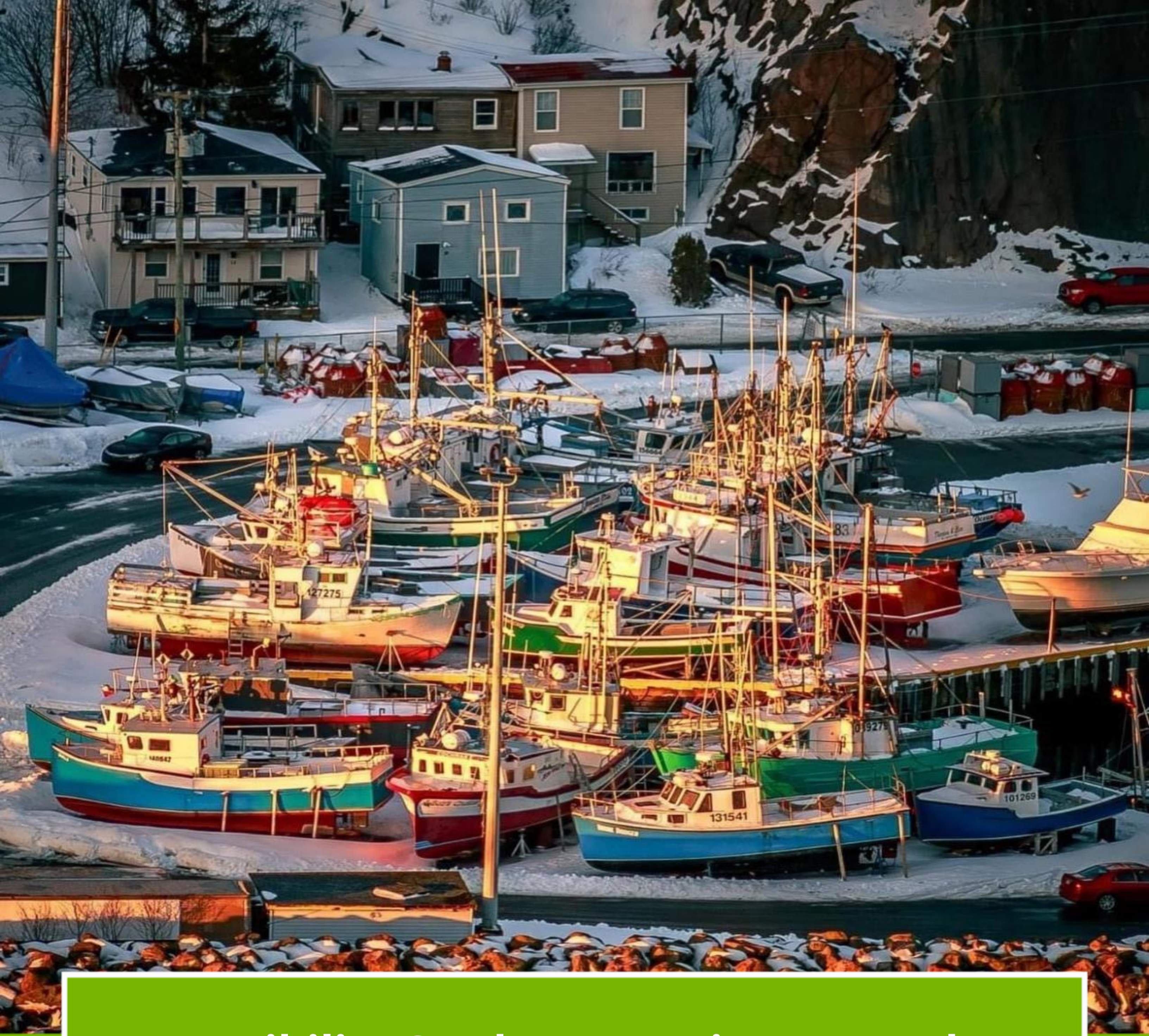


Feasibility Study on Moving Towards an Electric Powered Fishing Fleet

FFAW | Unifor Fish, Food & Allied Workers

Draft Report

207553.00 • November 2021

0	Issued for Final Submission	S. Molloy	11/09/21	D. Lea
B	Issued for Client Review	S. Molloy	05/07/21	D. Lea
A	Issued for Review	S. Molloy	01/29/21	D. Lea
	Issue or Revision	**Reviewed By:**	**Date**	**Issued By:**

207553.00-RE-001

CBCL
Solutions today | Tomorrow IN mind
Maritime Centre, 1505 Barrington Street, Suite 901
Box 606 Halifax, NS B3J 2R7
902-421-7241 | CBCL.ca | info@CBCL.ca

November 9, 2021

Robert Keenan
Procurement Specialist
FFAW | Unifor
P.O. Box 10, Station C, 368 Hamilton Avenue, 2nd Floor, St. John's, NL, A1C 5H5
Email: rkeenan@ffaw.ca

Dear Mr. Keenan:

RE: Feasibility Study on Moving Towards an Electric Powered Fishing Fleet
Draft Report

CBCL Limited (CBCL), in association with Glas Ocean Electric, is pleased to submit this Draft Report for a feasibility study to move towards an electrically powered inshore fishing fleet in Newfoundland and Labrador.

Yours very truly,

CBCL Limited

Prepared by:	Reviewed by:
Dr. Sue Molloy, Ph.D., P.Eng.	David Lea, P.Eng.
Study Lead Engineer	Senior Project Manager, Energy Services
Direct: (902) 233-3265	Direct: (902) 492-6758
Email: sue@glasocean.com	Email: davidlea@cbcl.ca

Project No: 207553.00

Contents

Chapter 1 Introduction

1.1 Project Background

The commercial fishery in Newfoundland and Labrador has historically been the largest industry in the province, both in terms of monetary value and employment. The development of the offshore oil and gas industry, changes in fishing technology, and adaptation of the fishery to different species have contributed to reduce the importance of the fishery in the provincial economy although it still remains one of the key economic drivers in the province, especially in rural communities.

Ensuring the long-term sustainability of the fishery in Newfoundland and Labrador is one of the mandates of the FFAW. With an aging population, new technologies and techniques will be required to attract younger people into the fishery. This is critical not only to the fishery but also to the survival of the social fabric in many of the province's rural coastal communities. This study to examine the feasibility of beginning to electrify a portion of the inshore fishing fleet is recognition of the necessity that the fishery must continue to adapt to ensure its survival as an industry. This study will examine the GHG impacts of the fishery as well some other negative impacts of traditional fishing equipment and technologies on the fishers themselves. The study will then examine the benefits, challenges, and potentially the compromises that may be needed to permit electrification onboard inshore fishing vessels to start to be embraced by the industry.

1.2 Newfoundland and Labrador Inshore Fishing Fleet

1.2.1 Fleet Size, Categories, and Distribution

The average numbers of licenses issued in Newfoundland and Labrador during the years 2015 to 2018 was 3617[1]. On average, these license holders were using 6,188 inshore vessels (those less than 65' in length) per year, to conduct the inshore fishery[2].

[1] https://www.dfo-mpo.gc.ca/stats/commercial/licences-permis/fishers-pecheurs/fp18-eng.htm#table1-fna

[2] https://www.dfo-mpo.gc.ca/stats/commercial/licences-permis/vess-embarc/ve18-eng.htm

The average number of inshore vessels, by length, in all Atlantic provinces, are detailed in Table 1.1[3]. Although this report will mainly focus on inshore, small scale vessels (<35'), all lengths of boats have been included for comparison of size and make up of fleet.

Table 1.1: Summary of Inshore Vessels in the Atlantic Provinces

Province	Region	< 35'	35'-44'11"	45'-64'11"	65'-99'11"	> 100'	Total
Nova Scotia	Maritimes	1,283	2,009	98	13	25	3,427
	Gulf	195	507	67	4	0	773
New Brunswick	Maritimes	123	412	55	9	2	600
	Gulf	524	1,157	167	24	2	1,874
P.E.I.	Gulf	106	1,178	97	1	0	1,382
Quebec	Quebec	475	525	177	14	2	1,193
Newfoundland	Newfoundland	5,141	646	401	25	16	6,228

The inshore fishing fleet of Newfoundland and Labrador is much larger (6,228 total vessels) than any other Atlantic province and has a much greater percentage of small (<35') fishing boats (82%) in its commercial fleet than any other province. Since vessels of this size are predominantly involved in day fishing, it is this class of vessel that is most suited to electrification due to its ability to recharge at dockside on a daily basis. Other vessel classes that may be involved in multi day fishing trips are less likely to benefit as much from electrification initially due to the size and weight of the batteries required to power a vessel for a multi day trip.

1.2.2 Historic Fuel Use and GHG Emissions

Data was collected from fishers in the area. Fishers were asked to report on fuel use, size of vessel, motor size, and fuel type, among other items.

The average weekly fuel consumption based on reported vessel is summarized in Table 1.2.

Table 1.2: Average Weekly Fuel Consumption

Size of Vessel	Weekly Fuel Consumption Reported (average) (L)
Decked <34'11"	262.5
Decked <34'11" and Speedboat	297
Speedboat	333

1.2.3 Fuel Costs for the Inshore Fleet

Fuel use is one of the costliest parts of a fishing trip and depends on vessel size, trip length and duration, speed, age of vessel and engine, weather conditions, and more. Most inshore

[3] https://www.dfo-mpo.gc.ca/stats/commercial/licences-permis/vess-embarc/ve18-eng.htm

fishing vessels are gasoline or diesel powered. Vessel power ranges from 10 horsepower outboard motor (lobster fishing typically) to 520 horsepower motor (otter trawl fishery).

Data gathered from Newfoundland fishers indicated that the fishers who were fishing for lobster within 20 miles of shore, had an average transit speed of 9 knots and an average hauling speed of 3 knots. These fishers reported an average weekly fuel consumption of 316L, inboard motors with an average 271 horsepower, and outboard motors with an average of 84 horsepower. Compared with some average daily fuel consumption figures from Nova Scotia fishers (refer to Table 1.5), the fuel consumption figures provided seem quite low suggesting that most fishing activity is occurring quite close to home or the number of fishing days per week is low.

Although exact numbers cannot be confirmed without further discussions with Newfoundland fishers, Glas Ocean has been collecting data on vessels since 2016. Using a reference vessel in the database we can estimate the expected fuel use for a typical 35ft long NL fishing vessel. The relevant boat particulars for this vessel are show in Table 1.3.

Table 1.3: Boat Particulars

Boat Particulars		
Length	35	Ft
Breadth	13	Ft
Draft	3.5	Ft
Engine	Diesel	
	160	Hp
	119	kW

GOE has a power versus boat speed curve for this vessel that can tell us the power required at any operational speed in an unloaded condition. If the boat was fully loaded with people, catch, or equipment the power referenced below would be expected to be higher at each speed. All power curves for boats follow the exponential trend shown for a 40ft boat in Figure 3. The numerical data presented in Table 1.4 is taken from the power curve for the 35ft boat. This means that at higher boat speeds the additional power for a fully loaded boat could be substantial. In the absence of direct fuel flow measurement on the NL boats we can use a reference from "*Coastwatch*"[4] that gives a rule of thumb for estimating fuel flow.

1Hp = 0.1GPH

[4] Reference: https://ncseagrant.ncsu.edu/coastwatch/previous-issues/2013-2/summer-2013/on-the-water-save-fuel-money-running-your-boat-by-the-numbers/

Table 1.4: Boat Power and Fuel at Speed

Boat Speed (knots)	Power		Fuel	
	kW	Hp	GPH	LPH
4	25	33.5	3.35	12.6
6	45	60.3	6.03	22.84
8	65	87.1	8.71	33.00
9	110	147.5	14.75	55.84

Using these fuel flow values we can build a profile for a typical trip, Table 1.5. The total litres of fuel per trip can be calculated by breaking the trip into transit and fishing operations. Using the conversion of 1lt of diesel= 2.66kg of CO_{2e} we can determine the GHG emissions per trip.

Table 1.5: Typical Trip Profile

Operation	Speed (knots)	Time (hr)	Fuel Flow Rate (L/hr)	Total Fuel Consumed (L)	GHG (kg)
Transit to Site	9	1	55.84	55.84	149
Fishing at Site	3-4	6	12.69	76.14	203
Transit to Port	9	1	55.84	55.84	149
TOTAL				**187.82**	**501**

The GHG emissions of the vessel per trip, per 50 days, 100 days, and per fleet of differing sizes is shown in Table 1.6.

Table 1.6: GHG Emissions of Vessel per Trip

	GHG per Trip (tonnes)	GHG per 50 Days (tonnes)	GHG per 100 Days (tonnes)
1 Vessel	0.5	25	50
10 Vessels	5	250	500
100 Vessels	50	2500	5000
1000 Vessels	500	25000	50000

Further discussion, including the impact of the carbon tax in the coming years, is presented in Section 7.2.

1.2.4 Historic Inshore Fleet Landings and Values

Landings (metric tonnes) for inshore fishing boats for the year 2018 are detailed in Table 1.7[5].

[5] http://www.nfl.dfo-mpo.gc.ca/NL/Landings-Values

Landings documented in 2018, per species, based on the province fished, are detailed in Table 1.7. The Atlantic totals include the Maritimes and Gulf areas of Nova Scotia and New Brunswick.

Table 1.7: Landings per Species

Species	PEI Total	Quebec Total	NL Total	Atlantic Total
Total Groundfish	70	2,694	44,000	86,752
Total Pelagics	4,761	6,158	47,881	142,516
Total Shellfish	23,714	36,897	107,556	363,981

The shellfish category includes clams, lobsters, and crabs, with lobster quantities making up 3% of reported shellfish landings. The large majorities of landings reported by Newfoundland fishers were shrimp (47%) and crab (26%). This report focuses on lobster and crab fishing. Inshore fishing boats in Newfoundland typically fish for lobster and crab, remain close to shore, and do not require overnight trips. This makes inshore fishing boats a good candidate for electrification.

Chapter 2 Engine and Onboard System Energy Requirements

2.1 Vessel Propulsion Systems

2.1.1 Typical Systems

A recent study by Glas Ocean Electric (GOE) on a selection of Nova Scotia fishing boats has allowed the team to collect information on lobster fishing boats and to give a general view of the sector in Nova Scotia. These boats (Figure 1) are similar to those in Newfoundland and Labrador (Figure 2). These boats are generally in the range of 10-14 m with beams ranging from 4 to 7 m (Table 2.1). The horsepower of the engines ranges from 160-300 hp and the max operational speed from 8.5 to 14 knots.

Figure 1: Typical Nova Scotia Lobster Boat

Figure 2: Newfoundland Fishing Boats

Table 2.1: NS Fishing Boat Particulars

Fishing Vessels Name	Length (m)	Length (ft)	Beam (m)	Beam (ft)	Draft (m)	Draft (ft)	Dry Weight (ton)	Max Horsepower	Max Speed (Knot)
Boat #1	12	39.37	6.7	21.98	1.4	4.59	14.8	300 hp	8.5
Boat #2	10.6	34.78	4	13.12	1.1	3.61	N/A	160 hp	10
Boat #3	11.3	37.07	4.9	16.08	N/A		N/A	210 hp	13
Boat #4	10.6	34.78	5.2	17.06	1.6	5.25	14.5	220 hp	14
Boat #5	12.8	41.99	4.9	16.08	1.1	3.61	21	225 hp	9.5
Boat #6	10.6	34.78	5.8	19.03	1.1	3.61	14.2	251 hp	10

2.1.1.1 Electric

GOE has converted one fishing boat to hybrid battery electric and is currently converting a second. Both of these boats can use a 135 kW (180 HP) motor to complete their operations as they fall into the curve presented in Figure 3, and operate in the speed range of 2-10 knots. The power requirements at 8 knots are approximately 30 kW and at 12 knots are approximately 120 kW. The cubic nature of a boat's power curve means that there can be big gains in power efficiency if there is an effort to reduce top speeds. Batteries are currently fairly large and heavy so the ideal operations are those that can offer a lot of time at lower speeds and power.

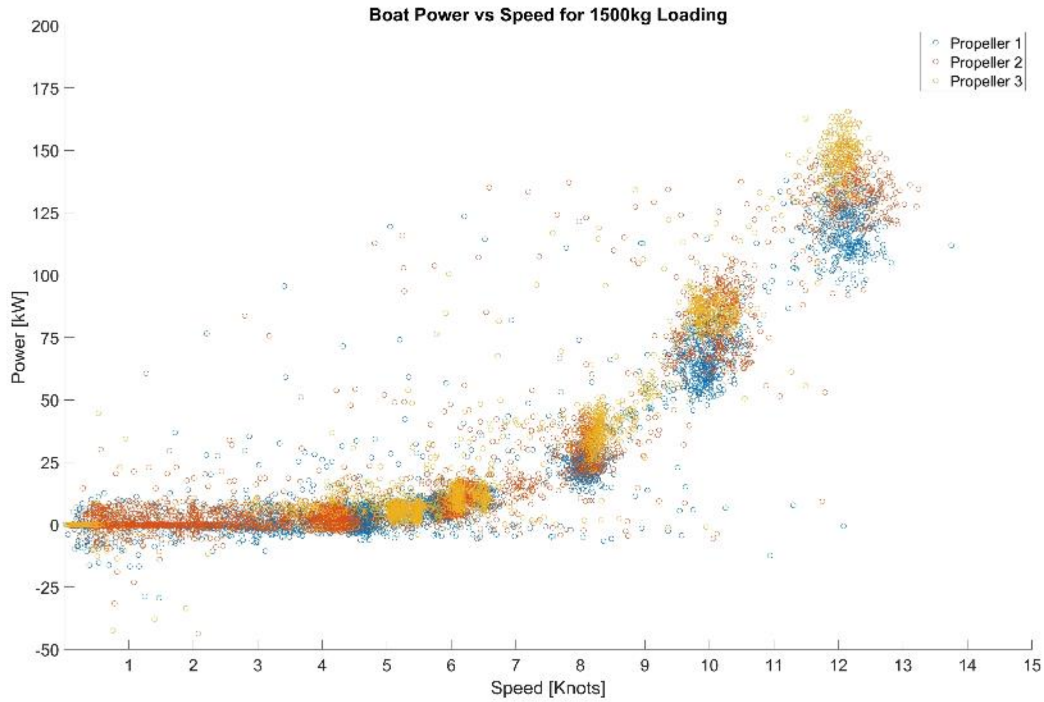


Figure 3: Power Curve for a Nova Scotia 40ft, Under 14 tonnes Fishing Boat

2.1.2 Typical Operational Profiles for Each Kind of Vessel

A typical operation, as measured on a Nova Scotia fishing boat, is shown in Figure 4. The time series (seconds x 10^4) shows that the boat travels to site at a top speed then slows down to a stop at the first pot and then speeds up to around 4 -6 knots and travels pot to pot stopping at each pot. The negative power is the propeller turning in the other direction when the boat quickly turns on reverse as they slow to the pot.

Looking at this profile it is clear that the boat is spending 6-8 hours at low speed and in the plot in Figure 4 indicates that for this operation a 35-50 kWh battery would provide enough power to cover all the low speed operations. For example, if this vessel travels at 3-4 knots for 6 hours, using the power curve in Figure 3, that will require approximately 5 kW x 6 hours = 30 kWh battery not accounting for losses. In a hybrid system, the diesel system can be used for the transiting operations and the battery can be used for the low-power operations. With control over speeds and some trip planning, the use of batteries can be optimized for scenarios such as these.

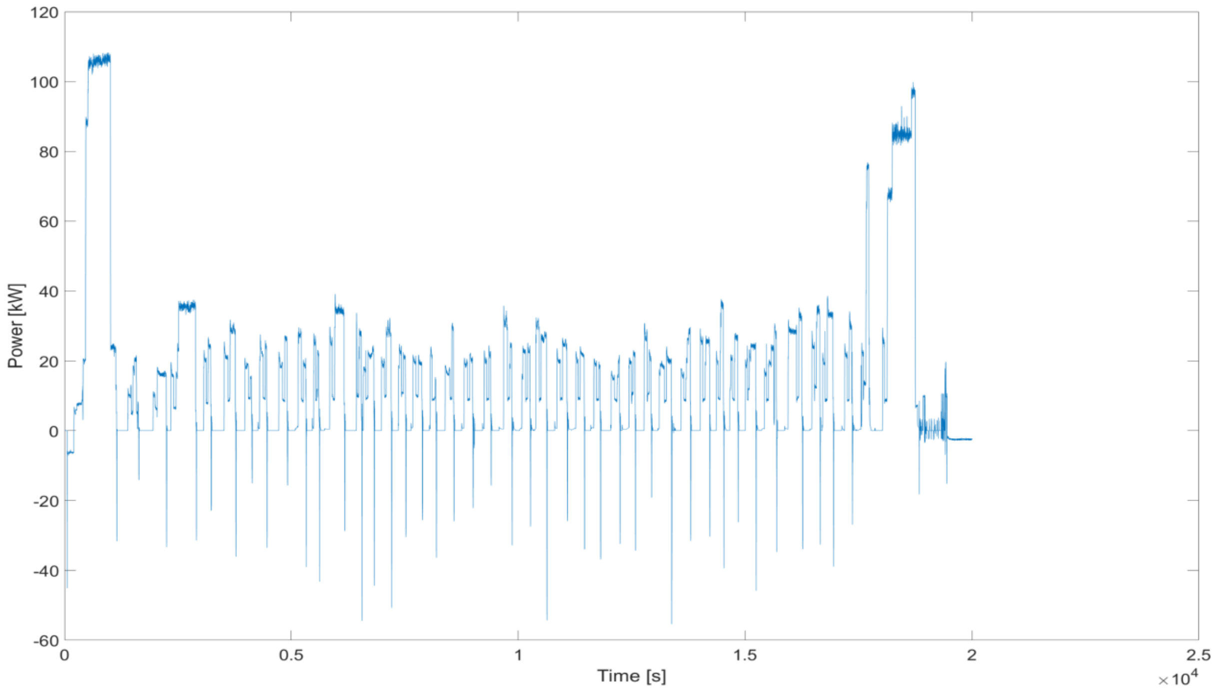


Figure 4: Time Series of Power Use in a Typical Fishing Day

2.1.3 Potential Power Use for Larger Vessels

Larger vessels have higher power curves. In general, the first 6 knots fall in the lowest 10% of the power curve. GOE has not collected data for larger vessels outside of the 35'-45' range but an example of an R-Class icebreaker power curve in Figure 5 shows that the trend of a cubic power curve is common across all vessels.

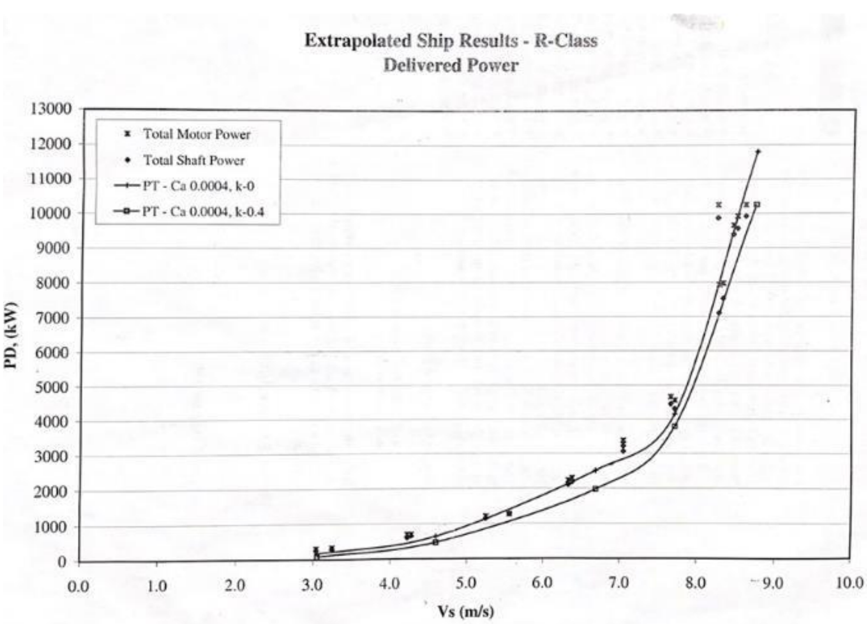


Figure 5: Sample Large Ship Power Curve

2.2 Onboard Power Requirements

2.2.1 Additional Power Loads

GOE has surveyed boat owners and Table 2.2 shows examples of the kinds of additional loads that are found on a typical fishing boat. All of these devices need to be powered from an electric or hybrid system. In some vessels this may mean changing the types of loads – e.g., LED lights, gas powered stoves rather than electric/engine heating, and electric pumps for the hydraulic systems. There are more energy efficient devices available and there is an option to investigate the ability to scavenge power using the systems on board, e.g., regen when lowering the hauler, small solar panels, or small wind turbines.

Sizing an electric or hybrid system needs to include a full analysis of the additional power loads.

Table 2.2: Typical Non-Propulsive Loads on a Fishing Boat

Boat	Batteries	Gas/Oil Powered Devices	Electrically Powered Devices	Hydraulically Powered Devices
1	4 x 8D	Gas Stove	fridge, microwave, 2x bus heaters, radar, plotter, sounder, auto pilot, stereo, lights, tv, PlayStation, VHF, Inverter, 3x bilge pumps	power steering, trap hauler, pole master
2	2 x 8D		VHF, lights, radio, CD player, 3x bilge pumps	power steering, trap hauler
3	5 x 8D	Diesel Stove	Vacuum Cleaner, 4x plotters, Inverter, sounder, 2x VHF, 2x GPS, stereo, radar, lights, 3x bilge pumps	power steering, 2x trap haulers
4	3 x 8D	Genset (6500 W)	2x computers, radar, 2x VHF, GPS, stereo, video surveillance, inverter (2000 W), heater fans, 3x bilge pumps, lights, autopilot, 2x 320 W crab lights	power steering, washdown pump, trap hauler, pole master
5		Genset (6500 W)	2x computers, radar, 2x VHF, GPS, stereo, video surveillance, inverter (2000W), heater fans, 3x bilge pumps, lights, autopilot, 2x 320 W crab lights	power steering, washdown pump, trap hauler, pole master
6	2 x 8D	None		power steering
7	4 x 8D		2x GPS, radar, plotter, sounder, coffee maker, stereo, VHF, bilge pumps, auto pilot, lots of lights	power steering, pole master, trap hauler
8	2 x 8D	None	2x plotters, 2x sounders, radar, GPS, video monitoring system, microwave, 2x inverters, VHF, heater	power steering, trap hauler, washdown pump

2.3 Equivalent Electric Power Requirements

2.3.1 Cranes/Hauling

Crane Haulers generally tend to be hydraulic because of their perceived higher reliability. There is an opportunity for manufacturers to provide better quality electric haulers, however, in the meantime electric systems can power the hydraulic haulers. For the lobster fishing industry some concern with hydraulic haulers may be related to speed. An assessment of the advantages and disadvantages of hydraulics for this application must be considered. The Hydro – Slave electric hauler appears to be a viable alternative to traditional haulers driven by the main engine and could permit operation from battery power.

2.3.2 Refrigeration

Not all vessels require refrigeration but the vessels that do often have an auxiliary engine or genset to run the refrigeration. In general, the day tripping boats that are the target of this study do not use refrigeration as they use seawater to hold the catch and are not travelling for long periods of time. There is an opportunity to reduce any onboard refrigeration requirements by investigating highly insulated cold boxes or new high efficiency refrigerators that do not add significant load to the vessel grid.

2.4 Electric Power Costs, Grid Power, Recharging Stations

2.4.1 Level 2 Charging

When charging lithium ion storage batteries, the type of charging system dictates the speed at which the battery will charge. For example, if charging from a home plug (level 1, 120 V) it would be expected to have a rate of approximately 3 kW. This means that a 30 kWh battery will take 10 hours to charge from completely empty not accounting for any losses in the system. A level 2 charger is much faster, closer to 7 kW so it would take just over 4 hours to charge. A level 3 charger that charges at 25-50 kW is less likely to be available at a wharf because they generally require additional cabling from the utility. A level 2 charger requires a 240 V connection rather than a 120 V which is more common in older built structures.

Standard Level 2 charging stations provide 6-10 kW of 240V AC power to onboard vehicular battery chargers. The onboard chargers rectify AC voltage to DC voltage to charge the battery systems. To make use of the batteries for onshore energy storage requires both the charging station and the vehicular charging system to be of “vehicle-to-grid” (V2G) design. This requires a bidirectional vehicular charging system with both rectification circuitry (AC to DC) and inverter circuitry (DC to AC). Such technology is rare and costly (approximately four times the cost of unidirectional circuitry).

Generally, Level 3 charging stations are required to achieve proper V2G operation.

The additional cost of a V2G Level 2 charger could be in the order of $30,000, in addition to onboard systems, and a Level 3 charger could be in the order of $100,000. In large harbours of up to 50 vessels, the additional onshore cost of V2G Level 2 chargers to supply the fleet could be in the order of $150,000, in addition to the onboard systems, and Level 3 chargers could be in the order of $5,000,000, depending upon the amount of grid upgrading required to supply high voltage power to the wharf. Depending upon the number of vessels requiring recharging each day, the harbour authority may be required to establish a recharging schedule.

2.4.2 Containerised Storage

Options for charging at the wharf can include containerised storage, such as that shown in Figure 6, which can offer high speed vessel charging when required without putting additional stress on the local grid. The container energy storage system is charged from the grid at an even continuous level and can offer grid support for voltage stabilization. This benefit is mostly considered for communities with isolated grids. This system can be sized, and the charging rates can be modelled in advance to give the best options to offer shore charging of batteries before every trip.

Figure 6: Containerised Storage from SPBES.com

Chapter 3 Currently Available Electric and Hybrid Vessels

3.1 Classes and Locations

The majority of progress in electrification has been in ferries, offshore supply vessels, river tour boats, and large aquaculture vessels in the commercial sector and in a range of boats in the recreation sector.

Glas Ocean Electric is building hybrid and battery electric systems for workboats in the 35'-50' range that meet Transport Canada regulations and are based in Nova Scotia, Canada.

Examples of electric only commercial vessels include the Ellen and the Elfrida in Norway.

Figure 7: Electric Vessels in Operation

Recreational electric systems can be found through companies such as those listed in Table 3.1.

Table 3.1: Selection of Recreation Focused Electric Boat Companies

Company	Focus	Country
Torqeedo	Inboard and outboard up to 100 kW	Germany
Aquawatt	Inboard and outboard up to 50 kW	Austria
Vision Marine Technologies	Outboards up to 135kW	Canada

3.2 Capital and Operating Costs

3.2.1 Batteries

In general, the batteries will be 30% or more of the cost of an electric vessel propulsion system. There are a number of companies that offer marine batteries, but Transport Canada requires that the Li-Ion batteries have a DNV, LR, or equivalent type certification and this limits the number of battery suppliers that can be used in workboats.

Pricing for certified batteries typically starts at $1,000 CAD/kilowatt hour. Inshore fishing boats will likely need batteries of 40-60 kWh for a full electric propulsion system. Although this is costly, as interest in electrification grows, the market will become more populated, and this will drive the cost of batteries down.

Table 3.2: Li-Ion Marine Battery Companies

Battery Company	Existing Installations	Certification	Country	Fires to Date
SPBES	Yes	DNV	Canada	No
CORVUS	Yes	DNV	Canada/Norway	Yes
Akasol	Yes	DNV	Germany	Unknown
EASy Marine	Unknown	DNV	Germany	Unknown
Leclanche	Yes	DNV	Switzerland	Unknown

DNV has taken a lead in certifying li-ion batteries on board ships and boats. There are European committees set up to catalogue and review any fire incidents and to continually review safety systems.

3.2.2 Motors

Electric motors in general are very robust and typically last 20-25 years in most marine applications with minimal maintenance. An automotive motor can be used on a vessel if it passes Transport Canada testing requirements. As interest in electrifying boats increases, the interest from automotive and bus/truck electric motor manufacturers increases as well.

Danfoss is a leader in this area and has a catalogue of large marine electric motors. Recently, Danfoss purchased a quality car electric motor company (UQM), and it is likely that the motors they produce will achieve DNV certification in the coming months/years.

The typical cost of a 135 kW marine electric motor, controller, and transmission (including shipping and taxes) is $25,000 USD.

Recreational electric marine motor companies tend to bundle their systems with the power control and batteries (refer to Table 3.1).

The usual commercial marine electric motor companies (Bosch, Yanmar, and Toshiba/Westinghouse) tend to have very large motors, minimum of 250 kW, and this is generally too large for a day trip vessel. The electric vehicle world has produced many motors and shown the way for smaller manufacturers to develop smaller motors in the 50-100 kW range for electric boats. Generally, these motors weigh 50-80 kg and occupy a footprint no larger than 30 cm by 30 cm.

Due to the high rotational speed of most electric motors, reducing gears and transmissions are required to transfer shaft power to the vessel propeller.

3.2.3 Integration Systems

There are some companies that produce custom integration systems but if a full turnkey solution is required then it is advisable to go with a company that has as many parts as possible from the same company. Most battery companies recommend integrators and some electric consulting companies have designed systems that are able to work with any motor or battery such as the integration kit Glas Ocean Electric has built.

Naval Architecture companies and boat builders are investigating this enthusiastically these days and building ferries is great training for understanding systems and applying that knowledge to smaller vessels.

3.2.4 Solar Panels

There is a lot of interest in putting solar panels on vessels. High quality rigid solar panels are often heavy and there needs to be care that the stability of the vessel is not impacted by the addition of a solar panel. If the boat is structurally sound a low in the hull placed battery is a good counterweight to any solar panels.

Flexible thin film solar panels are considered a good alternative to standard rigid solar panels for use onboard fishing vessels. Examples such as the S Flex series by Sunport Power offer efficiencies as high as 80% of high-quality rigid panels but with only 20% of the weight. This makes mounting them on the wheelhouse roof possible without significantly affecting the vessel centre of gravity.

3.2.5 Regeneration

Electric Cars and other vehicles are successful because they can take advantage of regeneration when braking or going downhill. In a boat if someone drives downhill they have taken a very bad turn and there is no braking. This means that to scavenge power through regeneration the options are limited to any system that has a vertical drop or pull release option. Examples of this are haulers and winches. Electronic parts are becoming inexpensive enough now that it is worthwhile considering ways to scavenge power from haulers as they lower pots and from winches as they release lines.

A recent Coast Guard call for proposals asked for ways to claim regeneration of power from wave impact. It is possible if there are any stabilizers on board or if a product develops from the Coast Guard call that regeneration from wave impact could be used on workboats.

3.3 Maintenance Costs

3.3.1 Regular

An example of a typical maintenance schedule for an electric marine propulsion system and a diesel system based on 100 days of operation 8 hours per day annually is shown in Table 3.3 where the legend is:

- I - Investigate
- R - Replace/Refill
- X - Overhaul

Table 3.3: Estimated Replacement and Repair Schedule of Electric and Diesel Marine Systems on a Fishing Boat

	Component	YR 1	YR 2	YR 3	YR 4	YR 5	YR 6	YR 7	YR 8	YR 9	YR 10	YR 11	YR 12	YR 13	YR 14	YR 15
ELECTRIC	Electric Motor								I							
	Battery		I		I		I		R		I		I		I	
	Coolant Pumps (SW)			I			R			I			R			I
	Coolant Pumps (FW)					I					R					I
	Gearbox (2:1)				I				I				I			
	Anti-freeze/Coolant			I			R			I			R			R
	Transmission Fluid Change								I							
DIESEL	Engine Oil Change	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	Anti-freeze/Coolant		R		R		R		R		R		R		R	
	Transmission Fluid Change		I		R		I		R		I		R		I	
	Overhaul								R							
	Serpentine Belt (Alternator)		I		R		I		R		I		R		I	
	Timing Belt						R						R			
	Alternator		I		I		I		R		I		I		I	
	Fuel Filter	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	Exhaust System	I	I	I	I	I	R	I	I	I	I	I	I	I	I	I

Over the 15-year lifespan of a diesel engine, it will need 15 filter and engine oil changes, seven (7) coolant changes, three (3) transmission fluid and alternator belt replacements, two (2) timing belt replacements, one (1) overhaul and one (1) exhaust system replacement. Using estimations for the cost of each of these services based on shared experiences from fishers and cost estimates from mechanics, the cost of maintenance on a diesel engine over a 15-year period will just under $8,000 dollars.

Although these prices reflect estimates of maintenance costs, specific maintenance may depend on the hourly rate of the mechanic and the ease of access to provide the maintenance. Fishers could see over $10,000 dollars worth of maintenance costs over a 15-year life span.

In comparison, the electric motor will likely not need any replacements until the sixth year of use. After which, replacements of various system parts happen every second year, with batteries needing a replacement once during the 15-year period. It is also unlikely that the electric engine will need to be replaced at the end of the 15-year period.

In general, with feedback from existing installed systems, the maintenance costs on a hybrid system drops 50-60% and the maintenance on an all-electric system drops 80-90% when compared with a fuel fired fishing vessel.

3.3.2 Warranties

Batteries are the biggest concern with respect to warranties and they tend to have long warranties that are based on the design of the system and service plans. A system is usually designed to have a battery that will maintain a minimum of 80% of the original capacity after 10 years. To be able to reach these limits the battery needs to be maintained as required so this includes things such as charging and discharging regularly, not going below 20% capacity, not overheating the battery, putting the battery into a dormant operation when not in use, and not overcharging the battery.

Motors and electronic components have much shorter warranty life. They tend to be in the range of 2-12 months. Electric motors tend to be very robust and provide very high performance levels with minor maintenance requirements. As the market for marine electric propulsion systems expands, the larger market will entice motor manufacturers to offer better warranties.

3.3.3 Enviro Disposal

Currently, there are a number of li-ion battery recycling companies being founded. It is expected that there will be ample choice in the coming years. Modern li-ion battery construction and chemistry allows for a high degree of recycling. A Canadian company, Li-Cycle is currently building the world's largest recycling facility in New York state and they expect to recover 95% of the precious metals in depleted batteries. Depleted li-ion batteries are being stored worldwide in anticipation of the recycling options in development.

3.3.4 Ballast Water

Ballast water and spillage from refueling are some of the largest contributors to water quality problems in small harbours. There are guidelines from organizations such as the US EPA on how to minimize oil and fuel spills and Transport Canada and Environment Canada have rules on what can be pumped directly into the water and what must be disposed of using a waste treatment facility.

Accidental spills are more of a pollution source than ballast water for boats that are operating according to the rules.

In hybrid and electric vessels, the spillage is either substantially reduced or eliminated. This has a very positive effect on the health of harbours and the ocean in general.

3.4 Suitability For The NL Inshore Fishery

Power data needs to be collected to fully understand the powering requirements of the vessels in the NL fishery but if comparing to the NS fishery it is likely in most cases that a hybrid system would be most appropriate. For any vessels that stay close to shore, within 1-2 nm, and are willing to drive below 6 knots to get to their fishing site then an all-electric system would be a good option.

It is also important to understand the types of vessels most common in NL. If there is a large number of boats with outboard engines they are likely to have very different cost models than inboard systems. In general, larger boats that have inboard systems can more easily have additional batteries onboard in a below deck space. Smaller boats with outboard systems can use the systems that the recreational companies have built, however, systems designed for that market tend to be more costly. In addition, most recreational market manufacturers are unwilling to warranty their systems for commercial use.

3.5 Financing Sources

Currently, there are efforts to include retrofit kits in the Canadian tax rules around electric vehicles. There are also programs from DFO, and provincial organizations focused on 'greening' the fisheries. Any low carbon or clean tech call for proposals is a potential source of subsidies for the systems.

If the hybrid or electric system is certified by DNV or approved by Transport Canada, the traditional financing companies and banks are likely to provide business/personal financing for individual boat owners.

There is an opportunity to claim carbon credits for installing a hybrid or electric system.

There is some interest by companies in this space in offering financing for systems in a way similar to car dealerships. These models are being developed.

Lastly, there is interest in potentially leasing or renting batteries which would positively impact the initial costs.

Chapter 4 Further Benefits

4.1 Energy Use Efficiency

Table 4.1 shows a comparison of energy density versus weight between three different energy sources: gasoline, diesel, and electric battery. Although electric batteries will require more weight to be added due to a lower energy density (0.14kWh/kg), electric systems are much more efficient users of energy. The engine efficiency of an electric motor is approximately 87%, while that of a diesel or gasoline engine is between 25% and 40%. Due to the low efficiency of the gasoline or diesel engine, a large amount of the energy bought and deposited into the system is wasted (unusable).

Table 4.1: Energy Density versus Weight

Energy Source	kg/litre	KJ/litre	kWh/litre	kWh/kg	Engine Efficiency	Useable kWh/kg	Unusable kWh/kg
Gasoline	0.72	3387	0.91	1.27	0.25	0.32	0.87
Diesel	0.83	3718	1.03	1.23	0.4	0.49	0.62
Electric Battery	NA	NA	NA	0.14	0.87	0.13	0.01
Sources: www.neutrium.net; www.torqeedo.com; www.wikipedia.com							

4.2 Engine Weight

Table 4.2 shows a comparison between the weight of three gas/diesel engines compared to that of three electric motors. Although electric batteries have a lower energy density, which has a larger impact on the weight of the boat, as discussed above, electric motors themselves are typically 50% lighter than a gasoline or diesel motor.

Table 4.2: Weight of Gas/Diesel Engines versus Electric Motors

Make	Type of Motor	Weight (kg)
John Deere	4.5L Generator Drive Engine	570
Cummins	4.5L	560
Volvo Penta	3.7L Diesel Engine	455
	Average	**528.3 kg**

Make	Type of Motor	Weight (kg)
Danfoss Electric Motor	55-126 hp	125
Danfoss Electric Motor	110-336hp	210
Elco Electric Inboard	100hp	335
	Average	**223.3 kg**

The transmission of an electric motor will likely be heavier than the diesel or gas motor, as more gears are required to transfer the power.

4.3 Decreased Sound Levels

Sound levels onboard small-scale fishing boats (<65') have been shown to measure up to 83 dB at maximum speeds[6]. These sound levels have yet to be restricted by any regulatory body, as sound requirements are only restricted on large scale vessels. A voluntary set of guidelines[7] for owners and operators has been produced to provide guidance for the design of vessels and safety during fishing operations, but it is not enforced and does not provide guidance on sound levels. Most workplaces require hearing protection for workers regularly exposed to sound power levels of 80 dB.

A review of the workers compensation cases conducted by Workplace Newfoundland showed an alarming trend that those employees of the fishing harvesting industry reported many more hearing related ear injuries per 10,000 employees than those in the province (refer to Figure 8).

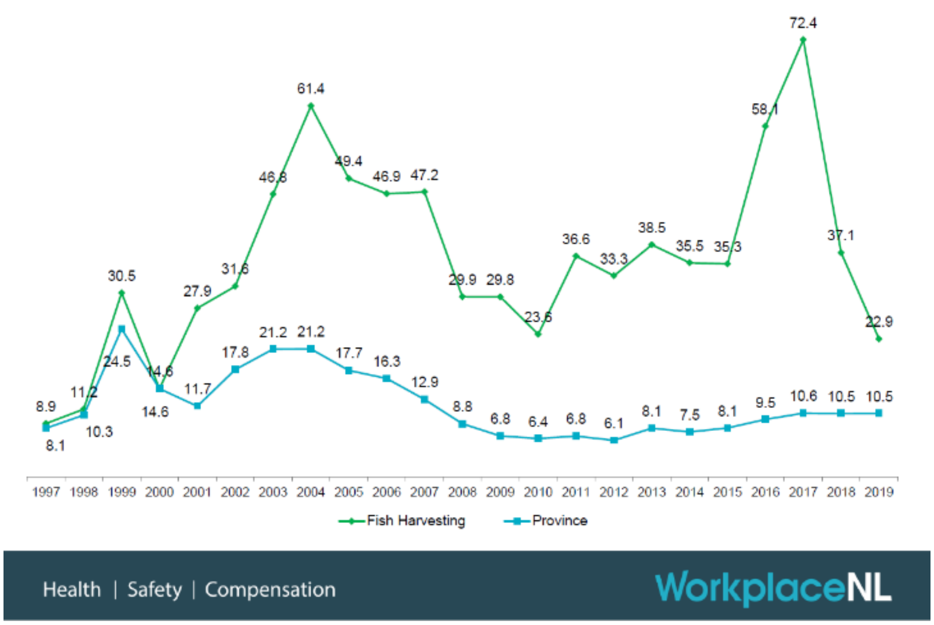


Figure 8: Fish Harvesting Industry Ear Injury Rate/10,000 Employees – NL 1997-2019

[6] Moro & Burella, 2019

[7] IMO, FAO, and ILO, 2005, 2012

Electric motors are much quieter than diesel or gasoline powered engines. An electrically driven small fishing vessel should typically see sound levels while steaming of no more than 40-50 dB associated with the propulsion system. Fishers exposed to levels this low would not experience any hearing loss associated with this exposure. Compensation claims for work related hearing loss cost all workers in the province so reducing the incident claims would be a benefit.

Following an analysis on healthcare costs associated with hearing loss, for adults suffering from hearing loss, the cost per person on the healthcare system is estimated to be $1,071.12 (based on a study conducted in the Netherlands for adults aged 18-65 years, 2010[8]).

4.3.1 Reduction of Fuel Use – Reduced Exposure to Fumes, Oil Spills

Another health benefit that presents itself if electric motors are used in favor of diesel or gasoline motors is an elimination of worker exposure to exhaust fumes and their associated health risks. Eliminating onboard fuels and lubricating engine oil will also reduce the environmental risk associated with fuel and oil spills.

4.3.2 Reduced Fatigue

Continuous exposure to sound power levels above 60 dB have been shown to increase fatigue in employees in all fields (US Department of Health and Human Services). Increased fatigue may result in injuries, especially when operating machinery on open waters.

[8] Global costs of unaddressed hearing loss and cost-effectiveness of interventions, World Health Organization, 2017

Chapter 5 Sustainable Fisheries Programs

5.1 Locations, Eligibility, Requirements

The most well-known sustainable fishery certification program is the Marine Stewardship Council (MSC). MSC offers a fisheries standard that is internationally recognized and permits seafood caught under a certified fishery to market and sell the catch with the MSC blue fish label. The certification is open to all fisheries catching marine or freshwater organisms in the wild. The standard is regularly reviewed and updated in consultation with scientists, the fishing industry, and conservation groups.

All fisheries applying for certification are assessed by accredited independent certifiers call Conformity Assessment Bodies (CABs).

The MSC fisheries standard has three core principles that every fishery must meet to achieve certification:

1. **Sustainable Fish Stocks –** Fishing must be at a level that ensures it can continue indefinitely with no decline in fish population or health.
2. **Minimising Environmental Impact –** Ensure that the fishing activity is managed carefully to minimize impact on other species and habitats within the ecosystem of the fishery. Electrification of fishing boats to reduce marine noise, air pollution, and water pollution could enhance the assessment score in this category.
3. **Effective Fisheries Management –** Are all fishers complying with all relevant laws and regulations, as well as adapting to changing environmental conditions. Examples of this could include removing fishing gear in areas where right whales have been spotted or changing a season opening or closing date based on environmental or weather conditions.

Our discussions with fishing organizations and conservation groups did not indicate that electrification of fishing boats is as of yet a compliance metric for MSC certification, however, it is being watched and may be added to future performance indicators.

Certification typically takes 12-18 months and once approved lasts 5 years. More than 300 fisheries around the world are currently certified. Of interest is the Maritime Canada Inshore Lobster Trap fishery which received MSC certification in February 2021. With this fishery being adjacent to the Newfoundland fishery and fishing the same species, it appears quite possible that the Newfoundland inshore lobster fishery should also be capable of achieving this certification.

5.2 Benefits and Costs

Costs of MSC certification can vary depending upon the size and complexity of the fishery, the level of available data, the level of local stakeholder involvement, and the certification body chosen. There are multiple agencies that are accredited to serve as certification bodies, therefore, it is recommended that quotations be obtained from more than one. Payment is made directly to the certification bodies and can range between US $15,000 and US $120,000.

A certified fishery is eligible to market their catch with MSC certified buyers and retailers who are certified under a chain of custody standard. MSC certified seafood products typically command higher retail prices and are often promoted in higher end retail establishments.

Chapter 6 Grid Infrastructure Upgrades Needed

6.1 Isolated Grid Communities

Isolated grid fishing communities are those that are served by an independent diesel power plant and grid supplied by NL Hydro. These communities are primarily in coastal Labrador with a few still along the south coast of Newfoundland. These systems are well maintained and provide reliable service but at a high cost. Domestic customer rates are generally comparable with rates connected to the main grid, but this is due to high levels of subsidization from NL Hydro. Commercial rates are higher than the main grid by an average of $0.06/kWh, but this is still highly subsidized. True generation costs are reflected in the government service rates offered on these systems that average $0.80/kWh or more.

6.2 Grid Benefits, Now and Future

As noted in Section 2.4, onboard chargers are needed to convert AC voltage to DC voltage to charge the battery systems. To make use of the batteries, for onshore energy storage, requires both the charging station and the vehicular charging system to be of "vehicle-to-grid" (V2G) design. This requires a bidirectional vehicular charging system with both rectification circuitry (AC to DC) and inverter circuitry (DC to AC). Such technology is rare and costly (approximately four times the cost of unidirectional circuitry).

Generally, Level 3 charging stations are required to achieve proper V2G operation. Level 3 charging stations are high-speed DC charging systems that bypass the vehicular charging system and charge the vehicles batteries directly from shore. Level 3 stations are inherently more bidirectional in their nature but may cost ten times as much as unidirectional Level 2 charging stations.

During nighttime charging, Level 2 charges take several hours to reach full charge and are normally staggered in operation to avoid a string of chargers from drawing peak load simultaneously. As such, it is unlikely that multiple vessels could be used to provide significant onshore power if they only have 8-12 hours to charge before returning to service. Level 3 chargers are more likely to be of use with the ability to charge within an hour. In either case, any use for onshore power supply would be primarily effective in the off-season only.

During the off-season, onboard batteries could potentially function as a community-level energy storage system, with one of four purposes:

1. "**Peak shaving**," whereby stored energy is used to reduce the maximum or peak electrical demand of the community.
2. "**Peak shifting**," whereby energy storage makes use of less expensive fuel when it is available (i.e., solar power during the day or wind energy when active) to power loads at a later time when only expensive energy is available.
3. **Voltage assistance**, whereby batteries assist in increasing the system voltage during periods where demand cannot adequately be met by available generation.
4. **Reactive power compensation**, whereby stored energy is used to produce reactive power to assist in power quality issues.

Peak shaving may be of use in isolated communities where reducing the community demand may extend the life of a diesel generator nearing maximum capacity, or in grid-connected communities where a transformer may be nearing overload. It should be noted however, that in a small harbour of up to 10 vessels, the additional cost of V2G Level 2 chargers could be in the order of $30,000, in addition to onboard systems, and Level 3 chargers could be in the order of $100,000. In large harbours of up to 50 vessels, the additional cost of V2G Level 2 chargers could be in the order of $150,000, in addition to onboard systems, and Level 3 chargers could be in the order of $5,000,000. In a large, grid connected community, the additional costs of V2G technology far outweigh the costs required to improve existing infrastructure, while in a small, isolated community the cost differential may be worth consideration on a case-by-case basis.

Peak shifting is currently of little use in grid-connected communities, as Newfoundland and Labrador currently does not have "Time-of-Day" electricity rates but may be of use in the future. In isolated communities, peak shifting would be of use if the community had renewable generating capacity in addition to diesel generation.

Neither voltage assistance nor reactive power compensation are anticipated to be of tremendous value in larger, grid-connected communities, where recent upgrades to Newfoundland and Labrador Hydro transmission infrastructure for the implementation of Muskrat Falls generation will have resulted in higher quality service to customers. For small, isolated communities, these functions may be of some value on a case-by-case basis, but the impact will be minimal with the relatively small capacity of the total fleet (100 kW/100 kVAr is likely less than 10% of any community's electrical capacity).

6.3 Zero Emission Fuels

Alternatives would be required for offshore fishing vessels that participate in multi day trips. Maintaining sufficient battery capacity on board to permit full electric operation onboard for multiple days is not practical at present due to the cost, weight, and volume occupied by the batteries.

The most promising alternatives for onboard energy storage that will permit longer duration zero emission energy production involve the use of hydrogen. When combusted to produce energy, hydrogen fuel produces only water vapor as its exhaust. It is a key component in many petrochemical processes. There are typically three classes of hydrogen fuel based upon the quantity of carbon emissions released to produce each:

- Grey hydrogen is produced primarily from natural gas using a process called steam reformation where the natural gas molecule is split into hydrogen and CO_2 using high pressure steam and a catalyst. This process uses large quantities of natural gas to fuel the steam boilers and emits large quantities of CO_2 from the reformer.
- Blue hydrogen is produced using the same process as grey hydrogen, but the waste CO_2 is collected and stored underground instead of being vented to the atmosphere, thus reducing the carbon intensity of the produced hydrogen. The emissions associated with the production and transport of the natural gas fuel and feedstock must still be considered so this is still not considered a zero-emission fuel.
- Green hydrogen is produced by the electrolysis of water into hydrogen and oxygen using renewable electricity, thus rendering it a zero-emission fuel.

As a fuel, hydrogen can be used directly to produce energy in a fuel cell or in an internal combustion engine. At atmospheric pressure, hydrogen is a very light gas with little energy density. It must, therefore, be highly compressed or liquified to sufficient energy density to propel a vehicle or vessel. Compressed hydrogen systems typically operate at 2500 psig or higher which can be of concern to vessel or vehicle operators. Liquid hydrogen requires a temperature of -253°C which necessitates a highly insulated and specialized storage tank, as well as strict control of static electricity and open flames to avoid explosions.

Compared with marine batteries, however, hydrogen in liquid form offers much greater energy density which could allow for much greater range for a vessel. Table 6.1 below compares the energy density of batteries and liquid hydrogen.

Table 6.1: Comparison of Energy Density and Liquid Hydrogen

Energy Type	Energy Density (kWh/kg)
Hydrogen Liquid	33
Marine Battery	0.144

Another zero-emission fuel alternative that is being developed is ammonia produced from green hydrogen. While most ammonia in the world is produced for the fertilizer industry using grey hydrogen, there is growing interest in producing it using green hydrogen to reduce the carbon emissions associated with agriculture and for its potential as a replacement for fuel oil in transportation.

Ammonia (NH_3) contains no carbon, so its combustion produces no carbon dioxide. Its lower combustion rate compared with fossil fuels, however, means that existing internal combustion engines cannot use ammonia fuel directly. New engines are under development by marine diesel manufacturers such as MAN diesel with the first models set for introduction by 2023. These early models are quite large and intended for use on board bulk ammonia carriers and eventually other large commercial vessels. Engines for smaller vessels are not expected to be commercially available before 2030.

Compared with hydrogen, ammonia can be stored at much higher temperatures (-35°C) lower pressures (250 psig) making its storage onboard a vessel less costly and complicated. The energy density of ammonia is less than hydrogen or fuel oil but still considerably greater than batteries (refer to Table 6.2) which may make it eventually a zero-emission alternative for longer duration fishing trips.

Table 6.2: Comparison of Energy Density and Liquid Hydrogen

Energy Type	Energy Density (kWh/kg)
Ammonia	5.2 kWh/kg
Fuel Oil	11.3 kWh/kg
Hydrogen Liquid	33
Marine Battery	0.144

In summary, options for longer duration fishing vessels to fully electrify or utilize zero emission fuels will likely require some patience as the technology to produce and utilize zero emission fuels based on green hydrogen continues to evolve.

Chapter 7 Next Steps

7.1 Recommended Fleets/Vessels to Target

To begin, the vessels that are large enough to carry 40-80 kWh of batteries would give the best repayment periods. If a battery is used more often it will be repaid quicker. A battery system used 50 days a year will be very different from a battery system used 150 days a year. This means that boats that fish for more than one short season should be targeted. A utilization rate of 25-30% is best. There is value in converting a number of co-located boats at once because that will reduce the cost of any charging infrastructure required at a wharf.

Outboard systems can be converted quickly using the recreational systems, but the cost is quite high.

The first fleet should be the one that is most easily replicated around the province. If this is an inboard vessel 35'-45' and there are harbours with 5-10 boats these would be the best choice.

7.2 Potential Fuel and GHG Savings per 10 Vessels

The increased efficiency of the electric motor when compared to the diesel and gasoline motors is another added benefit of electrification. Electric motors are upwards of 95% efficient whereas gasoline and diesel motors are between 20-30% efficient. Further, electric motors in the main areas of Newfoundland fishing grounds would also have the added benefit of being connected to grid power almost exclusively by renewable energies (Muskrat Falls, etc.), further reducing their GHG emissions footprint. (Those in communities with isolated grids would not reap this benefit but would still see a GHG emissions reduction when compared to the energy usage of a gasoline or diesel motor).

Fuel savings is based on the use of the battery. The diesel system uses 50% less fuel idling than going full speed which is a substantial amount of fuel to be used for warming up.

Fuel prices will change over the next 20 years as carbon pricing is added. Using predicted fuel costs from Deloitte and a conversion factor based on the last 5 years of fuel pricing in NL the expected fuel costs per litre of diesel are shown in Table 7.1.

Table 7.1: Expected Future Fuel Costs per Litre of Diesel

Year	Expected Diesel Price including Carbon Tax ($/L)
2021	1.48
2022	1.49
2023	1.52
2024	1.59
2025	1.66
2026	1.73
2027	1.80
2028	1.87
2029	1.94
2030	2.01
2031	2.04
2032	2.07
2033	2.10
2034	2.14
2035	2.17
2036	2.20
2037	2.24
2038	2.27
2039	2.31
2040	2.35

Depending on the number of fishing days per year, the cost of diesel displaced is shown in Table 7.2 and corresponds to the fuel saved under electric operations versus hybrid operations. In this case, the hybrid operations use a shore charged battery and displace only power at 6 knots and lower.

Table 7.2: Cost of Diesel Displaced

Using 50 days per Year		Using 100 days per Year	
Electric 5 Years	$72,759	Electric 5 Years	$145,519
Electric 10 Years	$160,439	Electric 10 Years	$320,878
Electric 20 Years	$365,948	Electric 20 Years	$731,896
Hybrid 5 Years	$29,497	Hybrid 5 Years	$58,994
Hybrid 10 Years	$65,043	Hybrid 10 Years	$130,086
Hybrid 20 Years	$148,357	Hybrid 20 Years	$296,714

It is very clear that the more a system is used, the faster and better the payback of the system. Drivers such as CO_2 reduction, ocean health, underwater radiated noise (URN) reduction and health and safety will also influence decisions around the adoption of electric. To fully understand the value of electric systems the maintenance costs (reduced by 60% I hybrid and more in all-electric) should be considered. It would also be reasonable to place a value on the environmental and health cost of diesel operations to get a true accounting of the value of electric.

Fuel prices for fishers in Newfoundland tend to mirror the prices paid by motorists with a rebate program available for fishers to recover the vehicle tax portion of the price.[9] [10]

As described in Section 1.2.3, for a fleet of 10 vessels operating 100 days per year, all-electric, we can expect a displacement of 500 tonnes of CO_2 per year. This assumes that the electric propulsion system replacing the diesel system is being recharged from the NL integrated grid which will have a carbon emission intensity of close to zero once the Muskrat Falls hydro plant is fully operational.

Applying this to the entire Atlantic Canada fleet of 15,000 boats in this size range, all-electric operations could displace as much as 750,000 tonnes of CO_2 per year once the emission intensity of the grid throughout the region is as low as in Newfoundland and Labrador. This is a clear win for Canada and the oceans and starting in NL with a few boats is an important step.

[9] https://waves-vagues.dfo-mpo.gc.ca/Library/40621807.pdf
[10] https://academic.oup.com/icesjms/article/72/2/708/670365

Chapter 8 References

1 https://electrek.co/2019/08/21/worlds-largest-electric-ferry/

2 https://www.bairdmaritime.com/fishing-boat-world/aquaculture-world/successful-trial-for-electric-aquaculture-support-vessel/

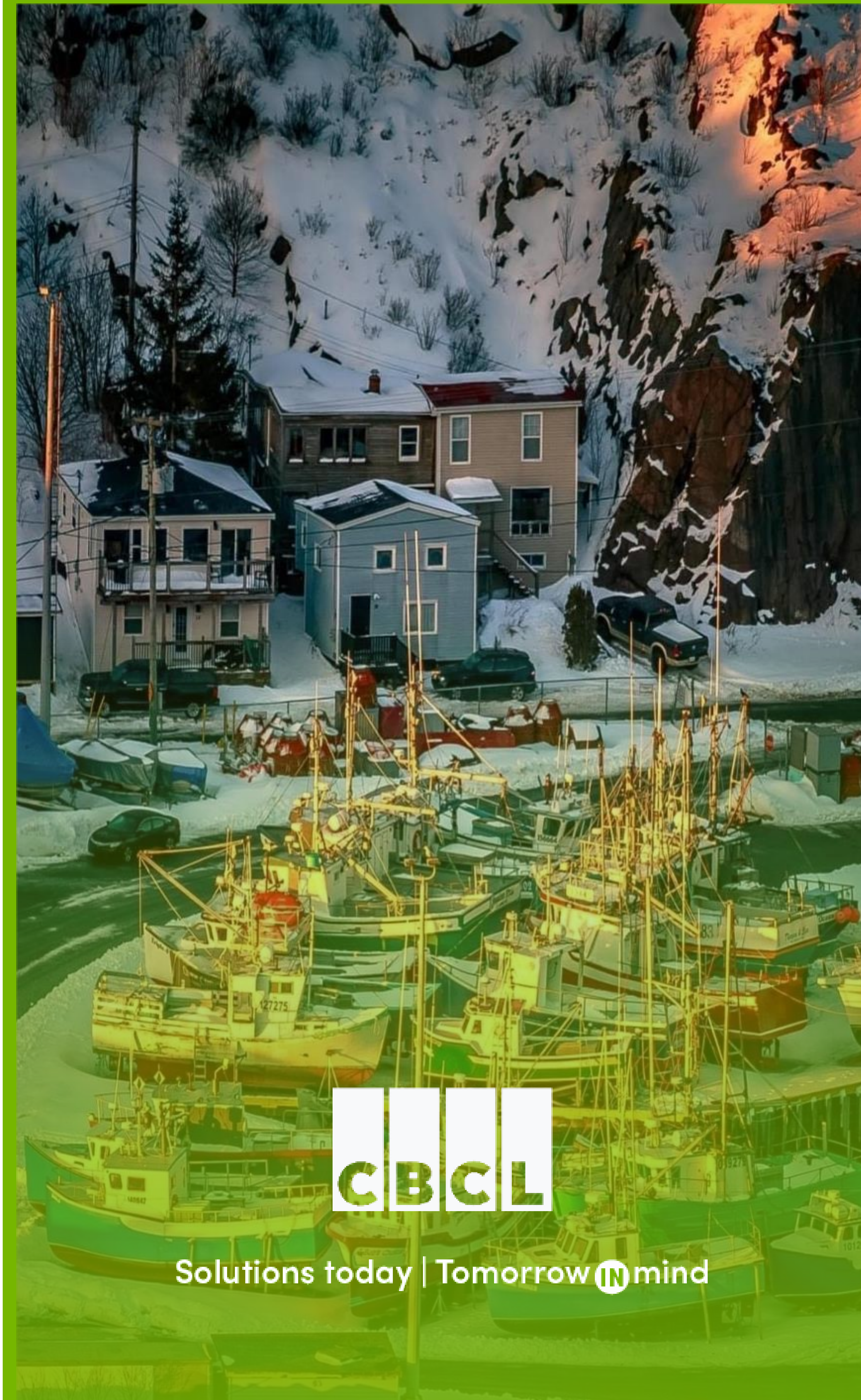
3 https://spectrum.ieee.org/energy/batteries-storage/lithiumion-battery-recycling-finally-takes-off-in-north-america-and-europe

4 https://www.boatingmag.com/calculating-fuel-consumption/

5 https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_6_e.pdf

Prepared by:
Dr. Sue Molloy, Ph.D., P.Eng.
Study Lead Engineer

Reviewed by:
David Lea, P.Eng.
Senior Project Manager, Energy Services



Solutions today | Tomorrow IN mind

www.CBCL.ca