunities in terms of environmental solutions and Canadian industrial growth. Furthermore, given the pan-Canadian efforts being expended to leverage Canadian SMR technologies to address climate change in the energy sector, it is also recommended for DND to actively seek participation within the SMR Action Plan[27]. Once the RCN has gained a better understanding of the pan-Canadian SMR landscape and its potential interfaces and roles within, it is also recommended for DND to leverage upcoming Major Capital Projects (MCP) to incentivize Industry investments in marine nuclear propulsion (or other green propulsion technology) research by ensuring the Value Proposition component of the bid evaluations incentivize investments in these key strategic areas.

[27] Ministry of Natural Resources. "SMR Action Plan". 2021.

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