NOVA SCOTIA'S OPPORTUNITY FOR MARINE ELECTRIFICATION

COVE

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ACKNOWLEDGMENTS

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Cover Photo Provided by Glas Ocean Electric

KEY FINDINGS

1. **Marine vessel decarbonization is a quickly advancing global industry**. Nova Scotia, and more broadly Atlantic Canada, is **primed to implement vessel electrification** and grasp potential market opportunities. With a readily serviceable fleet of over 20,000 in Eastern Canada, the **time-limited opportunity exists** for Nova Scotia industry to act as a technology provider for pending demand.

2. The recent **surge of new vessels built with diesel-electric propulsion** shows that owners and operators are seeing that this allows for a **less invasive and less costly retrofit** to a hybrid or fully-electric solution. This is sensible given marine vessels have an average operational **life span of 20-50 years**.

3. Atlantic Canadian industry input from a **rapidly growing ecosystem of operators, boat builders, technology companies, and naval architects** shows they are actively engaged in a broad set of Nova Scotia marine electrification demonstration projects, and that **access to enabling infrastructure and charging facilities** has been seen as a commercial barrier.

4. Alternative fuels, including **hydrogen and ammonia, have real opportunity to decarbonize long-haul voyages**. Opportunities for hydrogen remain relevant globally and are more nascent in Nova Scotia.

5. While officials have their eye on **regulatory innovation**, keeping up with this industry's rate of change can **accelerate the pace of electric vessel adoption** by providing a higher level of certainty and reducing cost.

CONTENTS

EXECUTIVE SUMMARY

Decarbonization of marine transport is a globally recognized imperative given climate change, energy security, and increasing operating cost pressures. The purpose of this report was to provide foundational information on the potential for a marine vessel electrification industry in Nova Scotia. By reviewing the local market, other jurisdictions' successes, emerging technologies, and the current supply chain capacity, this report demonstrates the opportunity for Nova Scotia to provide leadership in this global industry.

Eastern Canada, a market readily serviceable by Nova Scotia, has a fleet of over 14,600 fishing vessels and over 5,400 workboats. These present the largest market potential for vessel electrification technology in the region. When originally scoped, the expectation was that the marine electrification industry in Nova Scotia was limited and would require focused activities to increase the number of companies and organizations that were involved. Instead, what was found was a rapidly growing ecosystem of over 20 operators, boat builders, technology companies, and naval architects who see opportunity for marine electrification. These companies are actively engaged and are working quickly towards a broad set of demonstration projects; however, many challenges exist. Notably, the lack of charging infrastructure is a limiting factor for operators and technology companies in electrifying vessels. This presents a unique opportunity for COVE to enable industry growth through the deployment of marine charging infrastructure that can support a broad variety of vessels and serve as a test-bed for marine electrification technology innovation.

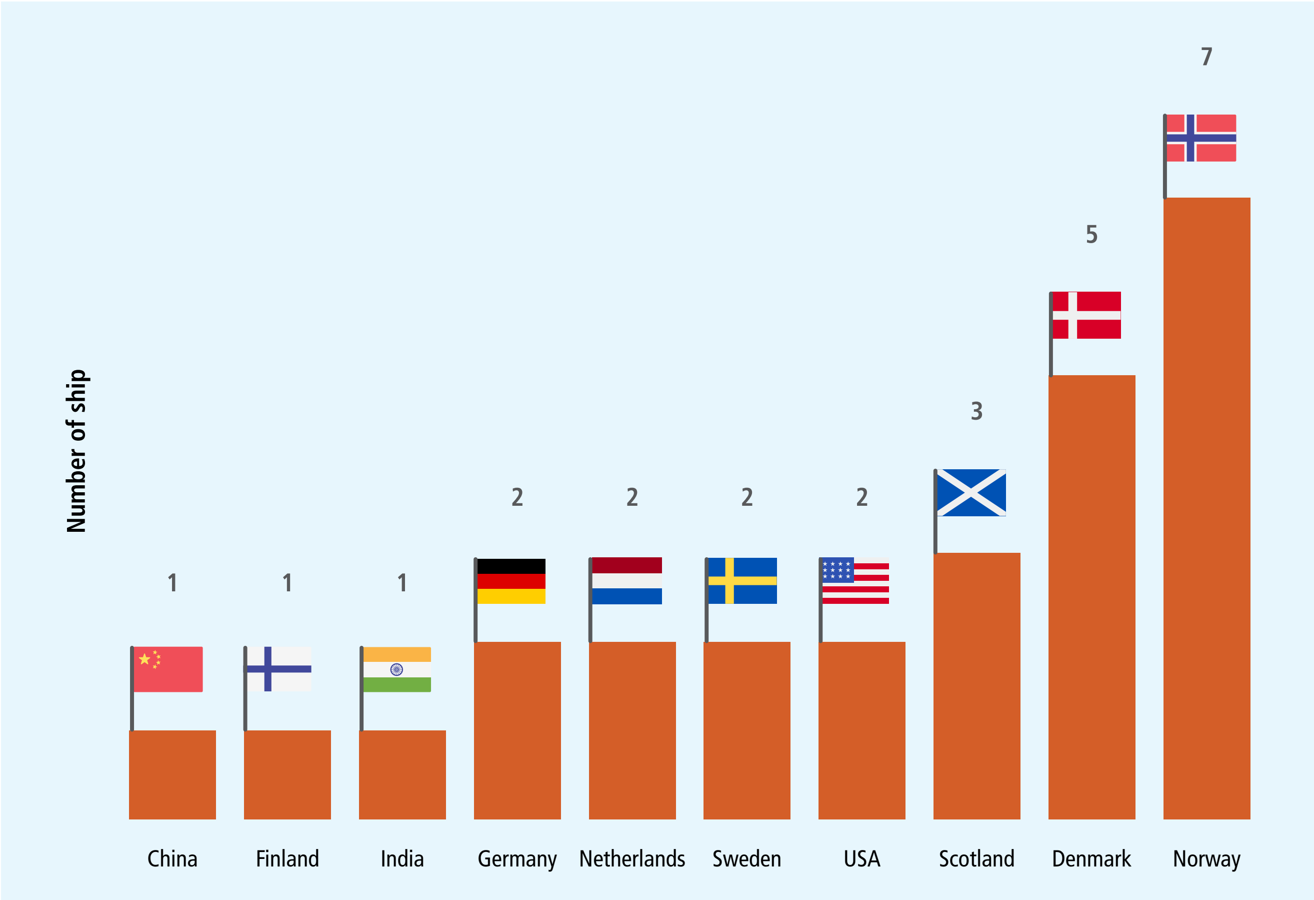
JURISDICTIONAL REVIEW

INTRODUCTION

The goal of this jurisdictional review is to provide an overview and analysis of the various vessel electrification and decarbonization projects that are being run in specific jurisdictions around the world. Many of these jurisdictions have been able to build emerging industries around these technologies and have implemented new vessels in unique use cases. This analysis will identify which challenges and opportunities from these jurisdictions are the most relevant to Nova Scotia, and more broadly Atlantic Canada.

Following a broad scan of global activity and review discussions, the jurisdictions were selected for analysis based on their likelihood to provide relevant information for Nova Scotia. This review looks at the ecosystem projects that have launched or are planned and underway in Norway, British Columbia, Bangkok, and Denmark. **Figure 1**, below, shows the number of fully battery electric vessels that are in service globally as of 2020. Through initial research it became apparent that there has been a recent surge in construction activity with many planned launch dates into 2022 and beyond, the best aggregated information only captures 2020 and prior. However, this information provided a strong starting point in early 2021 to select relevant jurisdictions for this review.

Figure 1: Countrywide Electrification of Ships (Anwar, Zia, Rashid, Zarazua de rubens, & Enevoldsen, 2020)



BRITISH COLUMBIA

Overview

British Columbia (BC) has long had a focus on environmental stewardship including greenhouse gas reductions, implementing the first broad base carbon tax in North America in 2008. In recent years, BC has helped incentivize the decarbonization of the transportation sector, specifically through CleanBC. CleanBC has most recently created a $5M fund to incentivize the purchases of zero-emission heavy duty vehicles such as trucks, marine vessels and buses (Sarabia, 2020). So far, British Columbia has found the most success with passenger and car ferry electrification.

Car and Passenger Ferries

BC Ferries is the provincial ferry service operator in British Columbia, connecting many of the coastal and island communities in the province. Formerly a provincial crown corporation, it is now an independently managed publicly owned company with strong provincial oversight. In the summer of 2019, BC Ferries published their Clean Futures Plan, a strategy and timeline for the organization to reduce their GHG emissions. In this plan they specifically refer to the challenge of affordability, and that without substantial external funding, their customers would carry the costs to reduce emissions (BC Ferries, 2019).

BC Ferries operates the Island Class of ferries, a set of 6 hybrid electric vessels with 300 person and 47 car capacity. As of Spring 2021, four of these ferries are in service, with two more to be in service by 2022 (BC Ferries' Island Class, 2021). The first two ferries in the Island Class received partial funding from the federal government through the Provincial – Territorial Infrastructure Component – National and Regional Projects. The ferries were designed and built by Damen Shipyards Galati in Romania. Of particular interest is that none of the Canadian companies that were invited to bid in the competitive RFP submitted a response (BC Ferries' Island Class, 2021).

The Island Class ferries were designed such that they may be entirely powered by electricity once the onshore capacity for charging is developed. BC Ferries is working with BC Hydro to design such charging infrastructure and seeking funding support (CBC News, 2021). Corvus, founded in BC, is a supplier of energy storage for the marine industry. The propulsion thrusters are driven by electric motors enabling the multiple power modes. The Island Class has 800 kWh of Corvus Energy lithium-ion battery storage with the capacity to expand to the 2000 kWh necessary for all-electric operations.

Per BC Ferries' Clean Futures Plan, the operations of the Island Class vessels will utilize hybrid electric propulsion as described below (BC Ferries, 2019):

> "In the absence of ready shore-side charging, the Island Class will operate in a hybrid battery power mode to maximize fuel efficiency of the generators. When the vessel power demand is lower, the generators will charge the batteries. On short routes, the batteries can be used as the primary power source to be re-charged by the generators only when necessary (Start/Stop). On longer routes, the batteries will supplement the generator sets when power demand is high (Peak Shaving). The power management system reduces fuel consumption and emissions."

BC Ferries is continuing to work with Transport Canada and Natural Resource Canada to fund research and development projects aimed at advancing clean technology and clean energy. Most recently, BC Ferries joined the Government of Canada's Clean Growth Hub and registered as a CIPEC Leader with NRCan's Canadian Industry Partnership for Energy Conservation (CIPEC), further cementing energy efficiency a top priority within the organization (BC Ferries, 2019).

Table 1 – Island Class Specifications

Island Class Specifications	
Overall Length (m)	80.8
Maximum displacement (t)	1778
Car capacity	47
Passenger & Crew Capacity	300
Maximum Speed (knots)	14.0
Motor	710 kW
Battery Storage	800 kWh (2000 kWh upgradable)

Additionally, TransLink, the Vancouver Metro transit operator, is in the midst of a feasibility study to electrify their "SeaBus" fleet, the ferries that run across the Vancouver Harbour. The feasibility study was expected to be completed in August 2021, however, the study has yet to be published (Chan, TransLink to study transition to electric-battery ferries for SeaBus, 2021).

Cable Ferries

British Columbia has also had recent success by launching an electrified cable ferry in March of 2020. Separate from BC Ferries, the BC Ministry of Transportation operates many cable ferry routes as a free service without any fees or tolls. The Arrow Park III, is the first part of a $27.9 million contract with Waterbridge Steel to design and build four new cable ferries for inland routes (Chan, BC government launches new electric cable ferry into service, 2020). These four ferries are a part of a broader BC government plan to electrify all inland ferries in the province by 2040.

Key Organizations in BC Supply Chain

Table 2 – BC Supply Chain

Organization Name	Focus	Location
BC Ferries	Operator	British Columbia, Canada
Damen	Ship design and build	Netherlands
Damen Shipyard Galati	Ship build	Romania
Corvus Energy	Battery design and supply	British Columbia, Canada
Templar Marine	Small electric boat builder	British Columbia, Canada
Waterbridge Steel	Ship design and build	British Columbia, Canada

NORWAY

Overview

Norway has become a global leader for marine vessel electrification, producing the first battery electric car ferry, MV Ampere, the first liquid hydrogen (LH2) ferry, MF Hydra, and the electric driven commercial fishing vessel, FV Karoline. The country has been particularly effective at electrifying a large number of ferries, a keystone for their transportation network due to the numerous fjords throughout the coasts. This domestic demand has helped create a nascent electric vessel industry in Norway, which is poised to support the global transition to electric vessels. Kongsberg, Vard, and Norwegian Electric Systems are all large companies that have begun to focus on this emerging industry. Additionally, the Norwegian government has provided strong incentives and funding to begin the early transition towards vessel electrification.

Fishing Vessels

Built in 2015, and owned by an individual fisher, Karoline was the first hybrid fishing vessel equipped with two 195 kWh battery packs and a 500-litre diesel engine. Together they power the vessel for a full day. Running on diesel to and from the fishing grounds, the vessel switches to electric for fishing, loading and unloading. It runs electric-only for almost three hours every day, and the batteries are fully recharged in port overnight (Corvus Energy, 2015). There is little information on this design becoming widely adopted and it appears to be the only vessel of its kind in Norway.

Photo provided by Kongsberg Maritime

Table 3 – FV Karoline Specifications

FV Karoline Specifications	
Overall Length (m)	11
Gross tonnage	95
Battery Storage	2x 195 kWh
Integrator	Siemens
Battery Supplier	Corvus Energy

Car and Passenger Ferries

In Norway, various ferry operators compete for routes by responding to government tenders. In 2013, the government released a tender for an operator to service a route using a zero emissions vessel (Ballard, 2019). Norled, one of the four main ferry operators, successfully bid on this tender and through this process designed and built the MV Ampere, which was put into operation in 2015. The MV Ampere, is a 79-meter car ferry, propelled by two 450 kW electric motors and is powered by a 1,000 kWh battery system. The vessel was built and designed in Norway, of note the battery and charging system was provided by Corvus Energy.

Table 4 – MV Ampere Specifications

MV Ampere Specifications (Ship Technology, 2021)	
Overall Length (m)	79
Car Capacity	120
Passenger & Crew Capacity	360
Maximum Speed (knots)	10
Route Distance (km)	5.7
Daily Trips	34
Battery Storage	1000 kWh

Photo above provided by Vard Electro Canada

The MV Ampere has become a very successful design in Norway. It has resulted in more than 80 copies of the design that are either in operation or planned for construction (Ballard, 2019). Norled alone is planning for 20 vessels of this design. However, there remain operational limitations for battery electric ferries in Norway. Not all of the routes are viable for the current power density and charging time requirements of battery electric. Due to these limitations, and in response to another specific tender request for a hydrogen powered fuel cell ferry from the Norwegian government, Norled has begun to develop a hydrogen fueled vessel, the MF Hydra, that is planned to enter operations in 2021/2022 (Ballard, 2019).

MF Hydra, the world's first liquid hydrogen powered ferry, began construction in 2019 and is of a similar size and function to the MV Ampere. Even though hydrogen has higher potential for longer routes and faster speeds, this first design will be on a smaller scale. The vessel was built by Westcon in Norway and as of spring 2021 is finalizing the outfitting and trials to begin operations in the near term (Linde, 2021). The MF Hydra project was funded roughly EUR 2.5 million in grant money from the European Union innovation project "Flagships" to support the deployment of one zero-emission hydrogen fuel cell vessel in both France and Norway (World Maritime News, 2019).

The greatest challenge facing the MF Hydra is not the construction or design of the vessel, although there were considerable safety regulations required by the Norwegian government due to the LH2. The greatest challenge is the supply chain requirements to fuel the vessel with green LH2; green meaning that the energy used to generate the LH2 comes from carbon-neutral sources. There are few green LH2 producers globally, and currently none of them in Norway (FuelCellWorks, 2020). For this, Norled has signed an agreement with Linde, a Germany company to provide shipments of green LH2 from a facility outside of Leipzig, Germany (Linde, 2021). Linde will also build and install onshore and onboard hydrogen storage, distribution and safety equipment for the MF Hydra.

The capital costs, supply chain requirements, and safety regulations for the MF Hydra exceed those for the MV Ampere (Ballard, 2019). However, there is remains a large amount of interest for the future of hydrogen fuel cell vessels in Norway. There are already plans for hydrogen powered cargo ships that will distribute LH2 along Norway's coastline and hydrogen powered cruise ships (FuelCellWorks, 2020). A green LH2 facility is also under construction in Bergen, Norway, with an expected completion in 2024.

Table 5 – MF Hydra Specifications

MF Hydra Specifications (FuelCellWorks, 2020)	
Overall Length (m)	82
Car Capacity	80
Passenger & Crew Capacity	299
Maximum Speed (knots)	9
Hydrogen tank size (m^3)	80
Hydrogen fuel cell capacity	2 x 200 kW
Generators	2 x 440 kW

Key Organizations in Norwegian Supply Chain

Table 6 – Norwegian Supply Chain

Organization Name	Focus	Location
Norled	Operator	Norway
Kongsberg	Ship build	Norway
Corvus Energy	Battery design and supply	British Columbia, Canada
Vard	Ship design	Norway
Linde	LH2 Production and integration	Germany
Norwegian Electric Systems	Energy and Propulsion Design	Norway

BANGKOK

Overview

Bangkok, Thailand's capitol, is a city of over 10 million people, roughly double the population of Norway. The city has gone through one of the fastest economic growth periods in all of Asia, with significant industrialization beginning in 1987 (Hussey, 1993). The city's recent focus on vessel electrification is unique compared to other jurisdictions this report is reviewing. Bangkok is primarily focused on electrifying passenger ferries that run along and across the river that bisects the city. What is unique is that these projects are not expected to be carbon neutral because a large percentage of Thailand's power is generated from coal. However, the goal is to reduce the amount of air pollution within the city center, something to which the current diesel ferries contribute (Kane, 2021).

There are two current projects that aim to reduce the air pollution, one through retrofits of existing vessels and the other by building a new electric ship design. Overall, Bangkok shows that smaller vessel electrification can be cost effective at small scale and while retrofitting existing assets.

The public transportation system in Bangkok is managed by the publicly owned Krungthep Thanakom Company, which has been trying to reduce emissions in the city that was recently ranked the most congested in the world (MarineLink, 2020). The first retrofitted electric battery ferry went into service in 2018 as a prototype. Due to its success, Krungthep Thanakom partnered with MariArt shipyard to retrofit seven diesel ferries to electric. This was completed in 2020 with all ferries going into service and operating on 15-minute route schedules (The Maritime Executive, 2020).

Table 7 – Bangkok Ferry Specifications

Bangkok Ferry Retrofit Specifications (The Maritime Executive, 2020)	
Overall Length (m)	14.5
Passenger Capacity	30
Route Length (km)	5
Electric Motors	2 x 10 kW
Batteries	12 x 3500 Wh lithium

Simultaneous to the ferry retrofits, another Thai company, Energy Absolute, began to develop their own catamaran battery electric ferry called the MINE Ferry (Mission No Emission). Energy Absolute has completed a few vessels and is planning on building a total of 27 all-electric ferries for the city. The MINE Smart Ferry has capacity for 235 passengers, partial standing and seated. It is a new design and has some quirky design features, such as 26 charging plugs (Kane, 2021). The vessel costs roughly $1M USD to build and Energy Absolute expects the total cost to be roughly $33M USD including the charging infrastructure (The Maritime Executive, 2020). Although the design is unique, it is worth noting that the capacity to build and deploy a large number of these vessels was built up in only a couple of years .

Table 8 – MINE Smart Ferry Specifications

MINE Smart Ferry Specifications (Kane, 2021)	
Overall Length (m)	24
Passenger Capacity	235 (104 seated, 131 standing)
Operating Speed (Knots)	11
Battery Storage	800 kWh
Max Range (Km)	80-100

Key Organizations in Bangkok Supply Chain

Table 9 – Bangkok Supply Chain

Organization Name	Focus	Location
Krungthep Thanakom	Operator	Thailand
Energy Absolute	Battery design and supply	Thailand
MariArt Shipyard	Vessel retrofit	Thailand
Torqeedo	Battery and motor supply	Germany

DENMARK

Overview

Denmark has been a leader of converting, building and operating battery electric vessels, operating some of the largest electric and hybrid electric ferries in the world. What is unique about Denmark's various electric vessels is their size and capacity, much larger than others around the world. Much of Denmark's demand for ferries are to run international routes between Denmark and neighbouring countries such as Germany, Norway, and Sweden. The total quantity (not all electric) of routes and the number of people travelling on them, roughly 560 ferries on 11 different routes, is much larger than anything we see in Canada (Direct Ferries, 2021).

MF Tycho Brahe

The MF Tycho Brahe originally entered operations in 1991 as a traditional diesel ferry. In 2017, the Tycho Brahe and its sister ship the Aurora were both converted to hybrid diesel electric systems. Each trip takes roughly 20 minutes and consumes approximately 1,175 kWh. In each port is a tower with a robot arm that connects the charging cable automatically every time the ship comes to the dock. The system charges for 6 minutes on the Danish side and 9 minutes on the Swedish side (Forsea, 2021). The batteries have a total capacity of 4,160 kWh, and it is worth noting that batteries are stored in shipping containers on the deck of the ship (pictured below). The entire conversion budget was $36M USD with $14.5M USD coming from the "European Union Fund".

Table 10 – MF Tycho Brahe Specifications

MF Tycho Brahe Specifications (Forsea, 2021)	
Overall Length (m)	111
Car Capacity	240
Passenger & Crew Capacity	1250
Thrusters	4 x 1.5 MW
Battery Storage	4.16 MWh
Charging time	6-9 minutes

E Ferry Ellen

The focus of a European Union "Horizon 2020" project, the Ellen was the largest electric ferry in the world when it entered service in 2019. The vessel was the first in the world to carry enough battery storage for both operations and emergency backup. A lot of design effort went into reducing the weight of the ship, such as an aluminum construction and recycled paper furniture instead of wood (The Maritime Executive, 2019). Initial calculations of operational costs have shown that the high investment costs for building the E-ferry will be compensated for after just five to eight years of operation, this includes the charging station capital infrastructure and the need to replace the battery packs during the vessel's lifespan (Blenkey, 2020).

Table 11 – E Ferry Ellen Specifications

E Ferry Ellen Specifications (The Maritime Executive, 2019)	
Overall Length (m)	59.4
Car Capacity	30
Passenger & Crew Capacity	200
Thrusters	2 x 750 kW propulsion, 2 x 250 kW thruster
Battery Storage	4.3 MWh
Daily Route	22 NM
Speeds	13-15.5 Knots

Europa Seaways - Hydrogen Ferry

In December 2020, a Danish and Norwegian coalition formed to build the world's largest and most powerful hydrogen-fueled ferry, the Europa Seaways. The ship is expected to be in service by 2027 operating a route between Denmark and Norway. The Europa Seaways will carry 380 cars or 120 trucks on a 48 hour long round trip, powered by a massive 23 MW hydrogen fuel cell (Morgan, 2021). This project is a massive undertaking, and its results will likely have a major impact on future hydrogen fuel cell vessels of this size.

Electric Fishing Vessels

In 2020, a consortium of Danish companies finished a three-year process to design a "Fishing Vessel of the Future". The purpose of the design was to try and create a fishing vessel that was optimized for energy usage and emissions reduction. The consortium found that their designs for a 24-meter vessel fuel consumption could be reduced by 61% and by 45% for a 17-meter boat (Bates, 2020). What is interesting about the study was that the overall design was based on technology and materials that exist on the market today batteries and fuel cells were not considered as being currently viable but were mentioned as a future opportunity.

KEY TAKEAWAYS

Overall, the goal of this review was to gain a better understanding of projects and regions that have been successful with marine vessel electrification and what takeaways can be used for a future project in Nova Scotia.

The mechanisms that Norway was able to use to incentivize electrification by requiring decarbonization for the private sector management of ferry routes is not a method that is practicable in Atlantic Canada. Although it is an effective method, the ferry routes in Atlantic Canada are largely run by provincial and municipal operators, not the private sector and are in significantly less quantity than Norway. While Norway does have the first hybrid electric fishing vessel in the world, there has been little further development in this sector.

The size and scale of the vessels being operated in Denmark are impressive, but they are not realistic at this time for operations in Atlantic Canada. It would be difficult to achieve this scale of a project with limited competency established in prior electrification experience. While there may be opportunities to electrify or hybridize mid to long ferry routes such as Nova Scotia to Prince Edward Island, Digby to Saint John, or Newfoundland to Nova Scotia, the size of these vessels makes these routes significantly more difficult to impact with current technology costs.

The speed at which Bangkok has been able to convert and build new electric ferries is impressive, and the passenger size of the MINE Smart Ferries are similar to the Halifax ferries. However, Bangkok's ferry designs likely do not meet the regulatory and operational standards required in Canada. It is an important takeaway to understand that the technology and equipment required to convert or build electric vessels are becoming more accessible, but this jurisdiction is not particularly relevant to the standards applicable in Nova Scotia.

British Columbia has a similar regulatory and governing environment that most directly relates to the opportunities for decarbonization in Nova Scotia. In addition, the similarity of cable ferry routes and metro ferry services are very similar to the operations found in Nova Scotia. Overall, British Columbia is the most similar and realistic region for comparison and activities should be undertaken to build relationships with companies and organizations in British Columbia as Nova Scotia moves towards vessel decarbonization.

STRATEGIC TECHNOLOGY REVIEW

The increasing trend of vessel electrification highlights the quickly changing landscape of vessel propulsion. The opportunity to decarbonize and the costs associated remain the two driving considerations for the adoption and development of propulsion technologies. Battery electric and hydrogen fuel cell propulsion systems both have in-service successful operations and significant projects under development. Among other technologies one potential propulsion method, ammonia, is worth paying attention to as the technology develops.

This Strategic Technology Review discusses the current opportunities, costs, and limitations associated with each vessel propulsion technology. It will also discuss the intermediary opportunity of hybridized diesel electric propulsion as a way to prepare fleets for future conversion. From there it will create a set of use cases for vessels where each technology has the competitive advantage. It is important to note that determining which decarbonization technology will "win out" for market adoption in the long term is a much more difficult challenge to predict and is largely one that will be determined outside Nova Scotia by international markets.

Although decarbonization technologies are discussed in this review, it should be noted that the current fleet and propulsion systems of vessels in Nova Scotia are largely dependent on petroleum. There is a significant amount of invested capital and infrastructure, which has evolved over many decades, and with it supply chains and distribution, port infrastructure, regulatory structure, and safety measures. Regulations require best practices and the adoption of design for safety, both during operations and in the event of collision or other emergencies. All the technology paths considered in this review will to a greater or lesser extent require development and adoption of measures in design and emergency response processes. For example, the safe handling and placement of battery storage, safe storage and transit on the vessel of hydrogen or ammonia.

ENVIRONMENTAL OPPORTUNITY

The environmental benefits of transitioning vessels to hybrid propulsion, battery electric, hydrogen, or ammonia are largely immediate. Depending on the percentage of renewable electricity used to charge the batteries or produce the fuel (hydrogen/ammonia), vessels can be made nearly carbon neutral. It has also been suggested that electric propulsion engines limit the amount of noise pollution compared to traditional diesel engines.

The opportunity and scale required to globally decarbonize marine vessels is massive. The shipping industry alone generates roughly 940 million tonnes of CO2 annually and is responsible for about 2.5 percent of the total amount of the global greenhouse gas emissions (European Commission, 2021). The growth of marine shipping due to globalization and integrated supply chains is expected to continue its high pace of growth and therefore increase its emissions if there is no change to the underlying propulsion systems. Fortunately, trends are changing in the shipping industry and some demonstration projects are moving ahead to test emerging technologies. In addition, the international shipping industry typically uses heavy fuel oil, commonly know as bunker fuel, which has higher GHG emissions compared to diesel fuel which is typically used in smaller vessels inshore.

Unfortunately, the global nature of shipping and the heavily cost driven focus on its operations make it difficult for Nova Scotia to influence the transition to green propulsion systems. In addition, the emissions generated from marine shipping are not well attributed to jurisdictions where they are operating. For example, the 2019 Environment and Climate Change Canada report attributes 474 kt of emissions from the marine transportation sector in Nova Scotia. However, this calculation only includes the "Consumption of fuels (excluding the biogenic CO2 emissions from Ethanol and biodiesel) by marine vessels navigating between Canadian ports" (Environment Canada, 2019). Therefore, international shipping is not captured in this number.

Although the broader shipping sector is difficult to influence, there remain significant opportunities to reduce the emissions in fishing, workboat, and public transportation vessel profiles in Nova Scotia. The 474 kt of emissions for the Nova Scotia marine sector are "inclusive of all fishing and military operations". The global fishing fleet was estimated to have generated 207 million tonnes of CO2 in 2016, with the small-scale fishing sector contributing 48 million tonnes to this total (Greer, Zeller, & al, 2019). With over 4000 registered fishing vessels operating and largely being purchased in Nova Scotia, this industry alone represents an opportunity to make an impact on provincial emissions. In addition, the technology required for significant decarbonization of fishing vessels, workboats, and ferries is mature enough for more immediate impact.

Hybrid Propulsion

One of the main challenges with transitioning large fleets to green propulsion systems is that there is often a mismatch between when vessel procurement decisions are made to when the green propulsion technology can meet performance requirements at a cost competitive price. For instance, many vessels have a planned useable service life anywhere from 25 to 50 years. Therefore, any vessels built today with a traditional carbon-intensive propulsion system will remain in service for decades and the future cost of conversion will be more expensive than designing a vessel for electric propulsion from the outset.

This challenge is where hybrid diesel electric propulsion has a strong business case. This type of propulsion relies on a diesel generator combined with a small battery storage capacity to produce electricity that drives electric motors on the vessel. Diesel electric propulsion remains largely comparable to traditional diesel propulsion for carbon emissions; however, it has three main advantages. The first is that nearly all of the cleaner propulsion methods use electric motors in their design, either by powering them with large battery storage or by using hydrogen or ammonia fuel cells to generate electricity on board. Therefore, as the technology becomes more affordable, diesel electric propulsion systems will be significantly easier and cheaper to convert to a greener propulsion method as costs decrease.

The second advantage is that a diesel electric system eliminates the need to run a generator to power auxiliary systems, especially if a modestly sized battery storage system is present. This means a vessel can be more fuel efficient by running a single larger generator instead of running a secondary, less efficient generator to power the ship systems. Finally, diesel electric systems have broad operational advantages over traditional diesel propulsion. Everything from noise and vibration reductions (due to a lack of driveshafts) to design flexibility, where one large generator can power multiple motors, or multiple generators can combine to power one large motor.

Diesel electric propulsion is a technology that already has widespread adoption and support. As seen in **Figure 1** below, in 2017 22% of larger industry vessels were using electric propulsion systems, with strong growth projected (Ammar & Seddiek, 2021). This technology broadly represents a strong intermediary option for marine vessel electrification and decarbonization.

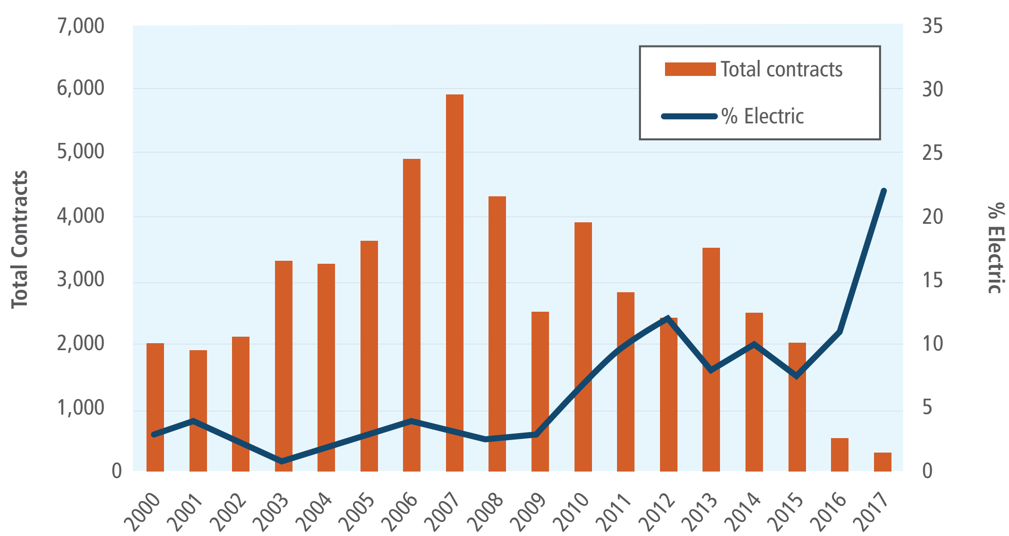


Figure 1 - Electric propulsion share in Global total ship contracts (left) and forecast of electric ship markets (right) (Ammar & Seddiek, 2021)

Battery Electric Propulsion

Battery electric propulsion systems take the diesel electric hybrid design further by designing a battery storage system with the capacity to supply the vessels operations, supported by a diesel generator as an emergency backup. Battery electric propulsion has been recognized as one of the most credible options in the short term to address the issue of GHG emissions and achieve decarbonization in the marine industry. There are numerous in-service battery electric vessels currently operating globally, with many more under design and construction.

The level of emissions generated by battery electric vessels largely depends on the emissions created when the electricity is generated. Electric grids are typically used as a power source to charge the vessels batteries. It is possible to create an independent source off-grid that runs purely on renewable energy to support the vessel charging.

An example is diesel-electric engines in fishing vessels, where the ships 'steam' out at full speed to save time to their intended location. Diesel is more efficient for 'steaming' out at full speed because the diesel burns cleaner at or close to full throttle and is more fuel efficient. Once at their intended location, operators can draw on the electric storage to travel around at lower speeds while moving along their fishing traps.

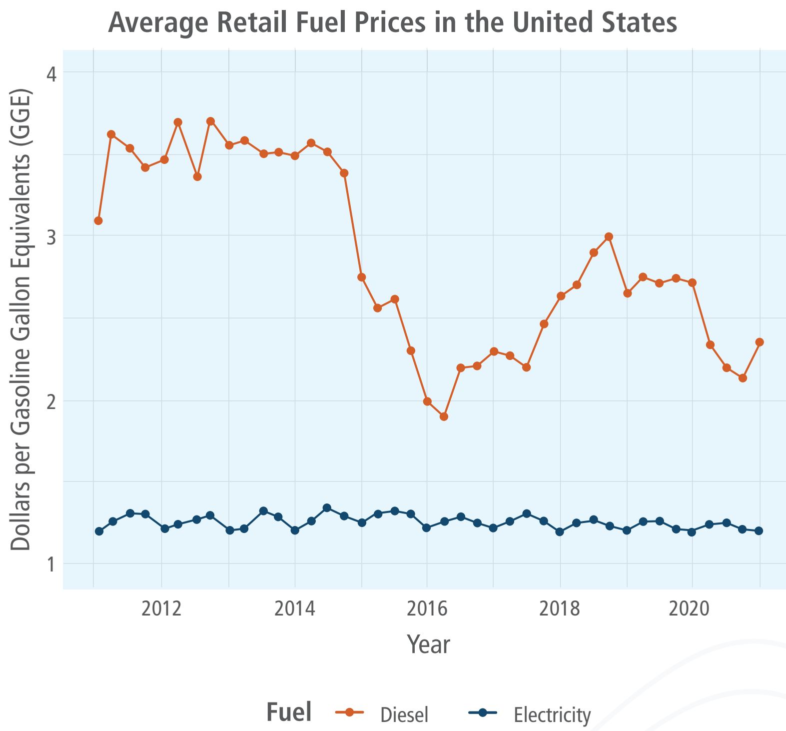
Overall, electric battery vessels are considered at this time to have potential for improving environmentally sustainability of the fishing fleet with reduced emissions (or no emissions depending on source). Since the electric grid necessary to charge the vessel batteries needs new development and infrastructure, there remains significant effort before the broader industry is able to fully decarbonize.

Fortunately, investment in electric vessels can also act as an investment into the grid. Fishing vessels operate on a mostly predictable schedule and when docked their batteries could be used to feed back into the grid, assisting with peak shaving.

Battery Electric Energy Comparison

When it comes to determining the operating costs for any type of vehicle, the cost of energy is one of the main components to consider. **Figure 2** illustrates the difference in average fuel prices in the United States for diesel and electricity.

Figure 2 – Average Retail Fuel Prices in the United States (U.S. Department of Energy, 2021)

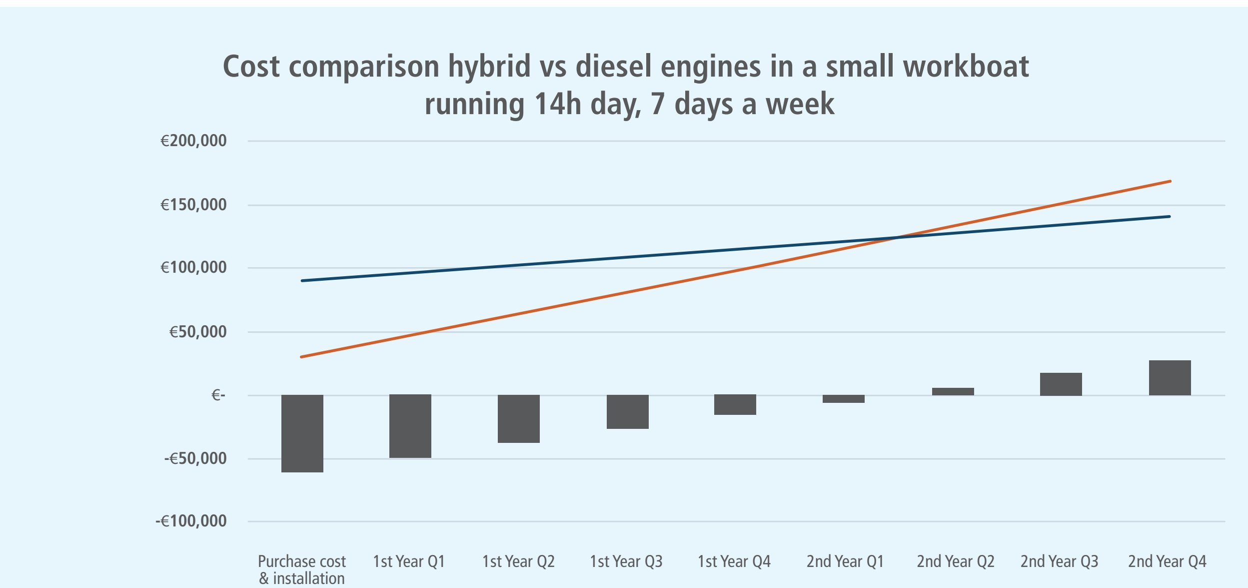


This indicates rates and fuel pricing in the US, these costs differ in Nova Scotia, and are generally higher, however are analogous. The Nova Scotia department of Natural Resources and Renewables monitors both diesel pricing and utility (residential and various classes of industry) rates.

The electricity rates have been relatively stable throughout the years since 2011, while diesel prices have not been as stable. From 2011 to 2021 the price of diesel varied between $1.90/GGE and $3.70/GGE. From 2011 to 2021 the price of electricity varied between $1.19/GGE and $1.34/GGE, a much smaller range of variation. It is important to note that electricity prices have been reduced by a factor of 3.6 because the source cites electric motors as 3.6 times more efficient than internal combustion engines (ICE) and that these prices are residential rates, so they do not include costs for infrastructure development, maintenance, along with other factors that may impact the rates. It is evident that diesel prices have larger variance in pricing due to fluctuations in demand and supply. Electricity prices remain more stable over time and the cost of carbon pricing for electricity will decline compared with diesel to an increasing share of renewable, low-carbon electricity. This volatility in diesel prices is important for vessel pricing considerations over the long term, and a more stable energy source will always be better for cost planning. In addition, any inclusion of carbon taxes also shifts the advantage further toward electricity pricing.

Although the current capital investment costs remain high for electric and hybrid vessels, their significantly lower operational costs are quickly reflected in return-on-investment calculations compared to traditional diesel vessels. This dynamic has been found true at many different vessel sizes and is demonstrated below in **Figure 3**.

Figure 3 – Cost comparison hybrid vs diesel engines in a small workboat in the EU (Oceanvolt, 2021)



	Purchase cost & installation	1st Year Q1	1st Year Q2	1st Year Q3	1st Year Q4	2nd Year Q1	2nd Year Q2	2nd Year Q3	2nd Year Q4
Diesel vs Hybrid difference	-€60,000	-€48,818	-€37,635	-€26,453	-€16,020	-€4,838	€6,345	€17,528	€27,960
Diesel engne TCO	€30,000	€47,325	€64,650	€81,975	€99,300	€116,625	€133,950	€151,275	€168,600
Hybrid solution TCO	€90,000	€96,143	€102,285	€108,428	€115,320	€121,463	€127,605	€133,748	€140,640

As seen in **Figure 3**, the graph demonstrates that a case study hybrid solution for a small workboat in Europe would cost around €60,000 more than a diesel engine for a small workboat operating 14-hour days, seven days a week. The purchase and installation cost are significantly higher for the hybrid compared to diesel, but in the long run the hybrid will be more cost effective. The graph also shows that the diesel engine slope is much steeper than the hybrid solution slope. This fact indicates that operating costs will keep increasing rapidly over the years for a diesel engine, while the operating costs for a hybrid or electric vessel will increase at much slower rate. The graph also suggests that a break-even point can be achieved in Europe in the second year. Just by the end of the second year, around €27,960 can be saved for the total cost of ownership when converting from a diesel engine to a hybrid solution. This puts into perspective the costs and benefits of owning a small hybrid workboat instead of a diesel engine boat over the long term of ownership the numbers can be even more encouraging looking into pure electric solutions.

For example, the electric ferry, Ellen was developed in Denmark for a cost of EUR 21.3 million and was for a time the largest pure electric vessel in the world. While this upfront cost is around 40% more expensive than a standard propulsion vessel, operating costs have been 75% lower (Blenkey, 2020). This cost competitiveness further asserts that battery electric systems can be more cost effective than a diesel boat due to significantly lower maintenance and operating energy costs over the long term.

There are few similar studies that have been conducted in Canada, however, much of this work is currently underway. One such example is the Alutasi, a workboat (Cape Islander) converted from diesel to become diesel-hybrid in 2020. Local Halifax company GlasOcean designed the conversion system and worked on monitoring the performance of this vessel to determine the efficiency of the onboard systems.

Battery Electric Operational Considerations

Along with the energy cost to operate an electric vessel, additional costs must be considered for the overall operation of the vessel, which can include maintenance, battery replacement, charging infrastructure development, and other factors. The following figure presents the lithium-ion battery price trend over the last decade.

Figure 4 – Li-ion battery price in the last decade (Anwar, Zia, Rashid, Zarazua de rubens, & Enevoldsen, 2020)

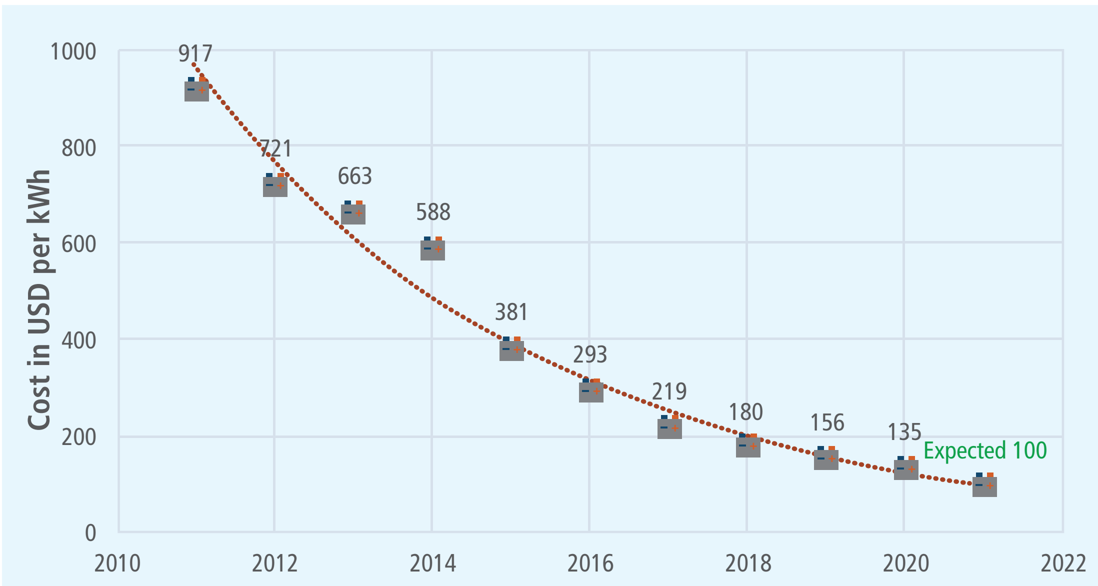


Figure 4 demonstrates that lithium-ion battery price has declined from $917 USD to $135 USD per kWh in the last 10 years, and it is expected to be reduced to $100 USD by the end of 2021. Still a 500 kWh Lithium-ion battery for a fully electric vessel can cost $67,500 USD. Reducing battery size can significantly decrease cost. For a hybrid vessel, a medium sized lithium-ion battery of around 300 kWh would cost $40,500 USD. For smaller vessels, smaller energy storage systems of 160 kWh could be used, and this would reduce the battery price to $21,600 USD. Lithium-ion batteries usually have a life cycle of 7-10 years, but it depends on the number of charging and discharging cycles, operating temperature, etc. Fortunately, the cost and energy density at the time of replacement can be expected to improve as new technologies are implemented and global demand grows.

Along with battery costs, electric vessels require an appropriate cooling system to make sure the electric motor does not overheat which could affect the performance of the vessel and create safety hazards. There are different types of cooling systems that could be integrated into an electric vessel, which includes air cooling, liquid cooling, and fin cooling. While no real data was found for cost of cooling systems for electric vessels, usually air cooling is the cheapest and simplest solution. Liquid cooling would be the most effective solution but is more complicated and costly. Battery applications in Canada also need to consider warming systems to operate in cold weather, both to keep minimum battery operating temperatures and for cabin heating. Diesel systems often use their waste heat for this purpose.

BATTERY ELECTRIC INFRASTRUCTURE CHALLENGES

Installation of charging infrastructure is a major additional cost that needs to be considered when converting to battery electric vessels. Currently the electrical infrastructure at most ports throughout the region does not have the capacity to support larger demand for vessel charging. Although the cost for transitioning a vessel to electric is well understood, the costs to upgrade port infrastructure are not, and the responsibility for who should manage this upgrade is often unclear. The cost of charging stations will depend on the power requirements of potential vessels, the regional grid capacity, and the current infrastructure state of the port. Single charging stations could cost between $30,000 and upwards of $3 million CAD depending on the power requirements and pre-existing infrastructure.

VESSEL MAINTENANCE

There is sparse literature on electric vessel maintenance, however it is generally accepted that less maintenance is required electric vessels due to having fewer moving parts in the motor compared to diesel engines. Currently there is little support available for maintaining electric vessel systems in Atlantic Canada, due to the lack of existing electric vessels. There is a Zodiac dealer in Dartmouth that has recently trained 2 staff for recently released electric boats. Additionally, there are two large electric battery suppliers that should be noted for operating in Canada in the marine sector.

Corvus Energy, founded in 2009 in British Columbia, but now owned by a Norwegian company, has supplied their energy storage solutions in over 400 ships worldwide. They offer various services for maintenance, such as 24/7 technical support, training, and a spare parts service, all under their Life Cycle Service Program. Notably, Corvus supplied the batteries for the BC Ferries Island Class ferries.

Shift Clean Energy (previously Sterling PlanB Energy Solutions) is the other Canadian company based in British Columbia. Shift supplied the batteries for the Alutasi, the first battery powered electric ship certified in Canada. They have an international presence, with their headquarters, R&D, and Product Development in Vancouver. Their ‘CellSwap’ technology allows batteries to be swapped easily without the need for a full system replacement.

BATTERY ELECTRIC OPERATIONAL LIMITATIONS

The following graphics and figures demonstrate statistics and results from the eight pure electric vessels that were studied throughout the world. The vessels come from Sweden, Norway, India, Denmark, China, and Italy.

Figure 5 - Battery capacity (kWh) and vessel length (m) of pure electric and hybrid vessels present globally (Anwar, Zia, Rashid, Zarazua de rubens, & Enevoldsen, 2020)

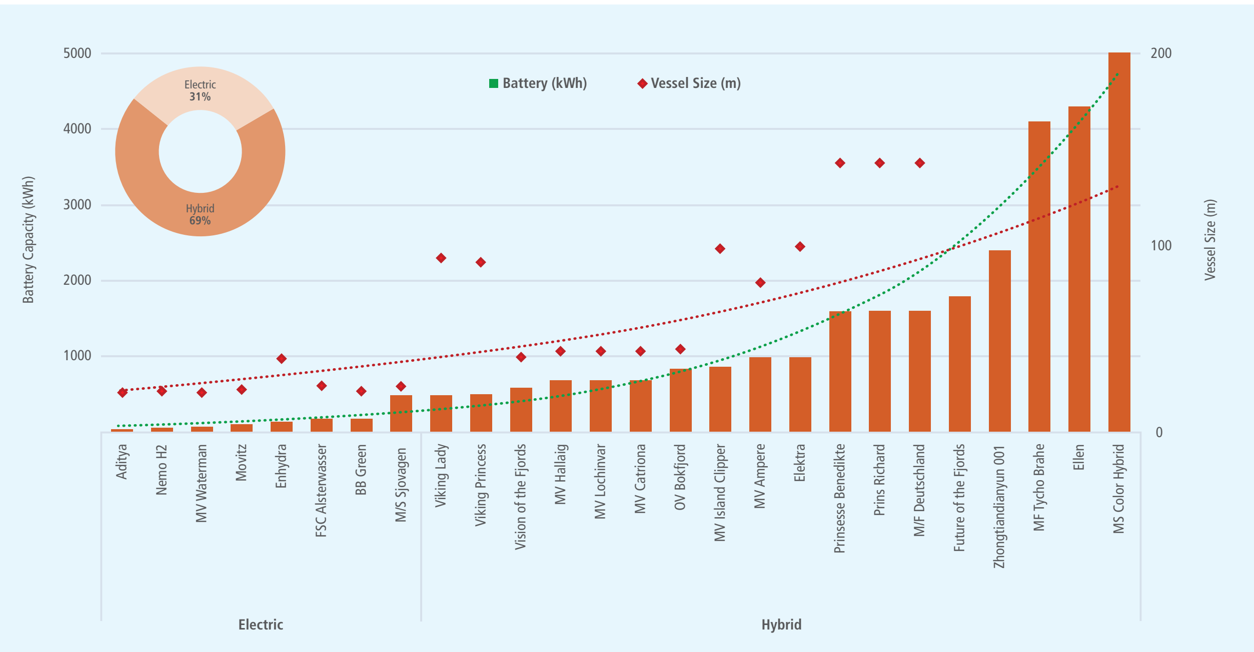


Figure 6 - Passenger/car capacity and vessel max. speed (knots) of pure electric and hybrid vessels present globally. (Anwar, Zia, Rashid, Zarazua de rubens, & Enevoldsen, 2020)

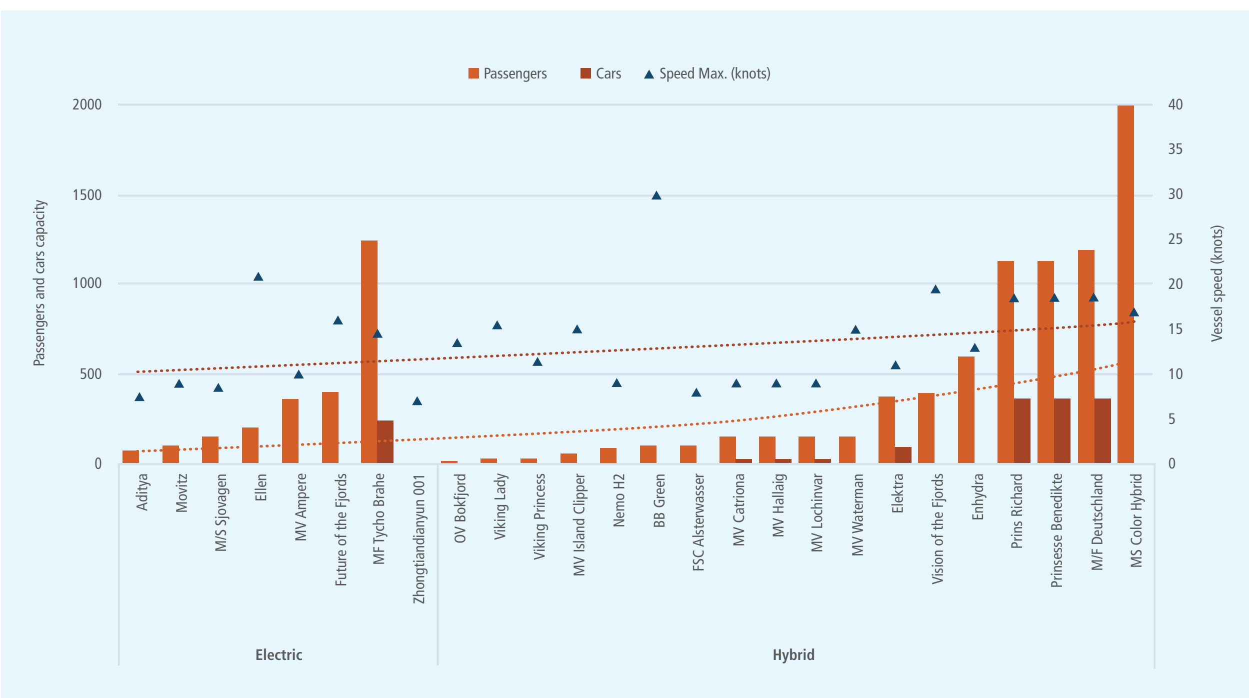


Figure 5 demonstrates that in-service pure electric vessels have a battery capacity that ranges between 5-500 kWh with an average of ~140 kWh. Additionally, the average length of electric vessels is 21-39 m with an average of ~22 m.

Figure 6 demonstrates that pure electric vessels have a passenger capacity of 75-1250 people (average ~ 200 people) and car capacity of ~240 cars. It also shows that the speed of electric vessels ranges from 7-21 knots with an average of ~9.5 knots.

Overall, the data provided in figures 5 and 6 demonstrates that electric boats are best suited for passenger vessels or vessels with short distances and limited time operations due to their limited battery capacity, if they are going to be able to carry sufficient passengers, freight, or vehicles.

Limited battery capacity and limited time operations creates a need for more consistent charging sources and introduces limits for vessels speeds. This poses a difficulty when implementing electric motors into certain types of vessels. Longer ferry routes, cruise ships, or cargo ships are currently not possible to support with fully battery electric systems.

An additional limitation would be the charging of the battery banks that are used to drive the electric motor of the vessel. For most of Nova Scotia there would be a need to upgrade the coastline electrical grid because Energy Storage Systems (ESS) have large system (MWh) demands. Current grids may not have enough capacity to deliver higher energy requirements in a short time. However, with the addition of a micro-grid that has onshore storage capacity, these demands could be met without putting undue pressure on the main grid.

Overall, electric battery vessels are a good solution to help reduce GHG emissions, however they are not ideal for all marine transports. Battery electric would be ideal for vessels that partake in short voyages and have longer “refuel” (charging time) periods. Additionally, the infrastructure needed is expensive and therefore investment will be necessary. Lastly, the energy density is still low which means that the batteries cannot store enough energy in relation to their size and weight to fit into many vessel formats.

Photo provided by Atlantic Towing

Photo provided by Nova Scotia Community College

BATTERY ELECTRIC IDEAL USE CASE

Today, there are many types of vessels that have been built or retrofitted to be hybrid electric or fully electric, including passenger vessels, fishing and aquaculture, research, sailing ships, tugs, workboats, offshore vessels, and cargo ships. Ferries are by far the most common, with retrofits and new builds being undertaken globally. Larger vessels, such as shipping containers and cruise ships have mostly been retrofits. Offshore and shipping vessels are almost exclusively retrofit to become hybrid electric, due to the length of their trips and the size of the vessels.

Ferries are the ideal use case for battery electric vessels. Their predetermined routes and definitive docking times make it easier to determine charging and energy storage requirements. The reduction in noise is favourable as well, making the voyage more enjoyable for the passengers and crew.

Fishing boats are also good candidates for hybrid electric propulsion, as their movement pattern allows for diesel and battery power to be used most efficiently. Based on the example from Glas Ocean's presentation at the H2O Conference in June 2021, found in **Figure 7** on page 29, the most fuel is consumed while fishing on site. However, the fuel flow rate is the lowest. While the fuel flow rate is low, it makes sense to use battery electric instead as such a low fuel flow rate diminishes the efficiency of the diesel consumption. However, due to familiarity and reliance on current technologies, fishers are likely to be more skeptical of transitioning to electric propulsion systems.

Figure 7 – Fuel consumption during fishing vessel operations (Glas Ocean)

Operation	Speed (knots)	Time (hr)	Fuel (flow rate (l/h)	Total Fuel Consumed
Transit to Site	9	1	40.0	40.0
Fishing at Site	4	6	18.5	111.2
Transit to Port	9	1	40.0	40.0

While larger all-electric vessels have started to emerge, the battery technology has not evolved enough for these vessels to match their diesel counterparts. The size of the energy storage solutions required to power larger vessels on longer routes would be too large to also carry cargo or passengers. However, hybrid electric in large ships can be considered for some GHG reductions.

Overall, vessels such as fishing boats, workboats and ferries that dock frequently are seen as ideal candidates for electrification. Docking routinely allows ample time for charging to support the voyage length and today there are many electric ferries operating around the world. The reduced noise is beneficial for crew, passengers, and marine life.

AMMONIA FUEL PROPULSION

Discussion of using ammonia (NH3) as an energy source for marine vessels is fairly new. Largely pressured by mounting environmental concerns and inevitable regulatory change, it has been proposed by the cargo industry as a potential green fuel to support the industry’s transition to a less carbon intensive future. Ammonia has a few interesting benefits; it can be burned in a modified engine with zero carbon emissions or used in a fuel cell similar to hydrogen. There is already a global supply chain network to support the transport and storage of ammonia, which is used for making fertilizer, and ammonia can be made “green” depending on the energy source used to generate it.

There remain significant environmental and technical concerns for ammonia. Ammonia by itself is toxic and damaging to the environment. It also faces similar green energy production challenges as hydrogen, where the carbon intensity is tied to the production’s energy source. However, there are demonstration projects moving forward in Europe to test the feasibility of ammonia in vessels. It is unlikely that ammonia will see widespread adoption in the near future, but it will be worthwhile to be aware of its development. Due to the cost benefits of the shipping industry standardizing a green propulsion fuel, it is likely that only one of LH2 or ammonia will be chosen as the standard, similar to a winner take all industry. In this type of economic competition, it is often the first to market technology that is able to build up a user base that wins out in the long run.

HYDROGEN FUEL CELL PROPULSION

Compressed hydrogen and liquid hydrogen fuel cells are leading the race for providing a path to decarbonization of larger vessels that battery electric systems cannot currently solve. In short, fuel cells take compressed gas or liquid hydrogen stored in a pressured container and mix it with air, which contains 21% oxygen, in a fuel cell. With the use of a catalyst, often platinum, the hydrogen and oxygen combine to generate an electric charge and water as the chemical byproduct. Like battery electric propulsion, hydrogen vessels use this electricity to power electric motors with a complement of batteries to support power demand. This technology is already used for some land vehicles and has the potential to scale up to larger vessels with some major projects currently under construction.

The immediate benefits of this technology are that hydrogen fuel cell ships are able to carry and refuel hydrogen in a similar way that diesel is used, significantly extending the range of a vessel compared to battery electric. As discussed in the next section, how 'green' hydrogen is depends on how it was produced, and the power used in that process, however when reacted, hydrogen produces no GHG emissions. Currently, there are a few compressed hydrogen boats in operation. There are no actively running liquid hydrogen vessels in the world, however many projects are underway with expected launches in late 2021.

HYDROGEN FUEL CONSIDERATION

There are three kinds of hydrogen to consider when comparing the cost of hydrogen fuel to that of diesel and battery electric. 'Gray' and 'blue' hydrogen are both produced through the process of gasification or natural gas reforming. The production of 'gray hydrogen' results in large volumes of carbon dioxide and is the least expensive. If the carbon dioxide is properly captured or used for other purposes, the hydrogen is designated as 'blue'. The most expensive type of hydrogen is 'green' hydrogen, which is produced via electrolysis, using electricity to break apart water into hydrogen and oxygen, capturing and liquefying just the hydrogen. If the electrolysis is powered by renewable sources, then the 'green' hydrogen produced is completely carbon emission free. **Table 1** lists the price of the various kinds of hydrogen production in 2019 (IEA, 2020).

Table 1 – Type of Hydrogen Production

Type of Hydrogen Production	$USD per kg
Natural gas (gray)	0.70 - 1.60
Natural gas with carbon capture & storage (blue)	1.20 - 2.10
Coal gasification (gray)	1.90 - 2.50
Coal gasification with carbon capture & storage (blue)	2.10 - 2.60
Electrolysis (green)	3.20 - 7.70

Comparing diesel to hydrogen requires the consideration of their differing energy densities. Diesel has an energy density of 13 kWh/kg and hydrogen has an energy density of 33.6 kWh/kg. This equates to roughly 2.5 kg of diesel required for every 1 kg of hydrogen. The cost of diesel currently is $1.25/kg USD. A comparison between the different types of hydrogen and diesel for 1000 kWh worth of energy is shown in **Table 2**. Note that the most expensive price ranges from **Table 1** were used in the calculations.

Table 2 – Energy Source Pricing

Energy Source	Cost for 1000 kWh ($USD)
Diesel ($1.25/kg) (GlobalPetrolPrices, 2021)	$96.15
Green hydrogen ($7.70/kg)	$220.15
Gray hydrogen ($2.50/kg)	$74.40
Blue hydrogen ($2.60/kg)	$77.38

We can see in the table above that based on fuel costs alone that the production costs of gray and blue hydrogen appear competitive with diesel. However, the calculations for the hydrogen were purely based on the production costs, and do not take into consideration the transportation or storage costs. Green hydrogen, the carbon reduction leader, is the most expensive. However, the IEA expects the cost of production by 2060 to be reduced to $1.30-$3.30, which would reduce the cost for 1000 kWh to $98.21 in today's dollars (IEA, 2020). Diesel prices can continue to become less cost competitive with the addition of further carbon taxes or international price spikes.

In addition to the fuel costs, costs of installation and maintenance must be considered. Domestic supply of hydrogen is limited in many parts of Canada; therefore, transportation and storage are required. At the current price of hydrogen, the transportation costs would be significant. Building and maintaining the storage solutions would require large capital investment(s) and long-term maintenance costs. Current supply chains and storage infrastructure have been invested in over a century to support diesel and other petroleum fuel use and will take time to transition to support alternative fuels. Overall, it is generally accepted that hydrogen propulsion systems are more expensive to run than current diesel propulsion.

HYDROGEN FUEL LIMITATIONS

Hydrogen vessels have a few limitations that need to be considered when discussing them as a potential option in Nova Scotia. The key limitation is the storage of compressed or liquid hydrogen, onshore and on vessels.

Hydrogen has a very high energy density compared to most fuels. However, its low density at room temperature results in a low energy per unit volume, which means that it requires high-pressure storage methods to attain a higher volumetric energy density. Liquid hydrogen requires cryogenic temperatures or high pressure for storage because its boiling point at atmospheric pressure is –252.8 degrees Celsius

Figure 8 - Comparison of specific energy and energy density for several fuels (U.S. Department of Energy, 2021)

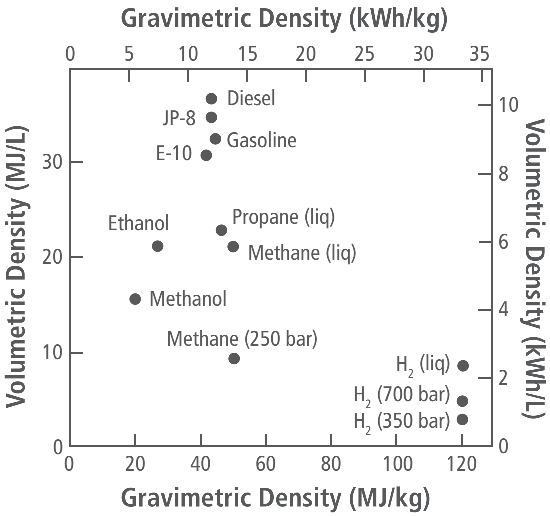


Figure 8, above, demonstrates liquid hydrogen and compressed hydrogen in comparison to other types of fuel and energy sources and shows that it has a high gravimetric density (MJ/kg) while having a low volumetric density (MJ/L). The low volume density of hydrogen is a challenge for both stationary and portable applications, which brings added costs. Currently compressed and liquid hydrogen are not cost competitive due to the need for specific storage requirements and the already high production cost. Overall, hydrogen is unlikely to be a cost-competitive energy source in Nova Scotia in the next 10 years. However, there is an argument to make that projects using hydrogen fuel cells remain viable to advance the technology and capacity in the region and that Nova Scotia should actively monitor energy prices.

Other limitations associated with hydrogen vessels are related to travel distances; the longer a vessel's route, the larger the vessel's storage tank capacity needs to be. This means that the vessel either needs to be larger or have less room for passengers or cargo. These are important practical considerations for vessel owner and operators.

Photo provided by Nova Scotia Community College

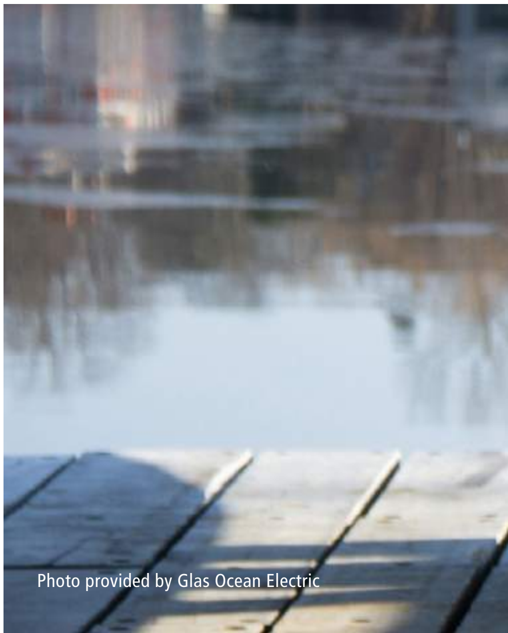


Photo provided by Glas Ocean Electric

HYDROGEN SUPPORT AND MAINTENANCE

There is little documentation on operating hydrogen fuel cells and equipment in Canada. Currently, there are no marine vessels in Canada operating hydrogen fuel cells. However, Loop Energy, with a presence in British Columbia, is a supplier of hydrogen fuel cells. They have not worked with ships; however, they have experience in urban deliver and transport, transit buses, heavy duty & semi-trailers and construction equipment. Ballard Power Systems, based in Canada, provides fuel cell power systems for public transit vehicles and offers the FCWave fuel cell system for marine propulsion applications. Additionally, Red Rock Power Systems, based out of Prince Edward Island, is focused on developing and commercializing fuel cell solutions for the marine industry, both in Canada and internationally.

HYDROGEN SUPPLY CHAIN DEVELOPMENT

As of now, any development of a liquid hydrogen supply chain in the Maritimes should focus on the start-up phase: that is satisfying local demand, building capacity, and focusing on innovation for hydrogen production, distribution, and storage. From there, the region can start focusing on systemization to increase capacity, improve efficiency and build relationships to continue growing the supply chain. The Atlantic Hydrogen Alliance was formed in the fall of 2021 to focus on these challenges and advance the opportunities for hydrogen in the region.

There remain significant challenges that need to be overcome in order to succeed in the development of a liquid hydrogen supply chain in Nova Scotia and across Canada.

According to a report from Natural Resources Canada (NRCAN, 2020) some of these existing challenges include:

ECONOMIC AND INVESTMENTS:

1. Hydrogen used as heating fuel is around 5 times more expensive than natural gas.
2. Since the hydrogen market is still in the early stages in Canada, large capital investments to scale production requires that demand grow simultaneously with supply. Long-term demand forecasting before industry can invest in large-scale projects is crucial.
3. Work needs to be done to reduce costs for infrastructure, materials, and manufacturing costs.
4. Investment in research and development for manufacturing process and facilities.
5. There is an economic challenge for developers to invest since there is an uncertainty in fueling demand growth over time.

TECHNOLOGY AND INNOVATION:

1. Support is required for research and development to reduce cost, find better solutions, and develop new technologies to benefit sector.
2. Not enough investments in R&D which limits innovation.
3. Canada's slowed investments in research compared to other countries.
4. Technology development and innovation are essential for the raw materials, end-use products, production, storage, and distribution of hydrogen.

POLICY AND REGULATION:

1. Lack of long-term policy and regulation framework for hydrogen. For policies that are in place, they are not consistent across regions.
2. Long-term 2050 targets could lead to a massive transformation in the energy sector and requires clear coordinated efforts.

INFRASTRUCTURE:

1. Development of production, storage and distribution infrastructure must be coordinated with the growth in demand and requires significant capital.

CODES AND STANDARDS:

1. To adopt development of hydrogen, gaps in existing codes need to be addressed.
2. Certification and approvals of deployments might require significant time.
3. Lack of codes and standards remains one of the limiting aspects to adopting the development of hydrogen.

AWARENESS:

1. Lack of knowledge about the benefits, opportunities and safety of hydrogen is affecting the growth in demand and slowing down deployment.

HYDROGEN IDEAL USE CASE

Liquid hydrogen has a potential use case for a variety of marine vessels, such as ferries, tugboats, fishing vessels, and cargo ships. However, the technology remains largely untested and the initial capital costs would be largely prohibitive without significant public funding. In the future, if the costs continue to decrease and pilot projects are successful hydrogen does have some unique advantages over battery electric propulsion. Compared to battery electric systems, liquid hydrogen is a better alternative for larger vessels that require high energy, travel longer distances, and have fewer opportunities for refueling; local examples would include inter-provincial ferries. With ferries doing several crossings a day, it is important for operations that fast-refueling time and better energy storage is achievable. Battery electric systems generally are a better fit for smaller ferries that travel short distances.

Liquid hydrogen could also be used for tugboats. While tugboats represent a small portion of the overall marine CO2 emissions, these boats often have operational requirements that require them to be quickly ready for service and therefore cannot afford wait times for charging. The benefit here is that if the infrastructure is in place, LH2 can be used to refuel vessels in the same span of time that it would take to refuel with diesel.

MATRIX OF POTENTIAL USE CASES

Table 3 – Viable propulsion technology for vessel type

Vessel Type	Viable Energy/Propulsion
Small passenger ferry	Hybrid electric and electric
Passenger and vehicle ferry	Hybrid electric and hydrogen
Tugboat	Hybrid electric and hydrogen
Inshore fishing vessel	Hybrid electric
Inshore workboat	Hybrid electric
Cruise ships	Hybrid electric and hydrogen
Cargo ship	Hybrid electric, hydrogen, and ammonia

MARKET ANALYSIS

INTRODUCTION

The purpose of this market analysis is to inform business decisions for those that are in, that may enter, and that support the Nova Scotian marine electrification supply chain by scoping the prospective size of the market: quantifying the regional fleet of vessels that could be electrified. The market analysis primarily focuses on the potential market in Eastern Canada, but touches on the New England region, and broader markets for exporting internationally. Historically, due to distance and costs, the market for finished vessels and for substantial contract work by the Nova Scotia supply chain has generally been limited to Eastern Canada and the New England region.

For each vessel that could be electrified, there are a wide series of potential products or services that Nova Scotian companies could provide. Design and naval architecture, battery research and design, boatbuilding, retrofits, vessel to grid interface, marine side infrastructure development, maintenance, and system monitoring are all opportunities for companies to develop capacity for vessel electrification. This report provides an overview of the markets for fishing vessels, passenger vessels, workboats, and tugs in Eastern Canada as well as discuss the opportunities for export to the US and other international markets.

USER BASE

This study is primarily interested in quantifying the total number of vessels that are operated in Eastern Canada. Although there are opportunities to export to Central and Western Canada, the shipping costs and logistics make the Nova Scotia supply chain less competitive in those markets compared to those regions' boatbuilding industries. Using statistics captured by the Department of Fisheries and Oceans and Transport Canada we can break out the regional totals for various vessel types. From there we can assume a replacement rate to estimate the annual new vessel market in Eastern Canada.

Fishing Vessels

Fisheries and Oceans Canada provides detailed fishing vessel totals for Eastern Canada by province, fishing region, and vessel length. **Table 1** shows the totals broken down for each region and vessel type, while **Table 2** provides an annual demand estimate for vessels given an average 20-year lifespan. Overall, there are a significant number of fishing vessels operating in Eastern Canada, primarily under 45 feet in length. This demand has been primarily serviced by the regional boatbuilding industry. However, the fleet of fishing vessels has declined significantly over the past 40 years with a declining trend over the past decade (Fisheries and Oceans Canada, 2021). This can be seen in **Figure 1**, where fishing vessel totals in Nova Scotia have decreased 10.6% since 2009.

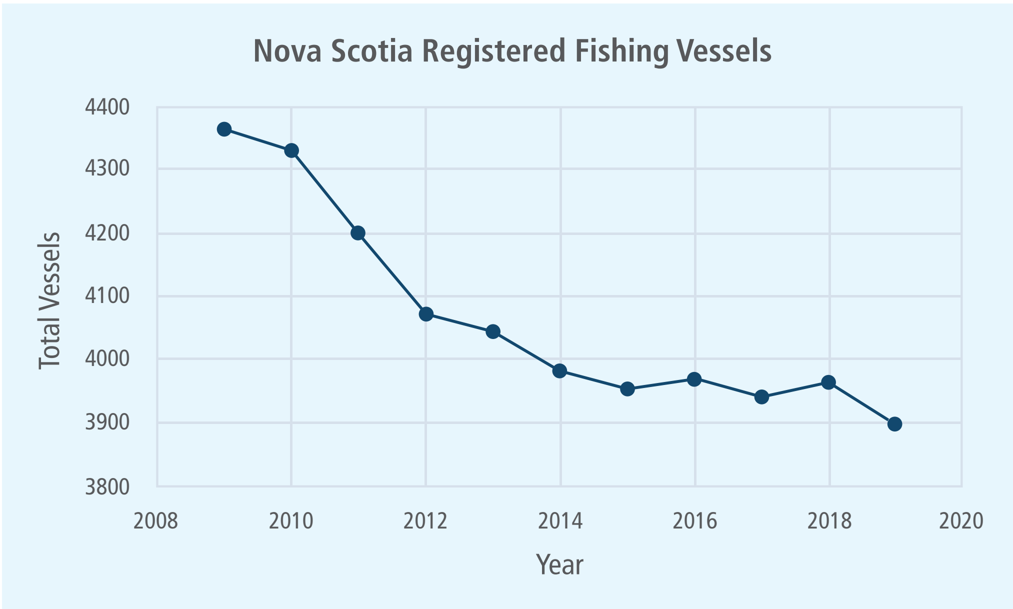
Table 1 - Number of vessels by length (in feet) by province and region, 2019 (Fisheries and Oceans Canada, 2021)

Province	Region	< 35'	35'-44'11"	45'-64'11"	65'-99'11"	> 100'	TOTAL
Nova Scotia	**Maritimes**	1,156	1,895	90	10	24	**3,175**
	Gulf	187	460	73	2	0	**722**
New Brunswick	**Maritimes**	125	362	57	9	1	**554**
	Gulf	474	1,054	236	29	2	**1,795**
Prince Edward Island	**Gulf**	99	1,065	142	1	0	**1,307**
Quebec	**Quebec**	317	530	189	18	0	**1,054**
Newfoundland	**Newfoundland**	4,898	667	385	28	15	**5,993**
Total Atlantic		**7,256**	**6,033**	**1,172**	**97**	**42**	**14,600**

Table 2 - Annual new vessel demand (assuming 20-year average lifespan) (Fisheries and Oceans Canada, 2021)

Province	Region	< 35'	35'-44'11"	45'-64'11"	65'-99'11"	> 100'	TOTAL
Nova Scotia	**Maritimes**	57.8	94.8	4.5	0.5	1.2	**158.8**
	Gulf	9.4	23.0	3.7	0.1	0.0	**36.1**
New Brunswick	**Maritimes**	6.3	18.1	2.9	0.5	0.1	**27.7**
	Gulf	23.7	52.7	11.8	1.5	0.1	**89.8**
Prince Edward Island	**Gulf**	5.0	53.3	7.1	0.1	0.0	**65.4**
Quebec	**Quebec**	15.9	26.5	9.5	0.9	0.0	**52.7**
Newfoundland	**Newfoundland**	244.9	33.4	19.3	1.4	0.8	**299.7**
Total Atlantic		**362.8**	**301.7**	**58.6**	**4.9**	**2.1**	**730.0**

Figure 1 – Annual Nova Scotia Fishing Vessels (2009-2019)



The fishing vessel fleet in Eastern Canada is a potential opportunity for vessel electrification and could provide a market base for companies looking to enter this new market. However, if the trend of declining vessel demand continues, then the market will continually become smaller and more competitive. As the fleet begins to transition to electrified vessels, boatbuilders who incorporate this new technology could have a competitive advantage compared to traditional diesel fishing vessels boatbuilders.

Passenger Vessels

Data for passenger vessels, workboats, and tugs were sourced from Transport Canada's "Small Commercial Vessel Registry" published in March 2021. The Small Commercial Vessel Registry:

"… includes registration information about small non-pleasure vessels powered by an engine of 10 horsepower (7.5 kW) or more and commercial river rafts.

Registration for small non-pleasure human-powered vessels (such as canoes or kayaks), or small sailing vessels and small power-driven vessels with propulsion motors less than 10 horsepower (7.5 kW) is not required, however owners have the option to register voluntarily."

To determine vessel location, this study used the Authorized Representative (AR) province data point instead of the owner province data. The Authorized Representative (AR) is responsible for acting in respect to all matters relating to the vessel. The AR is likely to be operating in the same location as the vessel more often than the owner of the vessel and should be more accurate for provincial totals.

Table 3 shows the totals for passenger vessels operating in Eastern Canada, as well as an estimated annual demand based on a 30-year expected lifespan. The 30-year expected lifespan was used for passenger vessels as they often run longer than other commercial fishing or industrial vessels. The passenger vessel totals include ferries, and any vessels used for commercial marine tourism. This market would likely have the strongest case for electrification. Governments generally have more capacity to absorb the costs associated with the initial transition to electric vessels, they also have a more direct public responsibility for decarbonization. In addition, tourism operators would likely find significant competitive advantages for being able to provide decarbonized experiences.

Table 3 – Passenger Vessels in Eastern Canada (2021)

Province	Vessels	Est. Annual Demand (30yr)
NS	191	6.4
NB	76	2.5
PE	19	0.6
NL	170	5.7
QC	784	26.1
Total	**1240**	**41.3**

Table 4 on page 41 is a list of operating ferries in Atlantic Canada and their vessel type. In total 46 vessels operate in Atlantic Canada as passenger ferries. The cable ferries present the easiest technical challenge for electrification however contribute relatively minimal amounts of carbon emissions as they require low power. For example, the Lahave cable ferry only uses a single 50 horsepower engine whereas the new Halifax-Dartmouth ferries have two 385 horsepower engines. Meanwhile, some of the ferry routes such as North Sydney to Port aux Basques are unable to be currently fully electrified due to current battery technology not having the energy density required to economically power the large ship over the longer voyage. Hybridization would bring some efficiencies and carbon reduction for these vessels. A compounding challenge is that there are few economies of scale for ferries through standardized design in Atlantic Canada as many of the routes require different duty cycles and vessel sizes. There are some viable routes for electrification in Atlantic Canada, however this would be a small market opportunity in terms of number of vessels. It does however provide an opportunity for the industry to build capacity in vessel electrification by supporting government contracts.

Table 4 – List of operating ferries in Atlantic Canada

Location/Route	Type
Halifax-Dartmouth Ferry – 5 vessels	Self-propelled passenger ferry
Lahave, NS	Cable ferry
Country Harbour, NS	Cable ferry
Little Narrows, NS	Cable ferry
Englishtown, NS	Cable ferry
Tancook Island, NS	Self-propelled passenger and car ferry
Petit Passage, NS	Self-propelled passenger and car ferry
Grand Passage, NS	Self-propelled passenger and car ferry
Digby – Saint John	Self-propelled passenger and car ferry
PEI-NS – 2 vessels	Self-propelled passenger and car ferry
Maine – Nova Scotia	Self-propelled passenger and car ferry
North Sydney – Argentia	Self-propelled passenger and car ferry
North Sydney – Port aux Basques – 3 vessels	Self-propelled passenger and car ferry
PEI – Magdalen Islands	Self-propelled passenger and car ferry
Belleisle Bay, NB	Cable ferry
Evandale, NB	Cable ferry
Westfield, NB	Cable ferry
Gagetown, NB	Cable ferry
Gondola Point, NB	Cable ferry
Kennebecasis Island, NB	Cable ferry
Summerville-Millidgeville, NB	Self-propelled passenger and car ferry
White Head Island, NB	Self-propelled passenger and car ferry
Deer Island, NB	Self-propelled passenger and car ferry
Grand Manan – 2 vessels	Self-propelled passenger and car ferry
Campobello Island, NB	Self-propelled passenger and car ferry
St.Barbe – Labrador, NL	Self-propelled passenger and car ferry
Bell Island – Portugal Cove, NL – 2 vessels	Self-propelled passenger and car ferry
St. Brendan's – Burnside, NL	Self-propelled passenger and car ferry
Fogo Island, NL	Self-propelled passenger and car ferry
Long Island – Pilley's Island, NL	Self-propelled passenger and car ferry
Goose Bay – Nain, NL	Self-propelled passenger and car ferry
La Poile – Rose Blanche, NL	Self-propelled passenger ferry
Ramea – Burgeo, NL	Self-propelled passenger and car ferry
Francois – Burgeo, NL	Self-propelled passenger ferry
Gaultois – Hermitage, NL	Self-propelled passenger ferry
Recontre East – Pool's Cove, NL	Self-propelled passenger ferry
South East Bight – Petite Fort, NL	Self-propelled passenger ferry

Workboats

Table 5 lists the total workboats operating in Eastern Canada and an estimated annual demand. Due to the high number of vessels and pre-existing boatbuilding industry, this market appears to be a strong electrification opportunity for the region with an estimated annual demand of 271 workboats. Although the standardization and power requirements of these vessels still requires review, these workboats are notionally in an ideal size range for current electrification technology with an average length of workboats operating in Nova Scotia at 6.07 metres and an average propulsion horsepower of 130.

Table 5 – Workboats in Eastern Canada (2021)

Province	Vessels	Est. Annual Demand (20yr)
NS	696	34.8
NB	403	20.2
PE	206	10.3
NL	646	32.3
QC	3466	173.3
Total	**5417**	**270.9**

Tugboats

Finally, the total tugs operating in Eastern Canada are shown in **Table 6**. This is a small market, however, there are many examples of tug electrification projects internationally and it could represent an opportunity for operators in Eastern Canada to transition their vessels. In particular, Aspin Kemp and Associates develops hybridization systems for tugboats internationally and has been successful in exporting their technology and design support.

Table 6 – Tugs in Eastern Canada (2021)

Province	Vessels
NS	9
NB	2
PE	0
NL	4
QC	61
Total	**76**

US – New England Opportunity

Although the Northeastern seaboard of the United States would have vessel totals that are higher than in Eastern Canada, the Jones Act makes it very difficult for Canadian companies to access this market. From a report by the Nova Scotia Boatbuilders Association on the Jones Act, the US Jones Act:

"… is a catch-all term commonly used for a series of US laws regarding Coastwise Trade and the Fisheries. The Jones Act affects all vessels operating in coastwide trade in the United States. This is accomplished by requiring all vessels engaged in US coastwise trade to be US-built, to be documented under US law, and to be owned and operated by US citizens. Coastwise trade is defined, for the Jones Act, as transportation of passengers or merchandise between two points in the United States. A boat that carries freight between US ports without stopping at a foreign port is considered to be in coastwise trade. A boat carrying passengers between US ports with out stopping in a foreign port is considered to be in coastwise trade. And, finally, a boat working in the US fisheries is considered to be in coastwise trade (Nova Scotia Boatbuilders Association, 2002)."

The definition for coastwise trade unfortunately captures almost all of the potential export opportunities for electrified vessels to the US market. However, Nova Scotian boatbuilders and those in the sector that are familiar with the challenges of the Jones Act have found ways to work within the system to service the US market. There are a few exceptions for personal use yachts, and vessels that belong to states, such as police and fire boats, are not considered to be in coastwise trade. State and Local authorities can use boats such as Nova Scotia-built RHIBs in the US as patrol and police boats (Nova Scotia Boatbuilders Association, 2002). Even though these opportunities for export remain, it remains a challenge that does not exist for Canadian buyers.

There is another Jones Act exemption that came out of a judicial decision and is frequently used for importing fishing vessels into the US. In short, the ruling states that any vessel which measures less than 5 net tons may engage in the fisheries in US territorial waters (Nova Scotia Boatbuilders Association, 2002). However, the 5 net ton measurement is not the weight of the vessel, it is instead the boat's internal volume and is measured in varying ways depending on the design and size of the vessel. In practice, fishing vessels up to 50 feet in length are often eligible for this exemption and can be imported into the US.

Beyond the market opportunities for personal yachts, small workboats, and fishing vessels the New England market also presents an opportunity for companies looking to provide technology or design support in the broader vessel electrification supply chain.

International Markets

International markets, outside the Northeastern United States, are less attractive for the export of completed vessels due to additional transportation costs, tariffs, and the existence of many strong native ship and boat building industries internationally. The opportunity remains for companies that provide the technical design work, or subcomponents that are integral in vessel electrification. Corvus Energy, a company founded in British Columbia, is a great example of how a region with no electric vessels was able to build an international revenue stream and become involved in battery design and installation for many of the largest electric vessels in the world.

CONCLUSION

Nova Scotia's blue economy is strong, with a varied supply chain equipped to deliver a breadth of capabilities, including vessel design, build, operations, and associated technologies. As companies look to retain and to grow their competitive advantage, many are monitoring trends in marine vessel decarbonization elsewhere and market opportunities emerging locally. The adoption of alternative fuels such as ammonia and hydrogen is fast-changing internationally, and a number of Nova Scotia companies are engaged, including those in the Atlantic Hydrogen Alliance. For smaller to mid-sized vessels, marine electrification is closest at hand. For vessel owners and operators, electrification offers operating cost savings, some operational benefits while requiring some modified practices, and the environmental and marketing benefits of decarbonization. However, the higher price of vessels is still a factor, as is less regulatory certainty and the lack of shore-based charging infrastructure. Meanwhile, a shift to diesel-electric propulsion for new builds has been observed and will ease future transition as retrofitting vessels to become hybrid or fully-electric is less invasive and less costly. Public focus to address barriers these firms identify, such as regulatory innovation and reliable means to charge vessels, like the agile charging infrastructure being planned at COVE, will allow local firms to grasp the commercial opportunity and accelerate the pace of electric vehicle adoption. This demonstrated experience will position service providers and technology companies to export to broader geographic markets.

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