Energy Efficiency and Conservation Authority (EECA)

Maritime Transport Emission Reduction Market Scan and Analysis Report

28 February 2023 – Final Issue Redacted

Prepared by Beca Ltd
Reviewed by Sarah Bacon
Approved by Phil Robson

Executive Summary

Sector Carbon Impact Potential by Technology

Medium Petrol Powered Boat (Inboard)
24% emissions reductions
104,000 tCO_2e/yr

Ferry
3.9-5.9% emissions reductions
40,800-61,200 tCO_2e/yr

Commercial Fishing Boat
0-1.4% emissions reductions
0-15,000 tCO_2e/yr

Medium Petrol Powered Boat (Outboard)
37% emissions reductions
156,000 tCO_2e/yr

Ferry
2.0-2.9% emissions reductions
20,400-30,600 tCO_2e/yr

Ferry
0-2.0% emissions reductions
0-20,400 tCO_2e/yr

CAPEX Insights

- Most technologies analysed require <$1m Capital funding per instance so are well suited to the LETF
- Hybridisation and Hydrogen technologies are the exception

OPEX Insights

- Most technologies analysed show a reduction in operating costs
- Alternative fuel technologies are the exception

Key Challenges to Overcome

Increasing Challenge:

- CAPEX/OPEX costs
- Infrastructure
- Operational Lifecycle
- New Build vs. Retrofit
- Mindset

Recommendations

- Future funding of Hydrogen
- Invest in infrastructure
- Policy, legislation & regulation
- Support technology scaling
- Transitionary options

Key technologies

Propeller Optimisation | Electrification | Hydrofoils | Biofuels | Hull Coating | Hybrid Drives | Shore Power | Hydrogen

Study Process Overview

State of Play	Long List	Short List	Short List Analysis
• Deliver an overview of the NZ carbon emissions in the maritime transportation sector split by relevant sector, fuel, or type. Appendix A – State of Play	• Undertake a market scan of domestic and international maritime transport decarbonization technologies and create a long list. • Engage with industry to create a long list of maritime decarbonization technologies • Assess and rate the technical potential in an NZ context for all the options. investigation in Part B. Appendix B – Long List	• Rank the long list using criteria to create a short list that have the areas of most promising technical potential for carbon emission reduction and in date order • Provide indicative guidance on the end use commercial characteristics compared to incumbent fossil fuel equivalent. • Engage with EECA to agree short list options for further analysis Appendix D – Weighted Short List	• Summarise technology principles • Analyse technologies commercial and environmental characteristics. Measure the technology and commercial readiness using appropriate methods or relevant measures • Undertake sector engagement and provide a list of the barriers and challenges for project commencement/adoption Appendix E – Short List Analysis

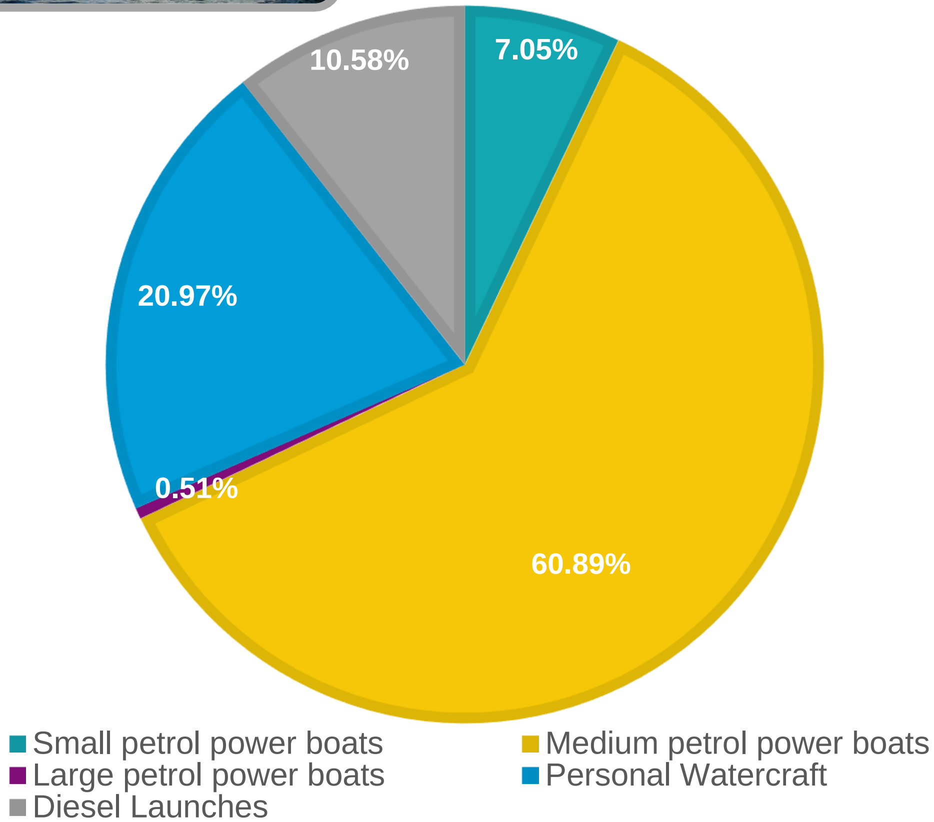
In Scope (typical areas but not limited to)	Out of Scope
• Small size domestic costal shipping for freight and passengers • Small size costal shipping for freight, coastal tankers, traders and research vessels • Domestic fishing (line fishing, trawling and aquaculture) • Domestic outdoor and adventure (Commercial jet boating etc) • Refuelling infrastructure for vessels (e.g. shore power charging) • Technologies, such as propellor design, clip-ons, foils, stabilisers, batteries, electric motor etc. • Technology and innovative processes for energy efficiency or reducing emissions (e.g. software for optimising vessel performance, routing etc) • Recreational boating (powered e.g. leisure boats, amusement craft such as bumper boats, jet-skis, electric foiling surfboards, electric pedal boats, recreational fishing, powered canoes and kayaks)[1]	• Foreign shipping such as cargo transport • International passenger cruises • Non powered craft (e.g. sailing boats) • Maritime infrastructure planning and design • Operational advice and analysis • Research and development projects • Production and distribution of marine low carbon fuels • Major infrastructure projects (e.g. ports)

State of Play Summary: Recreational Vessels

Number = 8550
Annual Usage = 100hrs
Fuel Consumption = 20L/hr
Annual Consumption = 17,100,000L
Carbon Impact = 0.05 $MtCO_2e$

Number = 93,000
Annual Usage = 40hrs
Fuel Consumption = 10L/hr
Annual Consumption = 37,200,000L
Carbon Impact = 0.09 $MtCO_2e$

Number = 250,000
Annual Usage = 10hrs
Fuel Consumption = 5L/hr
Annual Consumption = 12,500,000L
Carbon Impact = 0.03 $MtCO_2e$



Number = 450
Annual Usage = 50hrs
Fuel Consumption = 40L/hr
Annual Consumption = 900,000L
Carbon Impact = 0.0021 $MtCO_2e$

Number = 180,000
Annual Usage = 50hrs
Fuel Consumption = 12L/hr
Annual Consumption = 108,000,000L
Carbon Impact = 0.26 $MtCO_2e$

Total Carbon Impact of Sector = 432,100 tCO_2e

For detailed State of Play analysis refer to Appendix A

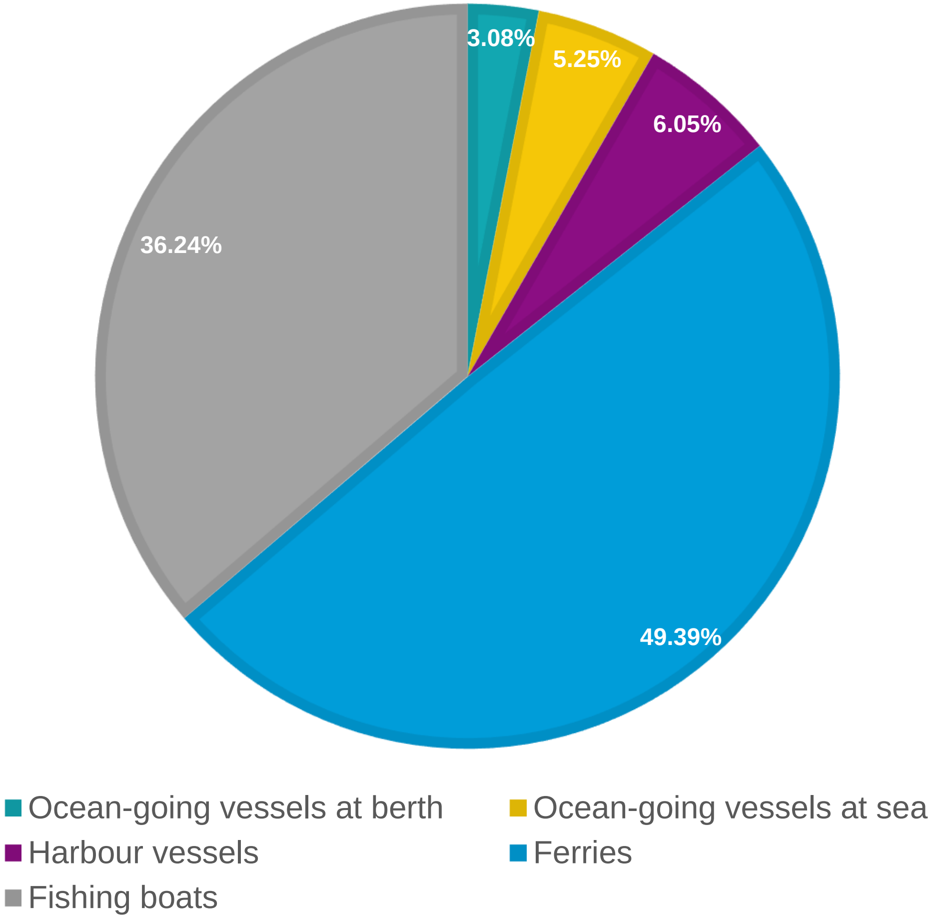
For detailed assumptions on calculations refer to Appendix E

$MtCO_2e$ is million tonnes of carbon dioxide equivalent greenhouse gas emissions.

State of Play Summary: Commercial Vessels

Carbon Impact of sector = 0.375 $MtCO_2e$*

Carbon Impact of sector = 0.51 $MtCO_2e$



Total Carbon Impact of Sector* = 1,025,000 tCO_2e

Carbon Impact of sector =
At Berth: 0.03 $MtCO_2e$
At Sea: 0.05 $MtCO_2e$

Carbon Impact of sector = 0.06 $MtCO_2e$

For detailed State of Play analysis refer to Appendix A

For detailed assumptions on calculations refer to Appendix E

* Carbon impact of Fishing Boats is updated from State of Play as a result of more reliable data coming available late in the project. See Appendix G for details.
$MtCO_2e$ is million tonnes of carbon dioxide equivalent greenhouse gas emissions.

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Industry Feedback and Themes

Full hydrogen distribution networks will be needed for marine

Consultation and communication on policy setting and standards will promote an understanding of the way ahead for the industry. Industry is hungry to understand

Some technologies are most suited to new-build vessels. Fleet retirement rate in NZ is low so technology introduction is low

Commitment to establishing adequate infrastructure (in marinas and ports) will encourage uptake – especially for electrification projects

Lack of competition in the market drives up costs

There is no carbon reduction silver bullet. Optimal solutions vary considerably across marine sectors & usage contexts

The regulator (Maritime NZ) and local bodies could learn from incentives applied in other jurisdictions and by international bodies (e.g. Europe and IMO)

New energy conversion technologies will demand new skills to sustain and operate them

Energy lifecycle (well-to-wake) impact is equally important to understand as tank-to-wake when assessing carbon reduction benefits

Fuel distribution needed for non fossil diesel and petrol fuels (Biodiesel/HVO/H_2)

IMO is encouraging a range of alternative practices. Are these being promoted here?

Change how we quantify and perceive "good". Can we accept inefficiency if the fuel is green? At what cost to the environment or the bottom line?

Combining technologies (e.g. alternative fuels & hydrodynamics) can amplify emissions benefits (such that the benefit is greater than the sum of the parts)

Costs of alternative technologies and fuels are barriers to the recreational sector uptake

Infrastructure

Education and Promotion

Costs and Tech

Compliance (from design/build stakeholders)

Barriers and Challenges

CAPEX and OPEX Costs

- Decarbonisation technologies command a CAPEX investment
- Alternative fuels typically require OPEX investment
- Critical market size has not been reached

Usage Rate & Duty

- Biggest gains made in high-use vessels. E.g. most commercial operators - Ferries, Harbour Vessels etc
- High investment for low use vessels. E.g. most recreational vessels.

Operational Lifecycle

- 20-30 year asset life of vessels
- Major retrofits not economically feasible
- Low fleet retirement rates = slow modernisation and change
- Speed of technology development exceeds swap-out

Mindset

- Need to want to use the technology
- Perception of new and untested
- Flip the "bigger is better" approach to powering
- Education required for recreational and commercial vessel owners to promote option uptake

Increasing Challenge

Dockside Infrastructure

- Low-power electricity supply to docks
- No dockside charging infrastructure is present
- Most alternative fuels need dedicated supply and distribution infrastructure
- Hydrogen needs dedicated and specialised supply infrastructure

Compliance

- Re-powering vessel invokes compliance to emissions standards (IMO Tier III)
- Design and safety regulations not keeping pace with advancements and implementation of alternative energy solutions (electric and H_2)
- Increase understanding of required regulations and/or changes
- Electrical charging facility standards needed

New Build vs Retrofit

- Many technologies better suited to new build vessels vs retrofit for holistic design approach
- Physical constraints and parameters of existing vessel dictate outcome
- Implications to performance and stability by adding equipment
- Ownership of risk

Technology Maturity

- Some maritime decarbonisation technologies are in their infancy resulting in:
  - Higher costs
  - Scepticism of claims
- Undeveloped regulations
- Equipment supply issues

Key technologies

Propeller Optimisation | Electrification | Hydrofoils | Biofuels | Hull Coating | Hybrid Drives | Shore Power | Hydrogen

Roadmap to Maritime Decarbonisation

Return on Investment (ROI) is considered from EECA perspective with respect to investment from the LETF

Technology	Use Case	CRI	CAPEX	OPEX	Sector Impact	Recommendation Notes
Propellor Optimisation	Ferry	5	$0-$0.5m	-20-0% Reduction	3.9-5.9% emissions reduction **40,800-61,200 tCO_2e/yr**	Strong Return on Investment
Electrification	Medium Petrol Powered Boat (Outboard)	5	$0-$0.5m	-20-0% Reduction	37% emissions reduction **156,000 tCO_2e/yr**	Strong Return on Investment. Use case is recreational, but has commercial potential. Infrastructure may be required.
Electrification	Medium Petrol Powered Boat (Inboard)	5	$0-$0.5m	-20-0% Reduction	24% emissions reduction **104,000 tCO_2e/yr**	Strong Return on Investment. Use case is recreational, but strong commercial potential (e.g. Ferries) with correct infrastructure.
Hydrofoil	Catamaran Ferry	5	$0-$0.5m	-20-0% Reduction	2.0-2.9% emissions reduction **20,400-30,600 tCO_2e/yr**	Good Return on Investment
Hull Coating	Ferry	6	$0-$0.5m	-20-0% Reduction	0-2.0% emissions reduction **0-20,400 tCO_2e/yr**	Good Return on Investment. Technology has high potential throughout the maritime industry.
Hull Coating	Commercial Fishing Boat	6	$0-$0.5m	-20-0% Reduction	0-1.4% emissions reduction **0- 15,000 tCO_2e/yr**	Good Return on Investment. Technology has high potential throughout the maritime industry.
Hydrofoil	Ocean Going Vessel	4	$0.5-$1m	-20-0% Reduction	0.3-0.4% emissions reduction **2,500-3,750 tCO_2e/yr**	Low Return on Investment
Propellor Optimisation	Medium Petrol Powered Boat (Outboard)	3	$0-$0.5m	-20-0% Reduction	3.3-5.5% emissions reduction **14,040-23,400 tCO_2e/yr**	Good Return on Investment. Can be applied in both recreational and commercial sectors.
Biodiesel (B15)	Ferry	3	$0-$0.5m	0-20% Increase	0-7.4% emissions reduction **0-76,500 tCO_2e/yr**	Strong Return on Investment. Can be applied in both recreational and commercial sectors but needs supporting infrastructure.
Biodiesel (B15)	Commercial Fishing Boat	3	$0-$0.5m	0-20% Increase	0-5.4% emissions reduction **0-56,250 tCO_2e/yr**	Strong Return on Investment. Can be applied in both recreational and commercial sectors but needs supporting infrastructure.
Electrification	Personal Watercraft (PWC)	2	$0-$0.5m	-20-0% Reduction	10.5% emissions reduction **45,000 tCO_2e/yr**	Good Return on Investment
Electrification	Commercial Jet Boat	2	$0.5-$1m	-20-0% Reduction	2.5% emissions reduction **12,750 tCO2e/yr**	Good Return on Investment. Use case is niche, but could pick up more of the Medium Petrol Powered segment.
Hybrid Drive	Ferry – Serial	6	Exceeding $1m Range $6-12m	-20-0% Reduction	12.3% emissions reduction	Good expected Return on Investment. Applicable industry-wide. Costs vary depending on vessel and use profile. Consider each business case.
Hybrid Drive	Ferry – Parallel	6	Exceeding $1m Range $6-12m	-20-0% Reduction	3.7% emissions reduction	Good expected Return on Investment. Applicable industry-wide. Costs vary depending on vessel and use profile. Consider each business case.
Shore Power	Commercial Fishing Boat	6	$0.5- $1m	-20-0% Reduction	0.4-0.9% emissions reduction	Good expected Return on Investment. Most applicable in commercial sector. Requires supporting infrastructure. Consider each business case.
Hydrogen Fuel	Ferry Hydrogen Fuel Cell	2	Exceeding $1m	Exceed 20% Increase	2.5% emissions reduction	Cost and timeframe exceeds LETF funding structure
Hydrogen Fuel	Ocean-Going Vessel Hydrogen as an ICE Fuel	2	Exceeding $1m	Exceed 20% Increase	0.4% emissions reduction	Cost and timeframe exceeds LETF funding structure

For detailed assumptions and calculations refer to Appendix E to Appendix F. Technology opportunities by sector is included in Appendix G.

Insights & Recommendations

Invest in infrastructure

Investment in key infrastructure will be instrumental to encourage uptake.
Access to distribution infrastructure will likely trigger commitment by end users to transition to alternative fuel technologies. This is clear in the case of electrification (and shore power) where power supplies at ports are generally not compatible (in capacity or characteristics) to support dockside charging rates required by electric vessels or the shore power demands of diesel fuelled vessels alongside. Similar infrastructure challenges exist for other alternative fuel technologies including hydrogen, hydrogen carriers and biofuels which require separation to prevent contamination.

Policy, legislation & regulation

Policy settings and legislation can play an important part in decarbonising the maritime sector.
In Europe (Denmark, Sweden and Spain), Council Implementing Decisions have promoted the use of shore power through the application of reduced taxation rates on shore power consumed by ships in port. Mandates are another tool Governments can use such as the biofuel mandate in New Zealand. These need to be fit for purpose for the marine industry and further research should be undertaken to understand the requirements and consequences of such actions.

Future funding of Hydrogen

Hydrogen in any form shows promise as a future fuel in the maritime sector, but current costs and time frames extend beyond the LETF funding.
Whilst hydrogen fuels show potential to contribute to decarbonization of the maritime sector, the technologies, application and policies are in their infancy, especially in New Zealand. Commercial applications are likely to be most prevalent with ferries leading the market internationally. Examples of hydrogen-fuelled vessels do exist in New Zealand (Emirates Team NZ Chase Zero) and are in consideration (Fullers hydrogen-electric hybrid ferry). These types of ventures should continue to be supported until the infrastructure and barriers are worked through across the transport spectrum. Further investigation into how hydrogen is supplied, stored & most effectively used in the maritime sector should be funded.

Support technology scaling

It is recommended that the latter stages of commercial scaling of proven decarbonisation solutions be supported by EECA through the LETF fund, or alternatively, the Technology Demonstration fund.
There is an encouraging number of local companies and fleet operators who are actively exploring the integration and application of market-leading technologies. They share a common goal of driving decarbonisation in the maritime domain and making a more sustainable industry. These companies are at different technical readiness stages, from proof-of-concept vessels to scaling-up production to meet domestic and international demand.

Transitionary options

It is recommended that EECA note other technologies from the Long List, (Appendix B) while not analysed in detail, can make a valid contribution towards carbon reduction.
The incorporation of the more effective decarbonisation technologies favours (economically) new-build vessels, but marine assets typically have significant operational lifecycles – particularly in New Zealand. Intermediary or transitionary technologies that can be adopted for use in the existing fleet and contribute to decarbonisation goals should be considered as part of the plan towards net zero and supported through the fund based on case-by-case merits. Transitionary fuels, albeit carbon-based (Ethanol, Methanol, LNG, etc) and retrofittable technologies such as optimised propellors, propellor boss caps, hydrofoils offer decarbonisation benefit without replacing the vessel.

Appendices

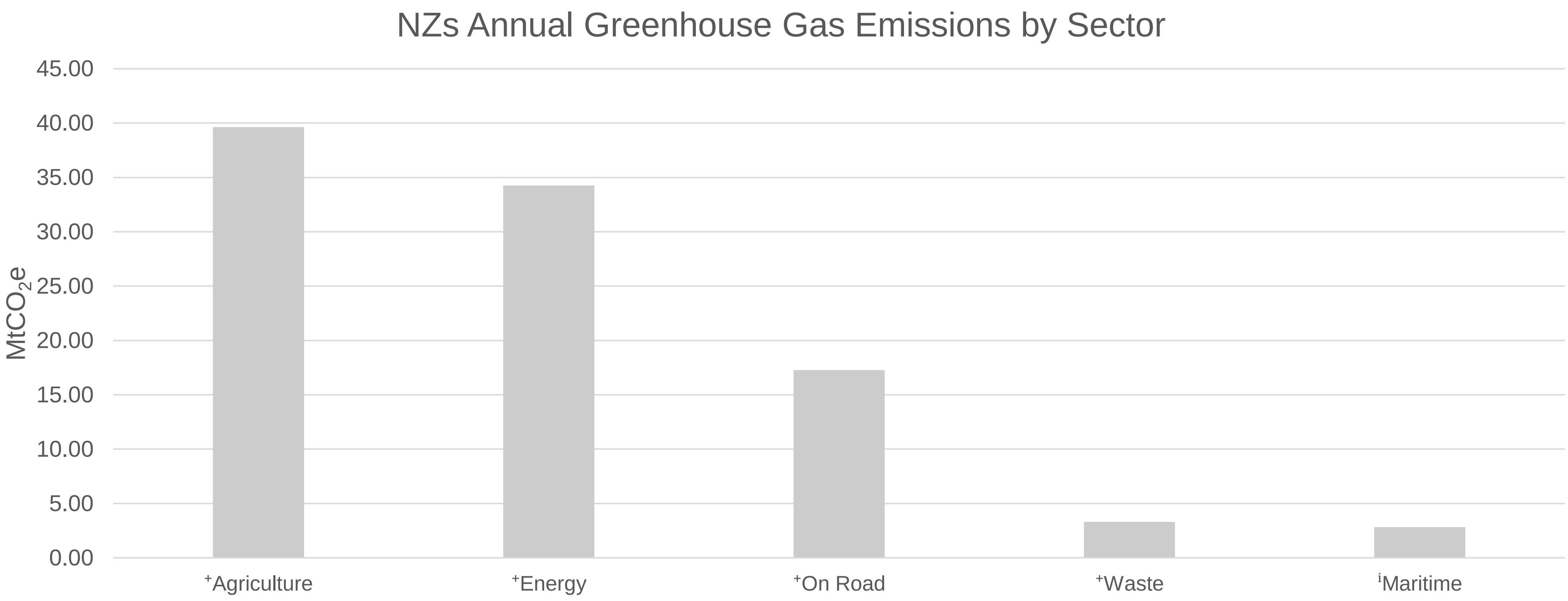
Appendix A – State of Play

Maritime Transport Emission Reduction Market Scan and Analysis

State Of Play Dataset

5 September 2022

Broad Sector Comparison



*$MtCO_2e$ is million tonnes of carbon dioxide equivalent greenhouse gas emissions.

[+]Source: Ministry for the environment – New Zealand's Greenhouse Gas Inventory 1990-2019

[i]Source: Auckland Council – Auckland Air Emission Inventory

Recreational Vessel Categories

Category for Study	Example Vessel	Typical Usage, Average Consumption
Small petrol power boats with removable power unit	• Tender or dinghy with outboard, 2hp - 10hp • Small fishing tinny with outboard, 10hp - 40hp	• 10 hours per annum, 5L/hr consumption • 25 hours per annum, 5L/hr consumption
Medium petrol power boats with permanent power unit	• 3-9 metres with engine(s), 50hp - 450hp • Average engine, 150hp Trailer required	• 50 hours per annum, 12L/hr consumption
Large petrol power boats with permanent power unit	• 7-14 meters with engines, 600hp-1800hp • Average engines, 700hp Typically stored on mooring, marina or dry stack	• 50 hours per annum, 110L/hr consumption
Personal watercraft (PWC) a.k.a Jet Ski	• Small PWC for general mixed entertainment • Larger PWC for coastal tripping or fishing	• 20 hours per annum, 10L/hr consumption • 40 hours per annum, 10L/hr consumption
Diesel power boats	• Classic launch with engine, 30hp – 200hp • Modern launch with engine(s), 200hp – 900hp • Large launch with engines(s), 900hp +	• 40 hours per annum, 15L/hr consumption • 60 hours per annum, 40L/hr consumption • 100 hours per annum, 100L/hr** consumption

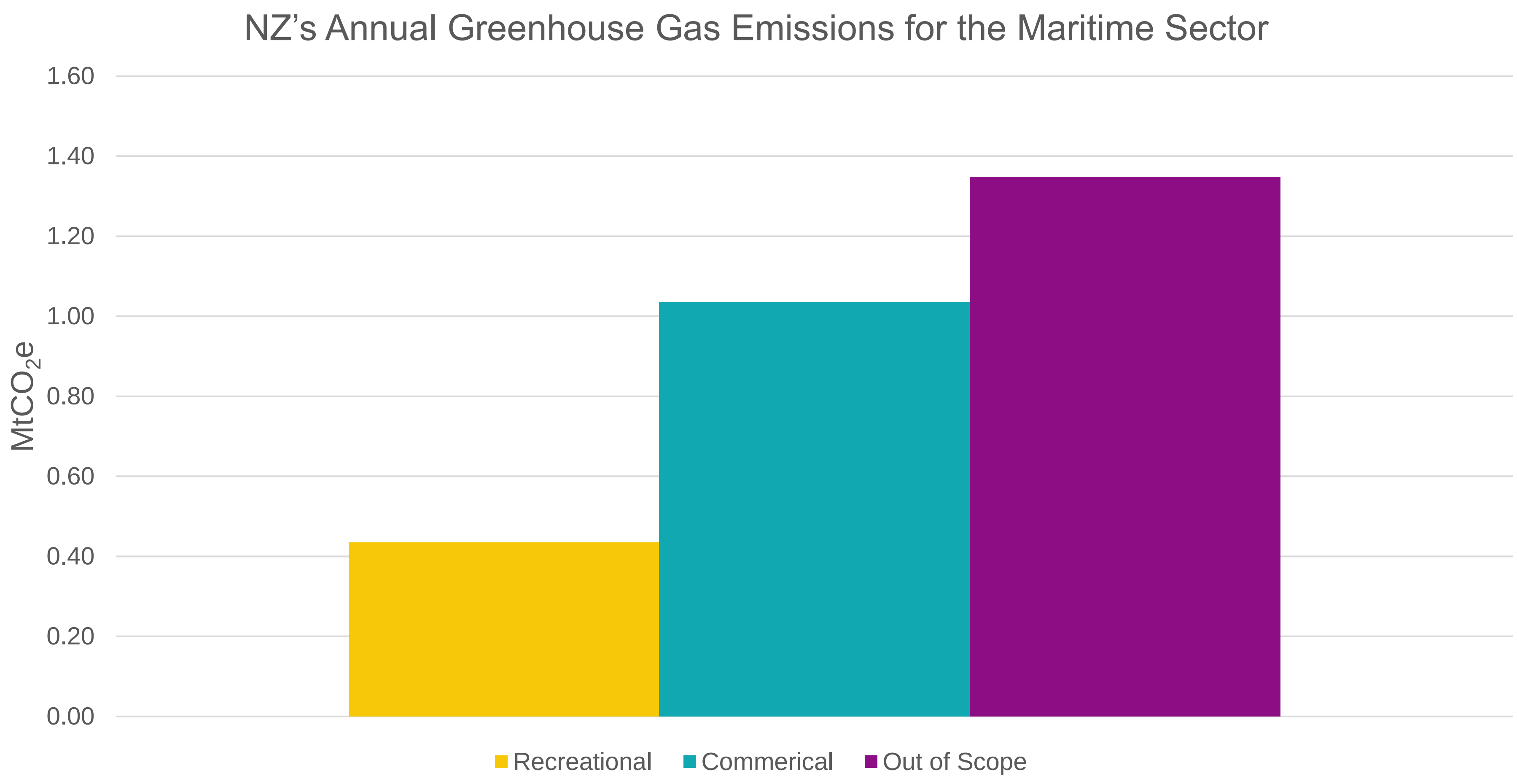
The typical usage is intended to be representative but may need to be modified at short-list analysis stage to suit the technology being analysed. This will be actioned and detailed during that analysis.
** this consumption number is yet to be confirmed

Commercial Vessel Categories

Category for Study	In Scope (New Zealand Flagged)		Out of Scope (Internationally Flagged)
Ocean going vessels (OGV's)	• Barge • Bulk Carrier • Domestic Container ships • General Cargo • Navy	• Research • RoRo Ferry • Supply Vessel • Offshore Vessel	• International flagged vessels • Vehicle Carrier • Cruise • Reefer Ship • Tanker • International Container ships
Harbour Vessel	• Pilot Vessel • Police • Port Tender • SAR	• Survey Vessel • Tug • Work Boat	
Ferries	• Harbour Ferry		
Fishing Vessels	• Fishing Boats		

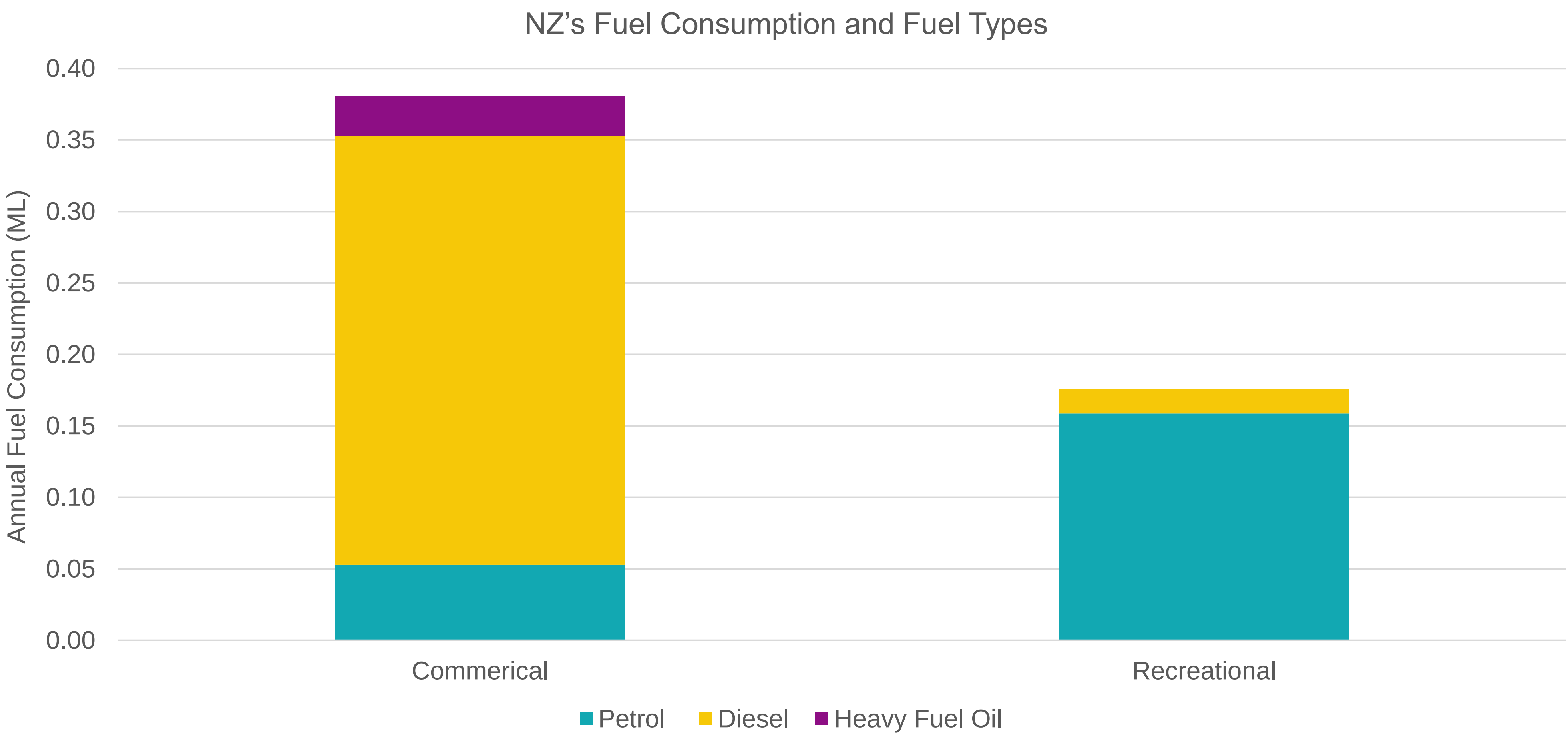
The typical usage is intended to be representative but may need to be modified at short-list analysis stage to suit the technology being analysed. This will be actioned and detailed during that analysis.

Greenhouse Gas Emissions Sector Breakdown

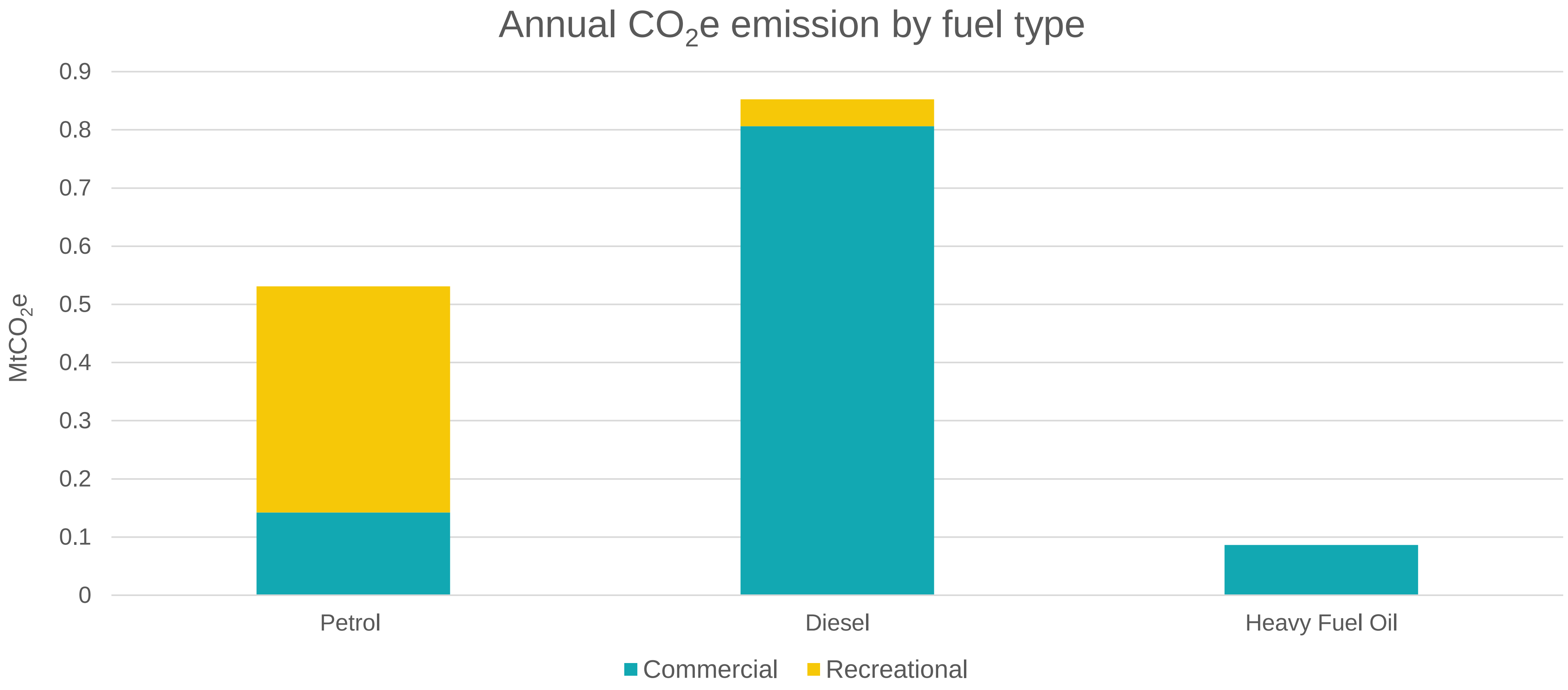


*$MtCO_2e$ is million tonnes of carbon dioxide equivalent greenhouse gas emissions.

In Scope Fuel Consumption Breakdown



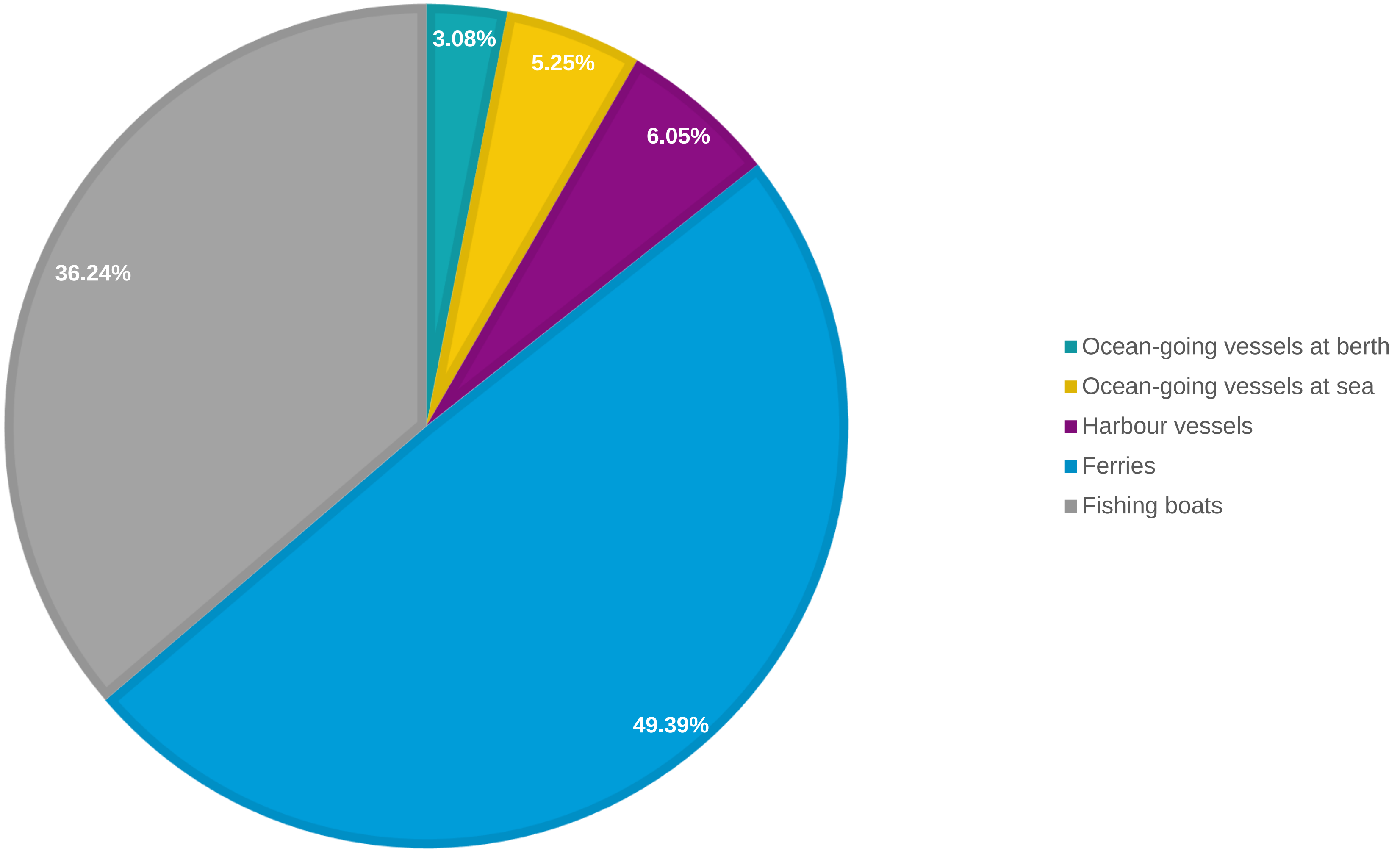
Greenhouse Gas Emissions by fuel type and sector



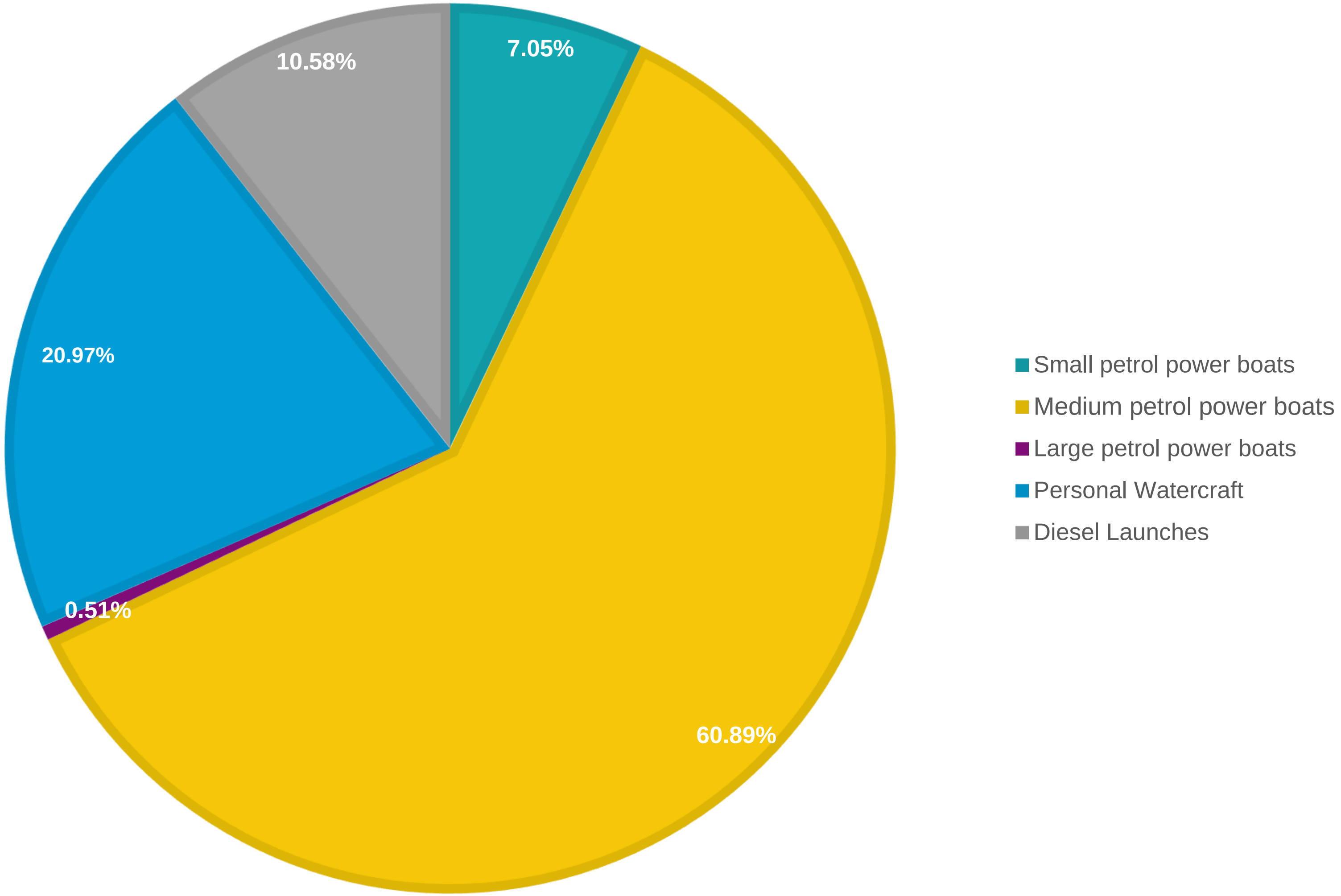
*$MtCO_2e$ is million tonnes of carbon dioxide equivalent greenhouse gas emissions.

Source: Ministry for the Environment – Measuring emissions: A guide for organisations

In Scope Commercial Vessel Emissions



Recreational Vessel Emissions Breakdown



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Resources

Title	Source	Published	Ref. Number
Auckland Air Emissions Inventory 2016 Sea Transport	Auckland Council	July 2018	[1]
Measuring Emissions: A Guide for Organisations	MfE	Dec 2020	[2]
Off-road liquid fuels insights, Survey results and analysis	EECA	May 2021	[3]
Oil data monthly tables	MBIE	Nov 2021	[4]
Calculation of petrol used in recreational boats in NZ	NZ Marine	Sept 2018	[5]
Estimated Stock of Boats in New Zealand	NZ Marine	Dec 2021	[6]
NZ Greenhouse Gas Inventory 1990 - 2019	MfE	Oct 2021	[7]
Jet Ski registration numbers	Auckland Transport	Mar 2022	[8]
Tonnage of cargo by sea around New Zealand	Figure.nz	Mar 2022	[9]

Commercial Sector Methodology

Data in the *Air Emissions Inventory from Auckland Council* [1] provides a comprehensive breakdown of commercial vessels and their environmental impact within the Auckland Council region.

Vessels that are out-of-scope in this study have been removed from this data by considering the number of domestic and internationally flagged ships. This action removes tankers, cruise ships and vehicle carriers and significantly reduces the influence from cargo ships and bulk carriers.

The emissions have been scaled by assuming the Auckland region shows a good representation of New Zealand's commercial maritime sector.

This extrapolation has been verified by comparing the results with the known tonnage of cargo ships in New Zealand [9] and the fuel consumption of fishing vessels [3]. Carbon impact of Fishing Boats is updated from State of Play as a result of more reliable data coming available late in the project.

Recreational Sector Methodology

Documents from NZ Marine [5] and [6] provide data for each vessel classification. This data includes typical annual fuel usage for each vessel type which has been verified against known users and real-world examples.

The total fuel consumption has been calculated for each vessel type along with the equivalent carbon dioxide emissions.

CO_2e emission factors for diesel and petrol were sourced from the Ministry for Environment Measuring Emissions Guide which [2]. These values are widely used within industry.

This data has been tabulated in excel to create the figures shown in this State of Play dataset.

Assumptions

- Some critical consumption data for off-road use relies on derivation and extrapolation
  - Data from different sources has been cross checked for validation
- The commercial vessel fuel consumption for the Auckland region is scalable to the all of NZ commercial vessel fuel consumption
  - This assumption has been validated by comparing the fuel consumption data for specific classes of vessel within the Auckland region with nationwide consumption data for vessels of the same class.
- Off road diesel consumed in the fishing, hunting and trapping industry sectors is aggregated in the data sets
  - The diesel consumption within the hunting and trapping industry is assessed as negligible compared to domestic and off-shore fishing

Small petrol power boats with removeable power unit

Fuel Consumption Estimate*	
Approximate Number	250 000
Annual Engine Time (hr.)	10
Rate of Consumption (L/hr.)	5
Total Annual Consumption (L)	12 500 000

*Source: NZ Marine - Calculation of petrol used in recreational boats in NZ [5]

Medium power boats with permanent power unit

Fuel Consumption Estimate*	
Approximate Number	180 000
Annual Engine Time (hr.)	50
Rate of Consumption (L/hr.)	12
Total Annual Consumption (L)	108 000 000

*Source: NZ Marine - Calculation of petrol used in recreational boats in NZ [5]

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Large petrol power boats

Fuel Consumption Estimate*	
Approximate Number	450
Annual Engine Time (hr.)	50
Rate of Consumption (L/hr.)	40
Total Annual Consumption (L)	900 000

*Source: NZ Marine - Calculation of petrol used in recreational boats in NZ [5]

Personal watercraft (PWC) a.k.a Jet Ski

Fuel Consumption Estimate*	
Approximate Number#	93 000
Annual Engine Time (hr.)	40
Rate of Consumption (L/hr.)	10
Total Annual Consumption (L)	37 200 000

*Source: NZ Marine - Calculation of petrol used in recreational boats in NZ [5]
Number sourced from NZ Marine - Estimated Stock of Boats in New Zealand [6]

Diesel power boats

Fuel Consumption Estimate*	
Approximate Number	8 550
Annual Engine Time (hr.)	100
Rate of Consumption (L/hr.)	20
Total Annual Consumption (L)	17 100 000

*Source: NZ Marine - Calculation of petrol used in recreational boats in NZ

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Appendix B – Long List

Sensitivity: General

EECA Maritime Decarbonisation Long List

Status: Issue for Approval
Date: 13/05/2022
Job Number: 2931169
By: BECA
Reviewed: Marine Industrial Design
Approved: Phil Robson

Technology	Group	Theme	Sector	Year Available	Carbon Impact Score	Technical Potential in NZ	Uptake Viability Score	Use Case	Market Carbon Contribution	Weighted Ranking	Shortlist (Y/N)
High Efficiency Propellor	Appendages	Reduce consumption	Both	2022	Medium	Sharrow Propellors tested on OEM engines shows ~30% greater range or less fuel @ same speeds Benefit of smoother handling, less vibration, less underwater radiated noise. Most applicable to fast planing boats over displacement. Props are designed for recreational outboard engines as well as commercial applications. Price point suggests commercial market the more likely uptake (ROI).	High	Launches Medium Petrol Power Large Petrol Power Harbour Vessels OGV	High	18	Y
Series Hybrid Drive (Electric drive with Diesel Generator)	Energy Conversion & Storage	Alternative Fuel	Both	2022	High	loses through energy conversion... Small, fuel efficient generator with batteries for peaks. No 20% reserve battery capacity to lug around for regs Combination with some energy storage aboard ferries can provide significant fuel savings while reduced cost compared to full electric vessel.	Medium	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	18	Y
Parallel Hybrid Drive (Diesel drive with Electric assistance)	Energy Conversion & Storage	Alternative Fuel	Both	2022	Medium	Offshore - mostly run on diesel and can use the electric to reduce engine running for peak demands. Means smaller energines can be spec'd Inshore - reduction of SOx/NOx in harbour running on electric only	Medium	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	12	Y
Propeller Optimisation	Appendages	Reduce consumption	Both	2022	Medium	Optimisation infers a case by case design. Some vessels will be already optimised for peak power or other parameter. Opportunity exisits to optimised for operating profile. Non-recurring engineering effort will be high so more likely to be an investment by commercial vessels operators.	Medium	Launches Medium Petrol Power Large Petrol Power OGV Harbour Vessels	High	12	Y
Electric - outboards (Retrofit)	Electrical Energy	Alternative Fuel	Both	2022	High	Installing electric outboards would require a some retro fitting and also relies on the infrastructure around marinas to supply power. Smaller outboards have better drop-in potential.	Medium	Medium Petrol Power Large Petrol Power	Medium	12	Y
Hydro Foil appendage (retrofit)	Appendages	Reduce consumption	Both	2022	Medium	Difficult to retrofit and achieve the same benefits as new design due to the hull and foil package being designed as one	Medium	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	12	Y
Shore power for vessels alongside (in harbour)	Dockside Infrastructure	Alternative Fuel	Commercial	2024	High	Large ocean going vessels could use shore power to replace using there diesel auxiliary engine. A large amount of infrastructure would be required to take power from the grind and supplying to large ships in Auckland harbour Shore power not available for ships use alongside. For example, Cement Carrier Buffalo (coastwise) only uses shore power when loading in Timaru. In Other discharge ports, they run Main Engine while discharging cargo to support large power needs.	Medium	Ocean Going Vessels Ferries Harbour Vessels Commercial fishing	Medium	12	Y
Electric Drive - Inboard (retrofit)	Electrical Energy	Alternative Fuel	Both	2022	High	Installing electric motors in boats with inboards would require a large amount of retro fitting and also relies on the infrastructure around marinas to supply power May be more viable in some larger vessels with large void spaces.	Medium	Rec trailer boats Launches Harbour vessels	Medium	12	Y
Bio-Diesel (various blends)	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	Low	Bio-Diesel can directly replace diesel in a marine diesel engine making the technology very viable. However it may be difficult provide supply to marina refuelling stations. Some blending capacity in NZ (small amounts only to date)	High	All Diesel vessels	High	9	Y
Hull coatings (anti-foul applications and niche/control surfaces)	Coatings	Reduce consumption	Both	2022	Low	Antifoul coats can be directly applied to any vessel to reduce fouling on the hull reducing drag and therefore saving fuel. Initial transition to these coatings may be costly, but ongoing maintenance on par with traditional	High	All Vessels	High	9	Y

Technology	Group	Theme	Sector	Year Available	Carbon Impact Score	Technical Potential in NZ	Uptake Viability Score	Use Case	Market Carbon Contribution	Weighted Ranking	Shortlist (Y/N)
Hydrogen Fuel Cells	Energy Conversion & Storage	Alternative Fuel	Commercial	2023	High	Low Temperature Proton Exchange Membrane (e.g. by Nedstack) packaged in 500kWe units exist for use in the marine environment. Push into the land transport sector before adoption into marine sector for infrastructure and supply. Enabling technologies required.	Low	All Vessels	High	9	Y
Hydrogen (as a fuel for ICE)	Energy Conversion & Storage	Alternative Fuel	Commercial	2025	High	Requires complex retro fitting or expensive new build and there is a lack of infrastructure around supply. Hydrogen fuelled engines under development now.	Low	OGV	Medium	6	Y
Ethanol (E85)	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	Medium	E85 has the potential to directly replace petrol with a moderate reduction in carbon emissions. Ethanol in high quantities can cause issues for marine use due to ability to absorb water. Not a big issue for higher use vessels and fuel doesn't sit around long enough, but can be an issue for recreational vessels where fuel turnover is low.	Medium	Small Petrol Power Medium Petrol Power Large Petrol Power Harbour Vessels	High	12	N
Synthetic Diesel (including e-diesel)	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	Medium	Synthetic diesel is made by reconfiguring another hydrocarbon fuel, such as natural gas, into liquid diesel fuel. Synthesizing diesel fuel from natural gas is possible through gas-to-liquid (GTL) technology such as Fischer-Tropsch conversion process. No processing infrastructure in NZ.	Medium	Marine Diesel engines	High	12	N
Liquified Petroleum Gas	Carbon Based Primary Fuel	Alternative Fuel	Commercial	2022	Medium	LPG is a fossil fuel with reduced emissions that can directly replace petrol in a converted petrol engine making the technology somewhat viable. It can be spliced with diesel or petrol for efficiency gains with minimal modifications. However it may be difficult provide supply to marina refuelling stations and requires additional tankage onboard. Successful use in slow speed diesels.	Medium	Petrol and Diesel vessels	High	12	N
Methanol	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	Medium	Methanol is an alternative fuel for ships that helps the shipping industry meet increasingly strict emissions regulations. It significantly reduces emissions of sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter. Methanol can be used with high efficiency in marine diesel engines after modifications using a small amount of pilot fuel (Diesel). The energy density of methanol may be lower than diesel so ship endurance (range) will reduce accordingly.	Medium	Petrol engines (as a blend) Marine Diesel engines (with minor modifications)	High	12	N
Niche area and control surface coatings	Coatings	Reduce consumption	Recreational	2022	Low	Benefits include extended sacrificial anode life and reduced marine growth (including IMO). Products need to be selected based on their location and application.	High	All Vessels	High	9	N
Dimethyl Ether (DME)	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	High	A relatively new fuel candidate that could be used to fuel modified diesel engines and gas turbines. Stored under pressure similar to LPG. Energy density is approx. 70% that of diesel and lower specific gravity means deep sea vessels will see a reduction is endurance for the same fuel volume (50%). Production/storage/supply issues in NZ	Low	All Diesel vessels	High	9	N
Hydro Foil appendage (new build)	Appendages	Reduce consumption	Both	2022	High	New build gives opportunity to optimise the hull, power, foil package design; something only practically achievable for new build boats	Low	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	9	N
Small tiller-steer Electric outboards	Electrical Energy	Replacement	Recreational	2022	High	Replacing a tiller steer outboard with an electric equivalent requires no additional retrofitting however the cost of the solution comparative to the fuel saves is large	High	Small Petrol Power	Low	9	N
Butanol	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	Medium	Butanol is an alternative carbon based drop in fuel for marine petrol engines making the technology very viable. However it may be difficult provide supply to marina refuelling stations	Low	Small Petrol Power Medium Petrol Power Large Petrol Power	High	6	N
Rerouting of fishing and deep sea vessels to mitigate weather conditions	Routing & Optimisation	Reduce consumption	Commercial	2022	Low	Simulation of e.g. Auckland ferry fleets is possible. Will need to mix up boats & routes to benefit from Electric Vessels	High	Ocean Going Vessels Ferries Commercial fishing	Medium	6	N
Electric craft (OEM)	Electrical Energy	Replacement	Recreational	2022	High	Replacing a boat with a new boat electric vessel involves a large cost compared to the value of the currently vessel as is and may not be feasible	Low	Swap out existing fleet	Medium	6	N
Synthetic Natural Gas (SNG)	Carbon Based Primary Fuel	Alternative Fuel	Commercial	2022	Medium	SNG can be derived form coal of biomass or synthetised using renewable energy. If bio mass is used the resultant bio-SNG/biogas. If renewable energy is used to produce the hydrogen the resultant product is e-gas or syngas. Typically run as a blend of SNG and LNG	Low	Harbour Vessels Ferries Offshore supply vessels OGV	Medium	4	N
Selective Catalytic Reduction (exhaust gas scrubbers)	Treatments	Exhaust treatment	Commercial	2022	Low	Technology is readily available, feasible and requires significant retro fitting (major space requirements issue). Cost is biggest issue for owners. Additional tankage for Urea solution.	Medium	Large diesel vessels Ocean Going Vessels	Medium	4	N

Technology	Group	Theme	Sector	Year Available	Carbon Impact Score	Technical Potential in NZ	Uptake Viability Score	Use Case	Market Carbon Contribution	Weighted Ranking	Shortlist (Y/N)
Wind Power Sails (Wing Sails)	Secondary Energy Source	Reduce consumption	Commercial	2024	Medium	This technology is available and in use. Can be retrofitted but is best suited to new-build.	Medium	Ocean Going Vessels	Low	4	N
Liquid Natural Gas	Carbon Based Primary Fuel	Alternative Fuel	Commercial	2022	Medium	LNG has the potential to replace HFO in OGVs. However LNG is slightly more expensive making it unattractive to large shipping organisations. It also can not directly replace HFO. Storage issues due to cryo needs, plus limited supply in NZ.	Medium	Ocean Going Vessels	Low	4	N
Compressed Natural Gas	Carbon Based Primary Fuel	Alternative Fuel	Commercial	2022	Medium	Storage volume is high, power loss also due to low power density. Engine wear is an issue. Retrofitability is a challenge due to size and weight of compressed gas storage	Low	Harbour Vessels Ferries Offshore supply vessels OGV	Medium	4	N
Ammonia Fuel Cells	Energy Conversion & Storage	Alternative Fuel	Commercial	2023	High	Requires complex retro fitting or expensive new build and there is a lack of infrastructure around supply Quite toxic, highly flammable Currently used as a refrigerant	Low	OGV	Low	3	N
Ammonia as an ICE fuel	Energy Conversion & Storage	Alternative Fuel	Commercial	2022	High	Requires complex retro fitting or expensive new build and there is a lack of supply and distribution infrastructure highly flammable Lower specific energy than diesel.	Low	OGV	Low	3	N
Sail Assisted, or other reduced emission Coastal Cargo	Secondary Energy Source	Reduce consumption	Commercial	2026+	High	Development of low emission coastal cargo vessels. Greater gains possibly available via reduced international vessel stops (multiple ports) and reduction of land based transport emissions. Tie in with the coastal shipping infrastructure / network project.	Low	Ocean Going Vessels	Low	3	N
Optimized Hull Form Design		Reduce consumption	Recreational	2026+	Low	Undertake research in cooperation with NZ vessel manufacturers to optimize their hull forms/ introduce new hull forms with increased efficiency (M-Hull or other optimized hull form designs), and make R&D resource available to bring these to market Standardising design for application	Low	VMG Boats Seablade	High	3	N
Electric (PWC)	Electrical Energy	Replacement	Recreational	2022	High	Replacing a jet ski with a new electric vessel involves a large cost compared to the value of the currently vessel as is and may not be feasible	Low	Swap out existing fleet	Low	3	N
MicroNuclear Power plants	Non-carbon Based Primary Fuel	Alternative Fuel	Commercial	2035	High	Complex and expensive technologies but produces ZERO carbon emissions. Could be viable for larger ocean going vessels in medium term (2035). 10MWhr being developed by Rolls Royce. Government buy-in required for storage of waste products.	Low	OGV	Low	3	N
Propeller Boss Cap Fins (PBCF)	Appendages	Reduced consumption	Commercial	2022	Low	Recover the energy wasted in the vortex that forms behind a rotating propeller and increases the thrust by breaking up this vortex. Analysis has shown that equipping a vessel with PBCF results in energy savings of 3% to 5%	Medium	Ocean Going Vessels	Low	2	N
Wind Power Kites	Secondary Energy Source	Reduce consumption	Commercial	2022	Low	This technology is available but requires installation and investment. Lots of excitement about this 6-10 years ago, but little progress suggests viability issues	Medium	Ocean Going Vessels	Low	2	N
Rotor Sails	Secondary Energy Source	Reduce consumption	Commercial	2022	Low	This technology is available but requires installation and investment.	Medium	Ocean Going Vessels Large Ferries	Low	2	N
Diesel Electric variants	Energy Conversion & Storage	Reduce consumption		2022	Low	DC grid power networks offer efficiencies and variable speed generators, highly variable power demands New build only due to design impost Higher upfront costs	Low	OGV Offshore Supply Vessels Ferries Harbour Vessels	Medium	2	N
Hull air lubrication	Treatments	Reduce consumption	Commercial	2022	Low	The Silverstream System is an air lubrication technology that reduces the frictional resistance of the vessel by creating a carpet of microbubbles that coats the majority of the flat bottom of a vessel's hull. The microbubbles, measuring 1–3mm in diameter, are generated by air release units (ARUs) in the bottom of the hull.	Medium	Large Flat bottom Vessels	Low	2	N
Solar panels	Secondary Energy Source	Reduce consumption		2022	Low	Solar panels are readily available to create auxiliary power for many vessels. Large area required to get meaningful power generation. House loads only.	Low		Low	1	N
Shroud/Nozzle/ Voith thrusters	Appendages	Reduce consumption	Both	2022	Low	The nozzle (Rice or Kort) applied to a vessel designed to deliver thrust (Offshore vessel, trawler or tug) will see gains in developed thrust per unit power. Some nozzles also claim increased speed over free running props Suitable for low speed high thrust vessels. Trawlers in the NZ market Voith thrusters (e-VSP) offer greater efficiency savings for tug and DP vessels. They are small in No. in NZ.	Low	Special application - trawlers, Dynamic Positioned vessels and Tugs	Low	1	N
Rudder and control surface Optimisation	Appendages	Reduce consumption	Both	2022	Low	For a rudder to be optimised it would have to be designed on a case by case basis. NRE required may be feasible for commercial vessels with heavy use at cruising speed.	Low	Launches OGV Ferries	Low	1	N
Fuel catalysing	Treatments	Fuel treatment	Both	2022	Low	Technology is readily available, feasible and requires minimal retro fitting. Some scepticism in market about whether it actually works or not would warrant further investigations. No emprical evidence of impact.		All diesel vessels All petrol vessels	Low	0	N
Containerised Battery Power Bank	Enabler	Alternative Fuel	Commercial	2023		peak load shaving , and effective as "spinning reserve" for DP vessels		Ocean Going Vessels		0	N

Technology	Group	Theme	Sector	Year Available	Carbon Impact Score	Technical Potential in NZ	Uptake Viability Score	Use Case	Market Carbon Contribution	Weighted Ranking	Shortlist (Y/N)
Charging interfaces	Enabler	Alternative Fuel	Both	2022		Manual vs. Auto, auto requires fleet standardisation, CCS2 protocol?, agreement of connector, how many connectors required				0	N
Electrical Power Sharing	Enabler	Alternative Fuel	Both	2022		If this is charging from one power source to the another then it is not an actual saving		All		0	N
On demand Hydrogen	Enabler	Alternative Fuel	Both	2022		Port side generation for filling H2 to ship in dockside. 30% stored energy to maintain the cold storage. Storage energy cost of hydrogen (cooling) is significant, so on-demand generation could be a significant energy saver. Still need to input energy FF or electric to produce H2				0	N
Full foiling vessels	Enabler	Reduce consumption	Commercial	2022		NZ industry are market leaders in these types of technologies and there is significant skill and expertise available. Enabling technology to allow greater range and efiiciency of electric craft		Seachange ETNZ ChaseZero Candela		0	N

Appendix C – Weightings Definitions

EECA Maritime Decarbonisation Ranking Metrics and Definitions

Status: Issue for Approval
Date: 4/05/2022
Job Number: *2931169*
By: *BECA*
Reviewed: *Marine Industrial Design*
Approved: *Phil Robson*

Metric	Description	Score	Metric	Description or Range	
Carbon Impact Score	The Carbon Impact Score ranks the effectiveness of a solution based on the expected reduced Greenhouse Gas emissions under normal operation.	Low	1	Technologies that optimise or modify the incumbent fuel or technology. Expected range of greenhouse gas emissions reduction, approx. 0 - 15%	
		Medium	2	Technologies that reduce emissions through add-on or modification of installed technology. Expected range of greenhouse gas emissions reduction, approx. 10 - 25%	
		High	3	Technologies that remove incumbent fossil fuel from use. Expected range of greenhouse gas emissions reduction, approx. 25 - 100%	
Uptake Viability Score	The Uptake Viability assesses the potential for a solution to be adopted successfully by the market. This includes a qualitative assessment of the technology, market and required infrastructure and relative cost of the alternative technology/fuel.	Low	1	Technologies that will require a large amount of infrastructure or investment to make the solution feasible or may require the current use case to be completely replaced (New build)	
		Medium	2	Technologies that may require work to be done before the solution can be implemented. This may be small amounts of supporting infrastructure, work done on the vessel, complex installation or specific design work based on the use case. Also includes solutions that require substantial investment compared with the potential ROI	
		High	3	Technologies that can be implemented straight away with no need for additional work or resources. The cost of the solution is also reasonable for the potential ROI	
Market Carbon Contribution	Based on the State of Play data set, the Carbon Contribution assessment indicates the potential total Greenhouse Gas (GHG) emissions reduction associated with the adoption of the option applied to the use case sectors.	Low	1	Lower Limit 0%	Upper Limit 20%
		Medium	2	Lower Limit 20%	Upper Limit 50%
		High	3	Lower Limit 50%	Upper Limit 100%

Appendix D – Weighted Short List

EECA Maritime Decarbonisation Short List

Status: Issue for Approval - Redacted
Date: 28/02/2022
Job Number: 2931169
By: BECA
Reviewed: Marine Industrial Design
Approved: Phil Robson

Technology	Group	Theme	Sector	Year Available	Carbon Impact	Carbon Impact Score	Technical Potential in NZ	Uptake Viability Score	Use Case	Market Carbon Contribution	Weighted Ranking	Shortlist (Y/N)	Use Case for Analysis
High Efficiency Propellor	Appendages	Reduce consumption	Both	2022	10-20 % more fuel efficient	Medium	Sharrow Propellors tested on OEM engines shows ~30% greater range or less fuel @ same speeds Benefit of smoother handling, less vibration, less underwater radiated noise. Most applicable to fast planing boats over displacement. Props are designed for recreational outboard engines as well as commercial applications. Price point suggests commercial market the more likely uptake (ROI).	High	Launches Medium Petrol Power Large Petrol Power Harbour Vessels OGV	High	18	Y	Outboard - Medium Petrol Powered Boat Inboard - Ferries
Series Hybrid Drive (Electric drive with Diesel Generator)	Energy Conversion & Storage	Alternative Fuel	Both	2022	Up to 70% reduction	High	loses through energy conversion... Small, fuel efficient generator with batteries for peaks. No 20% reserve battery capacity to lug around for regs Combination with some energy storage aboard ferries can provide significant fuel savings while reduced cost compared to full electric vessel.	Medium	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	18	Y	Ferries
Parallel Hybrid Drive (Diesel drive with Electric assistance)	Energy Conversion & Storage	Alternative Fuel	Both	2022	15% reduction	Medium	Offshore - mostly run on diesel and can use the electric to reduce engine running for peak demands. Means smaller energines can be spec'd Inshore - reduction of SOx/NOx in harbour running on electric only	Medium	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	12	Y	Ferries
Propeller Optimisation	Appendages	Reduce consumption	Both	2022	10-15%	Medium	Optimisation infers a case by case design. Some vessels will be already optimised for peak power or other parameter. Opportunity exisits to optimised for operating profile. Non-recurring engineering effort will be high so more likely to be an investment by commercial vessels operators.	Medium	Launches Medium Petrol Power Large Petrol Power OGV Harbour Vessels	High	12	Y	Included under High Efficiency Propellor option
Electric - outboards (Retrofit)	Electrical Energy	Alternative Fuel	Both	2022	100% reduction	High	Installing electric outboards would require a some retro fitting and also relies on the infrastructure around marinas to supply power. Smaller outboards have better drop-in potential.	Medium	Medium Petrol Power Large Petrol Power	Medium	12	Y	Medium (trailer) Petrol Powered Boat
Hydro Foil appendage (retrofit)	Appendages	Reduce consumption	Both	2022	7-15%	Medium	Difficult to retrofit and achieve the same benefits as new design due to the hull and foil package being designed as one	Medium	Harbour Vessels Ferries Offshore supply vessels OGV Launches	High	12	Y	Catamaran Ferries Ocean Going Vessel
Shore power for vessels alongside (in harbour)	Dockside Infrastructure	Alternative Fuel	Commercial	2024	45-70% reduction	High	Large ocean going vessels could use shore power to replace using there diesel auxiliary engine. A large amount of infrastructure would be required to take power from the grind and supplying to large ships in Auckland harbour Shore power not available for ships use alongside. For example, Cement Carrier Buffalo (coastwise) only uses shore power when loading in Timaru. In Other discharge ports, they run Main Engine while discharging cargo to support large power needs.	Medium	Ocean Going Vessels Ferries Harbour Vessels Commercial fishing	Medium	12	Y	Commercial Fishing Boats
Electric Drive - Inboard (retrofit)	Electrical Energy	Alternative Fuel	Both	2022	100% reduction	High	Installing electric motors in boats with inboards would require a large amount of retro fitting and also relies on the infrastructure around marinas to supply power May be more viable in some larger vessels with large void spaces.	Medium	Rec trailer boats Launches Harbour vessels	Medium	12	Y	Medium Petrol Powered Boat Commercial Jet Boat Operator
Bio-Diesel (various blends)	Carbon Based Primary Fuel	Alternative Fuel	Both	2022	CO2 neutral Bigger gains on the other GHG	Low	Bio-Diesel can directly replace diesel in a marine diesel engine making the technology very viable. However it may be difficult provide supply to marina refuelling stations. Some blending capacity in NZ (small amounts only to date)	High	All Diesel vessels	High	9	Y	Ferries Commercial Fishing Boats
Hull coatings (anti-foul applications and niche/control surfaces)	Coatings	Reduce consumption	Both	2022	3-5% reduction	Low	Antifoul coats can be directly applied to any vessel to reduce fouling on the hull reducing drag and therefore saving fuel. Initial transition to these coatings may be costly, but ongoing maintenance on par with traditional	High	All Vessels	High	9	Y	Ferries Commercial Fishing Boats

Technology	Group	Theme	Sector	Year Available	Carbon Impact	Carbon Impact Score	Technical Potential in NZ	Uptake Viability Score	Use Case	Market Carbon Contribution	Weighted Ranking	Shortlist (Y/N)	Use Case for Analysis
Hydrogen Fuel Cells	Energy Conversion & Storage	Alternative Fuel	Commercial	2023	100% reduction	**High**	Low Temperature Proton Exchange Membrane (e.g. by Nedstack) packaged in 500kWe units exist for use in the marine environment. Push into the land transport sector before adoption into marine sector for infrastructure and supply. Enabling technologies required.	**Low**	All Vessels	**High**	9	Y	Ferries
Hydrogen (as a fuel for ICE)	Energy Conversion & Storage	Alternative Fuel	Commercial	2025	100% reduction	**High**	Requires complex retro fitting or expensive new build and there is a lack of infrastructure around supply. Hydrogen fuelled engines under development now.	**Low**	OGV	**Medium**	6	Y	Ocean Going Vessels
Electric craft (OEM)	Electrical Energy	Replacement	Recreational	2022	100% reduction	**High**	Replacing a craft with a new electric craft involves a large cost compared to the value of the currently vessel as is and may not be feasible	**Low**	Swap out existing fleet	**Medium**	6	Y	Personal Watercraft

Appendix E – Short List Analysis

EECA Maritime Decarbonisation Short List Analysis

Status: *Issue for Approval* *By:* *Beca*
Date: *05/09/2022* *Reviewed:* *Marine Industrial Design*
Job Number: *2931169* *Approved:* *Phil Robson*

SUMMARY AND DEFINITIONS

It is important to note that these short-listed technologies should not be considered to exclude the other technologies identified during the long list task. All the technologies identified in the long list are viable and worthy of pursuit considering the big picture goal of decarbonisation by 2050. Rather, these short list technologies were selected to focus analysis efforts.

Throughout the content presented, the Technology/Commercial Readiness Level is defined in accordance with the Australian Renewable Energy Agency (ARENA), Technology Readiness Levels for Renewable Energy Sectors. Readiness will be quoted in reference to the Commercial Readiness Index (CRI), as represented in Figure 1 and 2 below (Technology and Commercial Readiness Tools | Australian Renewable Energy Agency, 2022). As depicted in Figure 2, technologies with a CRI number 4 or above are in the deployment phase and thus commercially available.

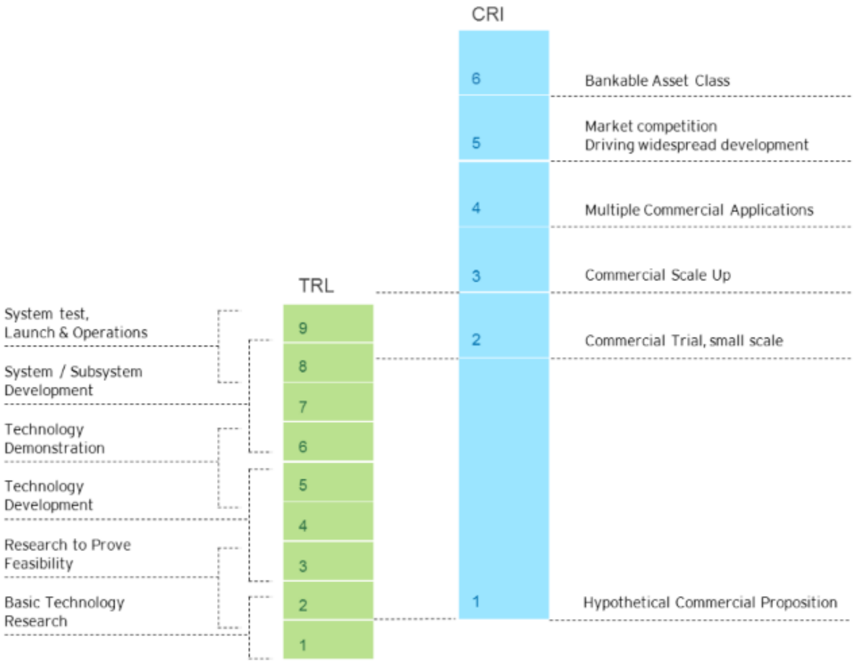


Figure 1: Technology Readiness Level (TRL) and Commercial Readiness Index (CRI)

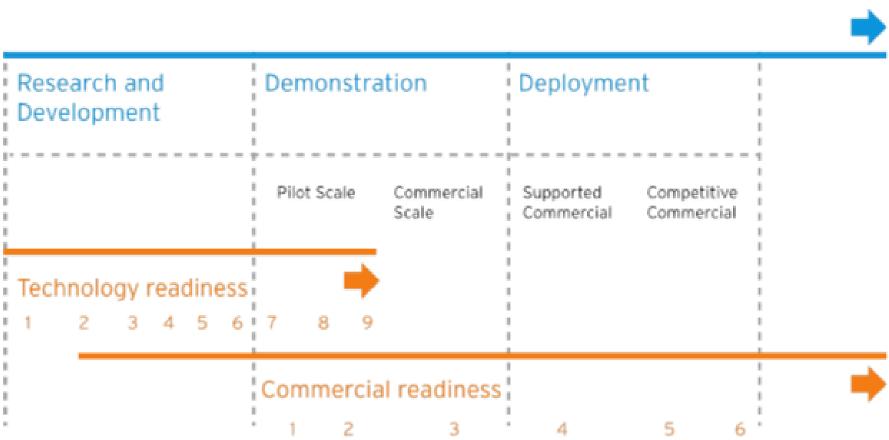


Figure 2: TRL and CRI mapped on the Technology Development Chain

EECA Maritime Decarbonisation Short List Analysis

Status: *Issue for Approval* *By:* *Beca*
Date: *05/09/2022* *Reviewed:* *Marine Industrial Design*
Job Number: *2931169* *Approved:* *Phil Robson*

When considering the commercial and environmental characteristics, the following definitions apply.

Metric	Discussion	Scale
CAPEX	CAPEX cost range will be considered differently based on the application type: **New Build** – uplift cost over and above installation of the incumbent technology **Retrofit** – total project costs	LOW: $0 – $0.5 mill MEDIUM: $0.5 mill – $1 mill HIGH: $1 mill – >$1 mill
OPEX	OPEX can increase or decrease by implementation of decarbonisation technologies which is reflected in the scale definitions. These are compared to the incumbent technology.	LOW: -20% – 0% MEDIUM: 0% – 20% HIGH: 20% – >20%
Carbon Impact	Align with the definition given in the long list: The Carbon Impact Score ranks the effectiveness of a solution based on the expected reduced Greenhouse Gas (GHG) emissions under normal operation. Carbon impact is assigned from the perspective of the use case, and a Low carbon impact score is still on the right side of the ledger with a net positive impact.	**Low**: Technologies that optimise or modify the incumbent fuel or technology. Expected range of GHG emissions reduction, approx. 0 - 15% **Medium**: Technologies that reduce emissions through add-on or modification of installed technology. Expected range of GHG emissions reduction, approx. 10 - 25% **High**: Technologies that remove incumbent fossil fuel from use. Expected range of GHG emissions reduction, approx. 25 - 100%
Sector Impact	Combines the carbon impact of the technology with the vessel applicability within the sector, giving a potential emissions reduction for New Zealand context, based on State of Play data. Uptake percentage will be assumed at 100% applied to the viable vessel percentages.	LOW: 0% – 10% MEDIUM: 10% – 20% HIGH: 20% – >20%

Whilst it is acknowledged that there are many through-life variables to consider when discussing decarbonisation technologies, this study is focussed on the tank-to-wake impact of the technologies presented.

Cost guidelines where provided are indicative and represent order of magnitude. These have not been completed by a Quantity Surveyor and should be considered for guidance only.

EECA Maritime Decarbonisation Short List Analysis

Status: *Issue for Approval* *By:* *Beca*
Date: *05/09/2022* *Reviewed:* *Marine Industrial Design*
Job Number: *2931169* *Approved:* *Phil Robson*

TE TARI TIAKI PŪNGAO
ENERGY EFFICIENCY & CONSERVATION AUTHORITY

Glossary

Berthed	When a ship is moored or docked in its allotted place.
Catamaran	A marine vessel with twin parallel hulls.
DNV	Det Norske Veritas is an international accredited registrar and classification society.
Domestic Load	These are the electrical demands on board a vessel that are the result of domestic equipment such as ovens, lighting, air conditioning etc.
Embrittlement	Significant decrease of ductility of a material, which makes the material brittle.
Fouling	Fouling is the accumulation of unwanted material on solid surfaces. The fouling materials can consist of either living organisms or a non-living substance (inorganic or organic).
Hauled out	When a vessel is moved from the water onto the shore.
Hydrofoils	A lifting surface, or foil, that operates in water. They are similar in appearance and purpose to aerofoils used by aeroplanes.
Industrial Load	These are the electrical demands on board a vessel that are the result of industrial equipment such as winches, refrigeration etc.
Interceptor	A small protrusion in an underwater surface that modified the flow of water across the surface and changing the lift and drag characteristics.
Lloyd’s Register	Lloyd's Register Group Limited (LR) is a technical and professional services organisation and a maritime classification society.
Monohull	A vessel with a single hull
Multi-hull	A vessel with multiple hulls configured as a Catamaran (2 hulls) or Trimaran (3 hulls).
OEM	Original Equipment Manufacturer
Power train	The complete propulsion system of a vessel, including the engine, gearbox, propellor shaft and propellor.
Rim-drive	A propulsion unit that utilises a propellor driven by a perimeter electric motor housed in the cowling rim.
Running gear	All the underwater propulsive and manoeuvring equipment of a vessel. Typically includes propellor shafts, brackets, rudders and propellors.
Sea Chests	The term sea chest is used for a rectangular or cylindrical recess in the hull of a ship that is used to bring seawater into the vessel for use as a coolant, lubricant or raw material.
Tip Vortex	A tip vortex is created on any lifting surface that experiences a pressure difference across the surfaces. As the high-pressure fluid moves to the low-pressure surface at the tip, a trailing vortex results in the wake. This vortex contributes to induced drag and decreased efficiency. The phenomenon is most associated with aircraft wings but is observable in marine and aviation propellors and wind turbines.
Type approved	Official confirmation from a government or regulatory other body that a manufactured item meets required specifications.
Underwater Cooler Boxes	A recess in the ships hull that may have a radiator-like assembly contained within that is used to exchange heat between the internal fluid and the surrounding sea water.

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Propellor Optimisation**	Applicable Sector:	Commercial and Recreational
Technology Group:	Appendages	Technology Theme:	Reduce Consumption

TECHNOLOGY SUMMARY

The vast majority of vessels in the global fleet use a propellor as their means of propulsive power. The propellor is typically designed for the vessel at the design and build stage and may be theoretically optimised for peak power or other performance target. For several reasons, including change of usage/application, geographical location or variation in design vs. as-built performance, the original optimisation may not suit the current situation.

Most propellor Original Equipment Manufacturers (OEMs) have the ability, and actively offer services, to optimise the propellor, alongside other underwater appendages (e.g. rudders). This can realise efficiency gains and emissions reductions and may be achieved by:

- optimising the running gear for a specific operation profile rather than for the peak power output or by matching the as-built performance
- reducing or eliminating tip vortex losses, a significant contributor to efficiency losses and an issue for all traditional propellor designs
- adjusting the propellor dynamics by use of "interceptor" strip inserts. This solution allows for flexibility on a new design and many variations can be installed and tested quickly resulting in fast optimisation and performance improvements.

Propeller optimisation technologies are well suited to existing vessels as it is non-invasive and can be implemented during maintenance periods when the vessel is already hauled out.

In the outboard propulsion market, propellor designs and supply are controlled by the outboard OEM, and they typically have a range of propellors to suit a particular outboard model, allowing for the propellor to be selected to suit the specifics of the boat characteristics. This is often achieved by sea-trial and error and results in the "best" combination from the options rather than the optimal configuration. Propellor optimisation in the outboard market is not a competitive space, but Sharrow Engineering (USA) are leading industry in this space with a patented product.

Sharrow Engineering (USA) produce a novel tipless propellor design which eliminates tip vortex losses. Sharrow have a library of propellor designs to suit a wide (and growing) range of OEM outboards, they are also diversifying into the inboard-drive commercial spaces with applications such as freighters, tankers, workboats, pleasure craft and submersibles. The Sharrow propellor design has been shown to be 9-15% more efficient than the industry standard Wageningen B-Series design. This is significant given industry experts traditionally evaluated gains of 1% efficiency as meaningful.

There are fringe benefits to propellor optimisation that are typically also of interest to owner/operators of all vessel types including:

- lower noise and vibration levels, including that radiated into the water
- reduced maintenance through lower wear and tear on the drivetrain components
- higher top speed, and elevated speeds throughout the RPM range, resulting in increased range or lower fuel consumption and thus emissions
- reduced engine load for a given RPM and speed

Maritime Decarbonisation Technology Summary Sheet

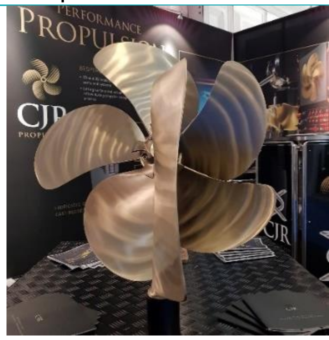
Technology: **Propellor Optimisation**

Applicable Sector: Commercial and Recreational

Technology Group: Appendages

Technology Theme: Reduce Consumption

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

Use Case for Analysis	Medium Petrol-Powered Boat Outboard engine 50hrs p.a., 12L/hr consumption		Ferries Inboard engine 4000hrs p.a., 180L/hr consumption	
State of Play Data	This technology is viable for all propellor driven vessels, which will be the majority (probably 90%-plus) of commercial, only excluding waterjet propelled vessels. In the recreational sector, this will be applicable to circa 60%, excluding personal watercraft, recreational jet boats and small petrol power boats.			
Example of Application	 Sharrow Engineering's (USA) tip-less propeller.		 CJR (UK) Optimised propellor and flow-aligned rudder  Veem (Australia) Optimised propellor with interceptor Strip	
Readiness / Availability	CRI-3	Commercial Scale Up	CRI-5	Market competition Driving widespread development
CAPEX	\$0-\$0.5m	COTS cost ~\$US5k	\$0-\$0.5m	Up to 80hrs non-recurring engineering costs, manufacturing of a single or pair of propellors ~\$NZ40k ea.
OPEX	-20-0% Reduction	Reduced fuel consumption as quoted by OEM and evidenced by testing	-20-0% Reduction	Reduced fuel consumption as quoted by OEM and evidenced by testing

Maritime Decarbonisation Technology Summary Sheet

Technology: **Propellor Optimisation**

Applicable Sector: Commercial and Recreational

Technology Group: Appendages

Technology Theme: Reduce Consumption

Carbon Impact	Medium 9-15%	Up to 15% efficiency gains quoted by Sharrow Engineering and tested	Medium 10-15%	Quoted by CJR and Veem, depends on the optimisation achieved from baseline
Sector Impact	3.3-5.5% emissions reduction **14,040-23,400 tCO_2e/yr**	Sector contributes 61% emissions. Assume technology is applicable to 60% of the sector as outboard powered vessels	5.4-8.1% emissions reduction **40,800-61,200 tCO_2e/yr**	Sector contributes 67.6% emissions. Assume 80% of ferry sector are propellor driven

BARRIERS AND CHALLENGES

Cost will be the biggest barrier to entry for propellor optimisation technology. Optimisation is, by nature, conducted on a case-by-case basis and each case will incur a non-recurring engineering (NRE) fee which will be a sunk-cost regardless of scope for improvement or not. Operators may not be able to resolve the ROI, especially if the vessel is nearing its end of life.

In the recreational space, the outboard-focused Sharrow (USA) propellor seems to be the only provider of optimization technology but it is expensive compared to the traditional off-the-shelf outboard propellor from the OEM. A recreational boater will need to balance their use of their vessel and fuel consumption against this cost and may not be prepared to wear the cost. This solution may suit high-usage commercial operators with outboard-powered boats as the payback period will be significantly less and the cost more palatable for a business.

Mindset/perception may be an issue for some owner/operators especially with respect to the Sharrow (USA) propellor that it is new and comparatively un-tested technology. This may be exacerbated by the fact the propellor looks so different to a traditional design.

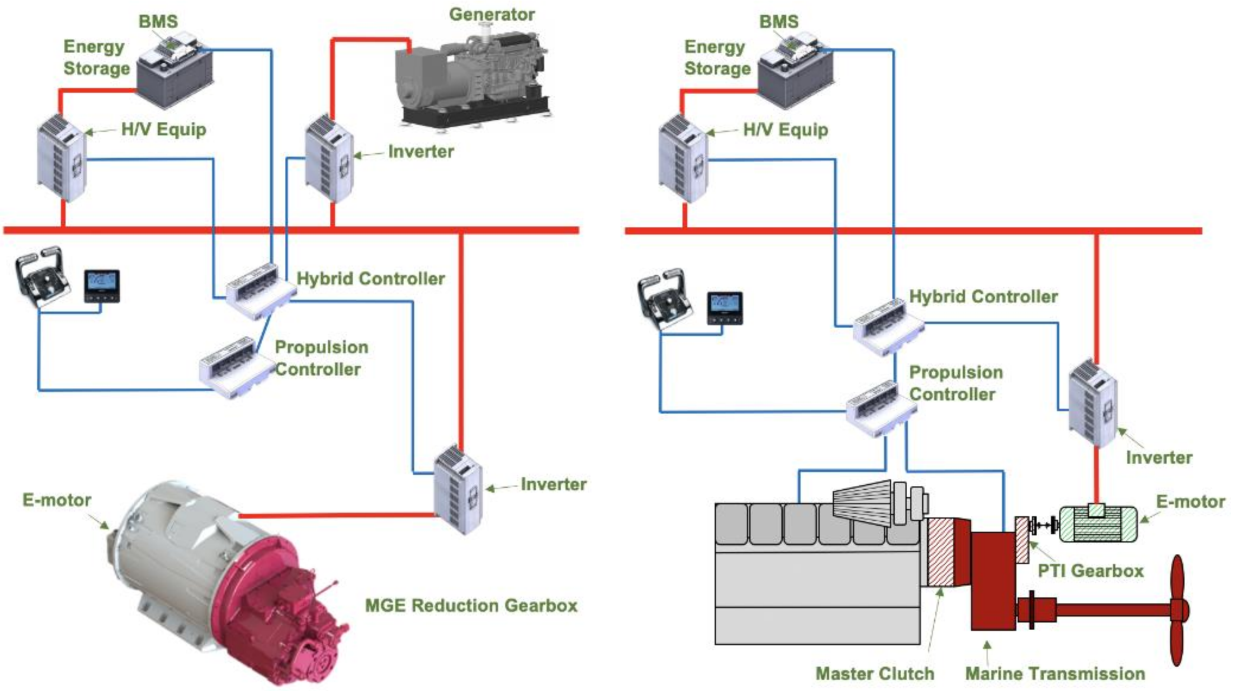
Maritime Decarbonisation Technology Summary Sheet

Technology: **Hybrid Drives**
Applicable Sector: Commercial and Recreational
Technology Group: Energy Conversion/Storage
Technology Theme: Alternative Fuel

TECHNOLOGY SUMMARY

Hybrid drive technologies can be considered in two traditional forms:

1. Serial (series) hybrid consists of an internal combustion engine (ICE) driven generator (typically diesel fuelled) that powers an electric motor. Only the electric motor is connected to the propeller shaft and this electric motor can be supplied either directly from the diesel generator or from the charged battery bank.
2. Parallel hybrid consists of an electric motor and an ICE propulsion engine (typically diesel fuelled) each coupled (either directly or through a gearbox) to the same driveshaft. Various modes of propulsion are available; direct (mechanical) drive from the propulsion diesel engine via the propulsion gearbox, electric motor drive through the power-take-in (PTI) connection to the same gearbox (and where the electric motor is powered from the charged battery bank) or the use of both direct diesel drive <u>and</u> electric motor drive in combination (e.g. for limited duration high power sprints).



Typical Serial (left) and Parallel (right) Hybrid marine drive systems.
(Electric & Hybrid Propulsion Systems | Twin Disc, 2022)

A third variant of hybrid drives is becoming popular with the commercial availability of fringe technologies. These emerging hybrid drive systems combine the decarbonisation benefits of the serial hybrid arrangement, with the low emissions of an alternative-fuelled electrical source (e.g. hydrogen fuel cell) to provide electrical power.

Hybrid arrangements have general advantages and disadvantages as set out below:

Advantages:

- Ability to run the ICE motor in its optimum operating range and switch to pure electric propulsion when outside of the ICE operating range.
- When running on pure electric:
    - reduced noise and vibration in the vessel

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hybrid Drives** Applicable Sector: Commercial and Recreational

Technology Group: Energy Conversion/Storage Technology Theme: Alternative Fuel

  - full, low-RPM torque, thereby enhancing manoeuvrability and reducing power spikes
  - significant reduction in emissions/SOx/NOx
- Reduction in maintenance, and related costs, of the ICE motor as it is operated less compared to conventional propulsion systems.
- Generally smaller ICE can be specified, directly reducing their CAPEX and OPEX through lower fuel consumption.

Disadvantages:

- Inefficiency through multiple conversions of energy: chemical to mechanical to electrical to mechanical.
- Overall CAPEX can be equivalent or higher than a conventional arrangement due to the additional electrical components: motors, batteries and power management systems that are required.
- The system power-to-weight ratio can be low due to the additional electrical equipment, in particular batteries. This may be beneficial if the weight is used productively as ballast.

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

Use Case for Analysis	Ferries – Serial Hybrid 4000hrs p.a., 180L/hr consumption		Ferries – Parallel Hybrid 4000hrs p.a., 180L/hr consumption	
State of Play Data	Ferries represent 67.6% of commercial vessel emissions in New Zealand. This group includes traditional ferries, but also tourism vessels such as those operating in Fiordland and off the Kaikoura coast.			
Example of Application	US National Park Service Alcatraz Hybrid Ferry operating a serial hybrid arrangement with diesel generator complemented by solar and wind power capture. 		Corsica-based Nave Va, operate a parallel hybrid propelled excursion vessel that takes tourists tours of the Scandola Nature Reserve.  	
Readiness / Availability	CRI-6	Bankable Asset Class	CRI-6	Bankable Asset Class
CAPEX	Exceeding $1m Range $6-12m	Procurement and retrofit of: Generator and electrical propulsion motor Electrical and control systems Energy Storage System Associated power equipment 24m+ vessel size	Exceeding $1m Range $6-12m	Procurement and retrofit of: Diesel main engines with suitable gearbox for PTI Electrical and control systems Energy Storage System Associated power and mechanical equipment 24m+ vessel size

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hybrid Drives** Applicable Sector: Commercial and Recreational

Technology Group: Energy Conversion/Storage Technology Theme: Alternative Fuel

OPEX	-20-0% Reduction	Through reduced fuel consumption as quoted by prime system integrators. Benefit is relative to the battery capacity-to-range matching of the vessel	-20-0% Reduction	Through reduced fuel consumption as quoted by prime system integrators. Benefit is relative to the battery capacity-to-range matching of the vessel
Carbon Impact	High 70%	With high battery capacity-to-range matching, this drive can operate mostly emissions free	Medium 15%	Parallel hybrid typically running more on main diesel engines than serial equivalent
Sector Impact	16.9% emissions reduction	Ferries contribute 67.6% emissions. Assume 50% of ferries sector can be retrofitted or replaced	5.1% emissions reduction	Ferries contribute 67.6% emissions. Assume 50% of ferries sector can be retrofitted or replaced

BARRIERS AND CHALLENGES

Implementation of hybrid drive technologies face a major barrier for retrofit in an aging fleet for several reasons:

- Most vessels in the commercial space have designed usable lifetime of 30-40 years so there is little incentive to retrofit or replace early, plus the number of new built ships per year is low, so ROI in innovative systems for the shipbuilders is low.
- Changing the main propulsion requires compliance with modern emissions standards (International Maritime Organisation (IMO) Tier III) which may result in an unfeasible investment.
- To make meaningful inroads into emission reduction using hybrid systems, the solution would normally include a battery bank. This requirement, however, adds significant weight and space claim making retrofit a challenging prospect. Physical space is typically at a premium and additional weight can unsafely impact stability and seakeeping of the vessel.

Owing to these barriers, hybrid dive systems are better suited to new build vessels and whilst they may come with a CAPEX premium, the OPEX benefits and fringe environmental benefits may balance the business case for a commercial operator.

In the recreational space, the decision to adopt hybrid will likely be driven by cost (primarily) and by owners' motivation to improve their environmental impact. Again because of the space and weight impost, integrating this technology into new-build vessels is more achievable than a retrofit approach.

Emerging electro-hybrid technologies are still in infancy and need further development and commercialization to bring to market. These also hold the need for alternative fuels and new equipment to convert the fuels into energy (i.e. Hydrogen fuel cells and on-demand hydrogen generators).

Maritime Decarbonisation Technology Summary Sheet

Technology: **Electrification**

Applicable Sector: Commercial and Recreational

Technology Group: Electrical Energy

Technology Theme: Alternative Fuel

TECHNOLOGY SUMMARY

Electrification in the maritime sector refers to use of a main propulsion system powered by electricity. Electrified vessels can be achieved by retrofitting, but there is a growing selection of turnkey electric vessels available to the consumer.

An electric drive system consists of an electric motor coupled to the drive shaft, an energy storage system, charger and control electronics. The form of the electric motor depends on the vessel type, but these can be outboard-equivalent, or inboard connected to a traditional drive shaft, stern leg, jet unit or sail drive. There are emerging electric drive technologies, such a as Sealence's (Italy) Deepspeed, that exploit the rim-drive motor arrangement and pioneering hydrodynamics to improve propulsive efficiency over traditional drive arrangements.

Electric vessels can be of a trailerable size where they can be charged from a domestic power supply or from the automotive charging network (with compatible onboard systems). Otherwise, they will need to be charged from dock-side infrastructure such as in a marina. Components are readily available from the automotive market to be modified and applied in the marine sector, if not purposefully developed for the marine market.

Key benefits of electrification over traditional propulsion methods are:

- Reduced operational emissions
- Reduced noise and vibration
- Reduced maintenance
- Higher motor efficiency for propulsion
- Low power requirements for manoeuvring
- High torque at low rpm

Electrification of the drive line opens the opportunity to hybridise and use stored electricity in combination with other decarbonisation technologies, such as Hydrogen fuel cells as a source of supplementary power or foiling technologies to reduce drag. The use of a hybrid system with electrification allows for range extending and a single combined power system, for propulsive and onboard demands, simplifying the vessel machinery.

When purpose designed, electric vessels can overcome some of the limitations and compromises that are required to achieve retrofit electrification and even exploit additional technologies to optimise performance. Some examples of commercially available electric recreational vessels include:

Boats	Personal Watercraft (PWC) a.k.a Jet Ski
Zerojet (New Zealand) Candela Electric Hydrofoil Boats (Sweden) X-Shore (Sweden) Arc Boats (USA)	Taiga – Orca (Canada) Narke - GT45 Electrojet (Hungary) SeaDoo - E-GTI (Canada)

Maritime Decarbonisation Technology Summary Sheet

Technology: **Electrification**

Applicable Sector: Commercial and Recreational

Technology Group: Electrical Energy

Technology Theme: Alternative Fuel

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

Use Case for Analysis	Medium Petrol Powered Boat Outboard engine Retrofit 50hrs p.a., 12L/hr consumption		Medium Petrol Powered Boat Inboard engine Retrofit 50hrs p.a., 12L/hr consumption	
State of Play Data	This vessel class makes up 60.9% of the emissions in the recreational sector with approximately 180,000 vessels in New Zealand consuming around 108 million litres of petrol per annum.			
Example of Application	Evoy (Norway) offers electric outboard motor systems that are high output. These are best suited for boats 18-25 foot for single unit installs and 25-35 foot for twin installs. The outboard motors are available as 120 through 400hp-equivalent Torqeedo (Germany) are a long-time market leader and provide electric outboard propulsion systems for kayaks, motorboats, sailboats, and commercial operators. Other players in the electric outboard market include: • EPTechnologies (Denmark) • Vision Marine Technologies (Canada) • E-marine (UAE) • Mercury (USA) • Aqua Watt (Austria) • Ecomar Propulsion (UK)		Naut, of Whangarei, have a proof-of-concept vessel on the water and functional technology demonstration of retrofit electric inboard drive.  Torqeedo (Germany) are a long-time market leader and provide electric inboard systems applicable to displacement sailing with heavy boats, planning with fast boats, sailing yachts and catamarans Other players in the electric inboard market include: • LTS Marine (Canada) • Zerojet (NZ) • Evoy (Norway)	
Readiness / Availability	CRI-5	Market competition Driving widespread development	CRI-5	Market competition Driving widespread development
CAPEX	$0-$0.5m	Cost of components and installation costs	$0-$0.5m	Cost of components and installation costs
OPEX	-20-0% Decrease	Lower cost of electricity vs. diesel	-20-0% Decrease	Lower cost of electricity vs. diesel
Carbon Impact	High 100%	Zero-emissions tank-to-wake	High 100%	Zero-emissions tank-to-wake

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Electrification**	Applicable Sector:	Commercial and Recreational
Technology Group:	Electrical Energy	Technology Theme:	Alternative Fuel

Sector Impact	37% emissions reduction **156,000 tCO_2e/yr**	Sector contributes 61% emissions. Assume technology is applicable to 60% of the sector as outboard powered vessels	24% emissions reduction **104,000 tCO_2e/yr**	Sector contributes 61% emissions. Assume technology is applicable to 40% of the sector as inboard powered vessels

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS CONT'D

Use Case for Analysis	Commercial jet boat Ferries sector from SOP New build 950hrs p.a., 70L/hr consumption	Personal Watercraft (PWC) a.k.a Jet Ski New build 20hrs p.a., 10L/hr consumption
State of Play Data	This class was disguised into the Ferries sector from state of play, so the specifics are not well known. Anecdotal evidence suggests that the major operators consume circa 500,000L of fuel per annum each.	PWC make up a sizable 21% of emissions from the recreational sector. There are approximately 93,000 PWC in New Zealand, consuming a combined 37.2 million litres of petrol fuel per annum.

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Electrification**	Applicable Sector:	Commercial and Recreational
Technology Group:	Electrical Energy	Technology Theme:	Alternative Fuel

<table>
<tr>
<td>Example of Application</td>
<td colspan="2">In 2019 EECA have funded $200K to assist in converting a Shotover (NZ) jet boat to electric drive.

The boat has a ~200kWh battery on board giving a run time of approx. 1hour and is intended to replace a petrol-powered boat.

</td>
<td colspan="2">Taiga (Canada) Orca Electric PWC

Orca can move through the water with up to 120kW peak power (160 hp) and a range of 45km.

Narke (Hungary) GT95 Electric Jet Ski

Within the body is a 24kWh battery pack powering an electric motor that can push out 95 hp. Top speeds reaching 43 mph. The battery itself can be fast charged in just 1.5 hours with a range of approx. 50km, or alternatively charged via a standard household socket for six hours.
</td>
</tr>
<tr>
<td>Readiness / Availability:</td>
<td>CRI-2</td>
<td>Commercial Trial, small scale</td>
<td>CRI-3</td>
<td>Commercial Scale Up</td>
</tr>
<tr>
<td>CAPEX</td>
<td>$0.5-$1m</td>
<td>Based on Shotover Jet’s funding of $200k for 36% of project costs</td>
<td>$0-$0.5m</td>
<td>Ranging $15,000 - $50,000</td>
</tr>
<tr>
<td>OPEX</td>
<td>-20-0% Decrease</td>
<td>Lower cost of electricity vs. diesel</td>
<td>-20-0% Decrease</td>
<td>Lower cost of electricity vs. diesel</td>
</tr>
<tr>
<td>Carbon Impact</td>
<td>High
100%</td>
<td>Zero-emissions tank-to-wake</td>
<td>High
100%</td>
<td>Zero-emissions tank-to-wake</td>
</tr>
<tr>
<td>Sector Impact</td>
<td>3.4% emissions reduction

12,750 tCO_2e/yr</td>
<td>It is difficult to ascertain the emissions contribution from these vessels as they are not specifically capture in data. Assume they make up 5% of the ferries category which contributes 67.6% emissions.</td>
<td>10.5% emissions reduction

45,000 tCO_2e/yr</td>
<td>Sector contributes 21% emissions. Assume swap-out rate of 50%.</td>
</tr>
</table>

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Electrification**	Applicable Sector:	Commercial and Recreational
Technology Group:	Electrical Energy	Technology Theme:	Alternative Fuel

BARRIERS AND CHALLENGES

Although there has been significant development in marine electric drive systems, there are still some key challenges surrounding their implementation and uptake on a wider scale, including:

- Limited power density, contributing to reduced range
- Poor power: weight ratio meaning heavier boats requiring more power to move
- Additional weight and distribution affecting the hydrodynamics of the vessel
- Fitting bulky hardware into existing voids and structure
- Lack of suitable charging infrastructure dockside and in marinas
- Lack of suitable power availability at marinas and docks to implement charging
- Cost of equipment, particularly batteries, when compared to incumbent technologies
- Battery life and swap-out period plus end-of-life disposal concerns
- Up-skilling training of engineers and technicians to operate and service systems

To retrofit bulky electric systems to an existing boat whilst maintaining the structural integrity, hydrodynamic performance and stability requires careful design and execution, not all boats will be viable for this process and careful donor vessel selection is required.

Marinised batteries are behind the automotive sector in terms of energy density. Nickel Cobalt Aluminium Lithium-ion batteries (NCA) are the automotive industry standard offering superior power density over the lithium-Iron-Phosphate ($LiFePO_4$ or LFP) batteries commonly used in the marine industry due to reduced fire risk. The Naut proof-of-concept vessel shows these power limitations, being able to support only 3-4 hours of general usage.

Dockside power supplies from the grid that can support the high-power demand are required for widespread adoption. In Wellington, the East-by-West electric ferry, Ika Rere, is currently limited by the power supply to its dockside charger. EV Maritime and Electric Wave are addressing this issue with the use of additional battery banks that can trickle charge over a long time and “dump-charge” into the boat in a short time, thus lowering the grid demand. There is a significant additional capital cost associated with these systems on top of the lost efficiency as batteries are charged/discharged twice within the system.

EV Maritime (New Zealand) have also considered a complimentary approach by conducting extensive modelling around their operation and ferry schedule to ensure that the vessels can receive small top-up charges at transfers and longer charges at breaks throughout the day. This approach can be expanded to look more holistically at grid-demand from electric vessels.

Standardisation and compatibility of infrastructure is also critical to the success of commercial operations such that they can share the charging points and the cost of shore-side infrastructure. Regulations must be developed and agreed between operators to ensure compatibility of charging parameters (voltage and current), connection types and communication protocols. This is ongoing work in New Zealand, with several stakeholders engaged.

In New Zealand the regulatory environment considering the design and build of electric vessels is rapidly changing, driven by Maritime New Zealand. The uncertainty surrounding regulation makes it difficult for companies to create compliant designs. The ambiguity can result in rework, additional time and resources redesigning to ensure that regulations are met and the potential cost to re-procure equipment.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Electrification**

Applicable Sector: Commercial and Recreational

Technology Group: Electrical Energy

Technology Theme: Alternative Fuel

Cost will remain a significant barrier for electric vessels until the cost of components is driven down in the international supply chain. This will be most prevalent in the recreational market, but commercial operators may be better placed to offset the capital costs with the right business case for water-taxi/ferry service or tourism venture, with a craft like the Candela (USA) P-8 Voyager.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hydro Foil** Applicable Sector: Commercial and Recreational

Technology Group: Appendages Technology Theme: Reduce Consumption

TECHNOLOGY SUMMARY

Hydrofoils are wing-like underwater structures mounted to the underside of a mono-hull vessel, or between the hulls of a multi-hull vessel, which generate lift and reduce the displaced volume of the vessel when underway at speed. Hydro-foiling vessels fall into two groups; full-foiling where the vessel is lifted clear of the water and assisted-foiling (displacement-foiling) where a portion of the vessel weight is supported by the foils, but the hull is still in the water. In both cases, the surface area in contact with the water, and the displaced volume significantly reduces, causing a resultant reduction in drag.

The primary advantage of foiling vessels is the reduction in fuel consumption, or increased speed because of the reduction in total resistance. There is a significant secondary advantage in the improved seakeeping of the foiling vessel which is less affected by the prevailing sea state and has dampened heave and pitch motions which contribute to improved passenger comfort and safety.

Full foiling vessels are prominent and eye-catching on the water, but there are many assisted-foiling applications that go un-noticed due to their under-the-water nature. In the recreational sector, Tauranga based Voodoo Yachts and the Chinese Aquila Yachts are pioneering the commercialisation of assisted-foiling catamaran vessels, with both pitching the advantages in drag reduction, increased range, reduced fuel consumption and increased passenger comfort. In the commercial space, these same characteristics have long been exploited by designers of high-speed catamaran ferries, patrol boats, workboats and other vessels including a significant number of vessels designed, built, and used in New Zealand already.

It is difficult to imagine large oceangoing freighters, container ships and fishing vessels being foil-assisted but Hull Vane B.V. (The Netherlands) have developed a retrofittable hydrofoil product that provides efficiency gains by modifying the wake and hull wave profiles of the ship. Wavefoil (Norway) are developing a technology that will help propel a ship using energy from its motion in waves. Both companies target the large ocean-going vessel market and design and engineer the foiling system to suit the unique vessel and operating parameters.

Whilst best suited to new design applications due to the inter-relation of the hull, power train and foil parameters, retrofitting hydrofoils to boats can be seen as a viable technology, however the advantages when compared with new-design solutions will be reduced. The costs associated with retrofitting make it less viable for recreational use.

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

Use Case for Analysis	Ferries – specifically catamaran hulls 4000hrs p.a., 180l/hr consumption	Ocean Going Vessels 6960 hrs p.a., 1715l/hr consumption
State of Play Data	Against these use cases, these is possibility to apply this technology to a small segment of the commercial sector. 11% from ocean going vessels and an unknown proportion of ferries. Unfortunately, not all vessels in the ferry category are multi-hulled vessels which will directly eliminate them. In the recreational segment the diesel launches segment will be the most applicable, but there are an even smaller number of vessels in this category that would be viable for retrofit.	

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Hydro Foil**	Applicable Sector:	Commercial and Recreational
Technology Group:	Appendages	Technology Theme:	Reduce Consumption

<table>
<tr><td>Example of Application</td><td colspan="2">Auckland based Teknicraft Design have been pioneering foiling displacement foiling for several years. They have designed numerous assisted-foiling catamaran vessels operating in New Zealand and abroad. These include Whale Watch Kaikoura and White Island Tours (shown below).

Whilst the exact foil size, positioning and installation varies between vessels, the foils span the hulls as shown below and can be designed with, or without, rear stabiliser foils.
</td><td colspan="2">Hull Vane BV (The Netherlands) provides assisted-foil solutions such as the custom, semi-custom and dynamic hull vane for commercial, naval, and superyacht vessels.
An application of a retrofit Hull Vane was for the 57m Guard vessel, Linde-G, shown below.

The TT shaped Hull Vane was installed in 2019 and resulted in 10-15% lower fuel consumption (Hull Vane, 2022)</td></tr>
<tr><td>Readiness / Availability</td><td>CRI-5</td><td>Market competition Driving widespread development</td><td>CRI-4</td><td>Multiple commercial applications</td></tr>
<tr><td>CAPEX range</td><td>$0-$0.5m</td><td>Non-recurring Engineering costs, fabrication and installation of retrofitted foil</td><td>$0.5-$1m</td><td>Non-recurring Engineering costs, fabrication and installation of retrofitted foil</td></tr>
<tr><td>OPEX range</td><td>-20-0% Decrease</td><td>Reduced fuel consumption by improved efficiency as quoted by OEMs</td><td>-20-0% Decrease</td><td>Reduced fuel consumption by improved efficiency as quoted by OEMs</td></tr>
<tr><td>Carbon Impact</td><td>Medium 10-15%</td><td>Add-on technology to reduce emissions</td><td>Medium 10-15%</td><td>Add-on technology to reduce emissions</td></tr>
</table>

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hydro Foil**

Technology Group: Appendages

Applicable Sector: Commercial and Recreational

Technology Theme: Reduce Consumption

Sector Impact	2.7-4.1% emissions reduction **20,400-30,600 tCO_2e/yr**	Sector contributes 67.6% emissions. Assume technology is applicable to 40% of the sector as suitable catamaran vessels	0.4-0.5% emissions reduction **2,500-3,750 tCO_2e/yr**	Sector contributes 7.2% emissions; this technology does not work at berth. Assume technology uptake 50% of the sector

BARRIERS AND CHALLENGES

The barriers to wide-spread adoption vary between full foiling and assisted-foiling vessels and whether they are being implemented as new build or retrofit solutions but include:

- preference to design the foil package as part of the initial vessel design, making retrofit more challenging
- reluctance of designer to take on the risk of retrofit to other designer's vessels
- non-recurring Engineering (NRE) costs that need to be "sunk" to establish if retrofit is possible
- the suitability of the operating parameters and physical characteristics of the vessel (i.e. beam, length, displacement, cruising and maximum speed)
- Cost and control challenges associated with active-control foils

It is technically challenging to retrofit full-foiling hydrofoils to an existing vessel due to the knock-on impacts to the drive train, controls systems and structural requirements. The reality is most existing vessels are inherently too heavy to be considered for full-foiling applications.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Shore Power**

Applicable Sector: Commercial

Technology Group: Dockside Infrastructure

Technology Theme: Alternative Fuel

TECHNOLOGY SUMMARY

Commercial vessels generate electrical power using onboard auxiliary diesel generators to provide power for the installed industrial load as well as the domestic load. Once berthed in port, ships must sustain the power supplies to the ships systems and cargo handling equipment using these same ship's generators consuming fossil fuel. This results in emissions including SO_X, NO_X and particulate matter (PM) being discharged into local urban centres.

In many "Smart Port" cities around the world the ability to transfer a ship's load to a shore supplied power source and shut down the ship's generators reduces the local particulate pollution. In New Zealand, the shore power supply is largely generated from renewable sources therefore, realising an equally significant reduction in CO_2 emissions.

A shore power (SP) system consists of three sub-systems as illustrated in Figure 1 below.

1. a shore-side power supply system – located at a port or terminal, receives electricity from the local power grid and converts the electricity to voltages and frequency suitable for the ship.
2. a shore-ship connecting system – consists of cables joining the onshore power supply interface to the power receiving interface onboard.
3. a ship-borne breaker and switchboard receiving system – receives the shore power and distributes it to the ships power network.

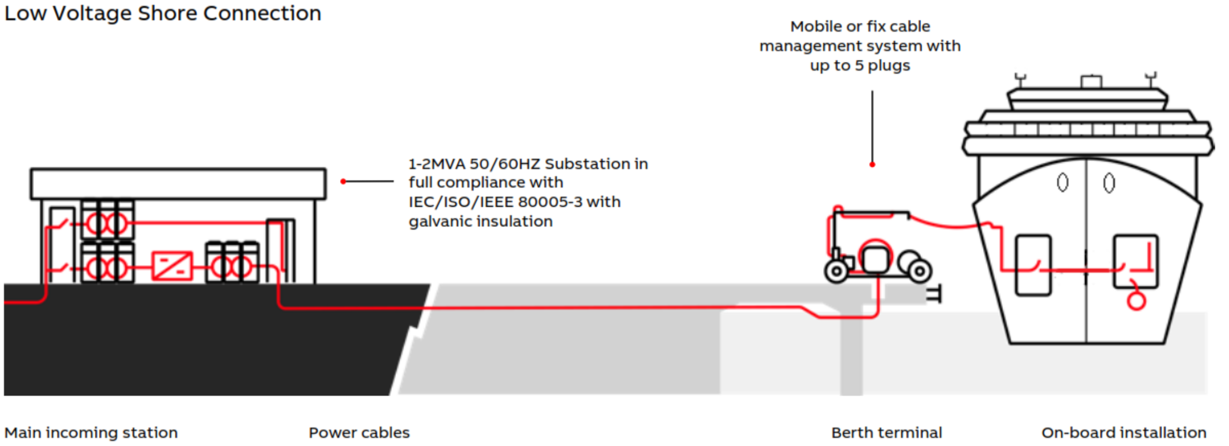


FIGURE 1 SHORE POWER CONNECTION ARRANGEMENT

Power electronics technology is proven, and deployed technology used to convert the incoming power (from the grid) to a voltage and frequency acceptable to a visiting ship and, importantly, able to vary these characteristics according to the exact requirements of each visiting ship. This technology is available from several suppliers including ABB.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Shore Power**

Applicable Sector: Commercial

Technology Group: Dockside Infrastructure

Technology Theme: Alternative Fuel

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

Use Case for Analysis		Commercial Fishing Boats Specifically a 4000 tonne Freezer Trawler in a “Home/base-port facility” 7800hrs p.a., 595l/hr consumption
State of Play Data		Commercial fishing boats represent a 12.7% share of emissions from the commercial sector and spend a reasonable time docked to offload catch.
Example of Application		Ports worldwide have successfully implemented this technology to drive down emissions from berthed ships, especially in cities with poor average air quality. The EU have EU recommendation 2006/339/EC, *« (…) urged port authorities to require, incentivise or facilitate ships' use of land-based electricity while in port »* has resulted in Denmark, Sweden and Spain being able to charge reduced tax on electricity provided to vessels at berth in a port.
Readiness / Availability	CRI - 6	Bankable Asset Class
CAPEX	$0.5- $1m	For shore-side power conversion and control system (at 750 kVA) including modifications to the vessel switchboard. Based on estimates from technology providers costs of shore side supply and frequency conversion technology in the order of $750k. If the shore power can provide more than one vessel the shore infrastructure costs and benefits can be pro-rated across multiple vessels.
OPEX	-20-0% Decrease	Reduced fuel consumption and maintenance costs. lower cost of electricity vs diesel fuel to generate onboard.
Carbon Impact	Medium 10-25%	Reduction of 120 t CO_2 per year per vessel The longer vessels spend on shore power docked, the greater the benefit.
Sector Impact	1.3-3.2% emissions reduction	Sector contributes 12.7% emissions. Assume technology is operable for applicable to 10% of the vessel's annual usage – only while docked

BARRIERS AND CHALLENGES

Barriers and technical challenges associated with implementing shore supply infrastructure include:

- Grid capacity limitations local to the port, can be mitigated with local onsite micro power plant
- Additional transmission lines (incomers) may need to be to run/reroute to the port facility
- Real estate/building in which to establish port power conversion infrastructure and control center will be required
- The need to also invest in (shore power) cable management system for ships with high demand
- The need to modify existing ships to take the higher shore power loads (breakers and shore power switchboard)
- The willingness of ships' crew to utilise the system if provided may be tested. The manual handling of shore power cables will require time and effort and ships' Masters will need to be committed to utilising it. Company policy and crew education will be a crucial aspect of the transition to this type of technology.
- Costs associated with establishing the shore side infrastructure and (for existing ships) the modification of the shore power switchboard, reception facility and control (synchronisation) circuit.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Biodiesel**

Applicable Sector: Commercial and Recreational

Technology Group: Carbon Based Primary Fuel

Technology Theme: Alternative Fuel

TECHNOLOGY SUMMARY

Fatty Acid Methyl Ester (FAME) biodiesel has potential as an alternative marine fuel but is limited to 7% blend, due to poor cold water performance and required engine modifications and approvals for higher percentage blends. B15 was selected for the analysis to represent the variety of blends commonly available (5%, 7%, 20%), weighted to the higher end where the most benefit is available.

In New Zealand, Z Energy supply Z Bio D, a B5 (5% blend) biodiesel targeted to the on-road commercial sector. This fuel is classified as ordinary diesel under the New Zealand fuel specifications meaning it can be used directly in existing fleet engines.

In the maritime sector, Go Fuel are the largest fuel supplier but do not currently have a biodiesel offering. However, they do supply Mobil Diesel Efficient an advanced formulation mineral diesel which offers an average of 22% reduction in particulates matter, 10% NO_X, and 2.8% CO_2.

Hydrotreated Vegetable Oil (HVO) green diesels are similar in composition to fossil diesel and overcome most of the limitations of FAME biodiesel. It can be used in diesel engines without blend walls or the modifications required for FAME biodiesel. Cold water applications can be achieved to as low as -20°C and HVO has no issues with stability, water separation, microbiological growth or impurities causing precipitation above cloud point.

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

<table>
<tr><td>Use Case for Analysis</td><td colspan="2">Ferries
4000hrs p.a., 180l/hr consumption</td><td colspan="2">Commercial Fishing Boats
7800hrs p.a., 595l/hr consumption</td></tr>
<tr><td>State of Play Data</td><td colspan="4">Together, Ferries and Commercial Fishing Vessels represent 80.3% of commercial vessel emissions in New Zealand. Both groups are high volume consumers of diesel fuel.</td></tr>
<tr><td>Example of Application</td><td colspan="4">Whilst not in this use case class:
In 2021, BP and Maersk successfully completed a 2-week trial of B30, 30% biodiesel blended with very low sulphur fuel oil in two product tankers (BP, Maersk Tankers complete marine biofuel trial of 30% biodiesel in 2 vessels, 2022)
In 2017, Port of Amsterdam operate its fleet of five patrol vessels on B30 Marine biodiesel supplied by GoodFuels Marine. Today the port is converting its patrol vessel fleet to run on 100% biodiesel</td></tr>
<tr><td>Readiness / Availability</td><td>CRI-3</td><td>Commercial Scale Up</td><td>CRI-3</td><td>Commercial Scale Up</td></tr>
<tr><td>CAPEX</td><td>$0-$0.5m</td><td>Potential engine modifications required</td><td>$0-$0.5m</td><td>Potential engine modifications required</td></tr>
<tr><td>OPEX</td><td>0-20% Increase</td><td>Increased cost of the fuel and more burnt due to lower energy density</td><td>0-20% Increase</td><td>Increased cost of the fuel and more burnt due to lower energy density</td></tr>
<tr><td>Carbon Impact</td><td>Low
0-15%</td><td>Tank-to-wake is low emissions reduction</td><td>Low
0-15%</td><td>Tank-to-wake is low emissions reduction</td></tr>
</table>

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Biodiesel**	Applicable Sector:	Commercial and Recreational
Technology Group:	Carbon Based Primary Fuel	Technology Theme:	Alternative Fuel

Sector Impact	0-10.1% emissions reduction **510,000 tCO_2e/yr**	Sector contributes 67.6% emissions. Assume technology is applicable to 100% of the sector	0-1.9% emissions reduction **100,000 tCO_2e/yr**	Sector contributes 12.7% emissions. Assume technology is applicable to 100% of the sector

BARRIERS AND CHALLENGES

The main barriers for the use of biodiesel include:

- increased cost to consumer
- lack of suitable supply infrastructure
- engine conversion costs, as required for higher blend ratios
- physical limitations of the fuel itself

In New Zealand, infrastructure for the supply and distribution of biodiesel fuels to the marine sector is challenging. Z Energy's biodiesel supply is focused on the road-based heavy transport sector and all supplies are inland. New Zealand domestic production of Biodiesel does not exist following the hibernation of Z Energy's Wiri biodiesel plant in 2020, meaning all biodiesel consumed in NZ is imported. Scope exists to increase domestic production or increase imports with the Sustainable Biofuels Mandate taking effect from April 1, 2023.

Go Fuel are the biggest marina-based fuel supplier in the country but have no biodiesel distribution infrastructure immediately available in the marine sector, though they confirm this will change as the industry moves to align with government mandate. Most marine vessels fueled by diesel that are candidates for biodiesel alternatives are large and permanently afloat meaning they need a marina-based fuel supply.

There are other physical limitations for widespread biodiesel uptake in maritime transport, including:

- Biodiesel has a lower energy density than regular diesel and therefore more fuel needs to be consumed for the same output power. Despite this, overall emissions reductions are still seen albeit at the cost of vessel voyage range.
- Biodiesel has a short storage life, due to its tendency to oxidation, so it is recommended that the fuel is purchased only before use and not stored for long periods of time
- Biodiesel has an affinity to water and as such a greater risk of microbial growth which requires increased fuel management practices to combat and increased maintenance if contamination gets out of control. Microbial growth has the potential to cause significant engine damage and fuel starvation that could pose a safety issue if at sea.
- Biodiesel has degraded low-temperature flow properties and is prone to gelling and solidifying without the use of additives or secondary heating. Feedstock choice influences the cold filter plugging point (CFPP) temperature of 100% biodiesel, which sits around 16°C for beef tallow, 13°C for palm oil and -10°C for low erucic acid varieties of canola seed feedstocks. These factors will limit biodiesel's application to regions with stable temperatures sitting above these limits.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Biodiesel**

Applicable Sector: Commercial and Recreational

Technology Group: Carbon Based Primary Fuel

Technology Theme: Alternative Fuel

Whilst HVO renewable diesel overcomes the issues associated with FAME biodiesel, there is limited supply to land transport in New Zealand and most HVO is blended with fossil diesel to comply with fuel standards thereby reducing its impact on emissions reduction.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hull Coatings**
Applicable Sector: Commercial and Recreational
Technology Group: Coatings
Technology Theme: Reduce Consumption

TECHNOLOGY SUMMARY

Hull coatings are antifouling paints that are applied to ship and boat hulls below the water line to restrict the biological growth that occurs naturally. When fouling builds up on a vessel's hull, it increases the vessel's hydrodynamic resistance, meaning more fuel is required to move the ship through the water, driving up GHG emissions (in fossil fuelled vessels). A study by Marintek (Turkey) on an international vehicle carrier ship estimated that fouling increases fuel consumption and emissions on an average vessel by around 15 per cent over a 60-month period.

Hull coatings are applicable to all vessel types and ages, although application to trailerable boats and Personal Watercraft (PWC) is not common due to their lack of prolonged time in the water.

Implementation of this technology is relatively straightforward and well known to operators as they will already be applying a hull coating. The application can be achieved during planned haul-out and docking periods when the hull will be cleaned, and the coating replaced or repaired under a general planned maintenance regime.

The emissions reduction associated with the application of advanced hull coatings is difficult to measure, but is possible when applying high end products, in combination with good hull condition monitoring and maintenance. Testing of silicone based and self-polishing types of coatings on commercial ships and laboratories have shown that high end products are able to reduce the overall ship's resistance by up to 8%. The reduction potential is dependent on vessel size, segment, operation profile and geo-location and is in the range of 1% to 4% on main engine fuel consumption (Hull coating: GreenVoyage2050, 2022).

An additional environmental benefit from the use of advanced hull coatings comes in the reduction of the spread of invasive species. This is particularly noted for the NZ environment where we have strict biosecurity measures in place to manage biofouling and invasive aquatic species on vessels and movable structures.

Complimentary to hull coatings, there are high-performing coatings available for niche areas and control surfaces which offer measurable efficiency improvements. Propspeed, a New Zealand company, market a product that is specifically designed for running gear surfaces. It is a silicone-based product that offers 4-8% fuel savings per application and is widely used throughout the international maritime industry. It has been applied to niche areas such as sea chests and underwater cooler boxes, but due to the soft nature of the product, it is not suitable for full hull applications.

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

Use Case for Analysis	Ferries 4000hrs p.a., 180l/hr consumption	Commercial Fishing Boats 7800hrs p.a., 595l/hr consumption
State of Play Data	Together, Ferries and Commercial Fishing Vessels represent 80.3% of commercial vessel emissions in New Zealand. Both groups are high running hours operators of vessels always at sea.	

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hull Coatings**
Applicable Sector: Commercial and Recreational
Technology Group: Coatings
Technology Theme: Reduce Consumption

Example of Application	All ferries will use a foul-release hull coating. The image below shows Ika Rere (Wellington, NZ) being launched, the hull coating visible as a dull red colour.  		All fishing vessels will use a foul release hull coating as evident in this image of an Ocean Fisheries vessel which also shows the unique gold coating of Propspeed on the propeller. 	
Readiness / Availability	CRI-6	Bankable Asset Class	CRI-6	Bankable Asset Class
CAPEX range	$0-$0.5m	One-off application costs through previous coating removal and surface preparation. Labour is dominant factor in install cost.	$0-$0.5m	One-off application costs through previous coating removal and surface preparation. Labour is dominant factor in install cost.
OPEX range	-20-0% Reduction	Driven by expected fuel reduction offsetting the slightly elevate coating costs. Manual cleaning should be considered if idle time limits are exceeded	-20-0% Reduction	Driven by expected fuel reduction offsetting the slightly elevate coating costs. Manual cleaning should be considered if idle time limits are exceeded
Carbon Impact	Low 0-4%	Optimises the incumbent hull coatings technologies	Low 0-4%	Optimises the incumbent hull coatings technologies
Sector Impact	0-2.7% emissions reduction **0-20,400 tCO_2e/yr**	Sector contributes 67.6% emissions. Assume technology is applicable to 100% of the sector	0-0.5% emissions reduction **0- 4,000 tCO_2e/yr**	Sector contributes 12.7% emissions. Assume technology is applicable to 100% of the sector

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hull Coatings**

Applicable Sector: Commercial and Recreational

Technology Group: Coatings

Technology Theme: Reduce Consumption

BARRIERS AND CHALLENGES

Given that most vessels in the world use a hull coating already and operators are well-versed in the requirements of application, the barriers and challenges for this technology should be minimal to non-existent. However, as with any advanced technology there are inevitable barriers to overcome.

The advanced coating technologies that exhibit the best performance in terms of drag reductions, resulting in lower consumption and fuel-burn emissions are inherently expensive. For commercial ships, this cost can be justified as an offset to fuel costs and the ROI period will be short with higher vessel usage. This may be more of an obstacle for recreation vessel operators.

Idle time also plays a part in the ongoing costs and cost-benefit. Coatings are self-cleaning with regular use and water motion over the hull but require manual cleaning if the idle time is exceeded. Manual cleaning costs can be significant for a commercial vessel employing divers, whereas recreational vessel owners may clean themselves.

Labour cost is the biggest component of application costs, especially if the old coating needs to be completely stripped from the hull before the new advanced coating is applied. Additionally, some coatings need to be applied by specially trained personnel, meaning higher associated costs.

Longevity of coatings should be considered for some vessels where they are hauled out or trailered regularly. Advanced coating systems are typically silicone based and as a result are very soft materials that are easily damaged by lifting strops, trailer skids or rollers. These applications benefit from the hardness of more traditional coating systems but of course loose the additional bio-shedding benefits.

Education will be important, especially in the recreational sector, to change the mindset about advanced hull coatings. Firstly, to illustrate that even the low absolute benefits (up to 4%) can equate to large emissions reductions over the course of a year and the typical 5-year lifecycle of the coating. Secondly to dispel doubts and skepticism of advanced hull coating technologies and encourage departure from the tried-and-trusted technologies of the past.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hydrogen Fuel**

Applicable Sector: Commercial

Technology Group: Energy Storage/Conversion

Technology Theme: Alternative Fuel

TECHNOLOGY SUMMARY

For the purposes of this study, we are considering the use of green hydrogen only. Hydrogen can be used in the maritime sector as a fuel to power either Hydrogen Fuel Cells or Internal Combustion Engines (ICE).

Hydrogen Fuel Cells

Although not mass produced, fuel cells are available for use in the marine context. The power demands for marine power systems typically range from a few kW to tens of MW. Currently, the maximum power output of a fuel cell module is only several MW, however, fuel cells can be stacked to create fuel cell power systems that accommodate onboard power demands.

Fuels cells have low reactivity to adjust their output power and should be combined with a battery bank to absorb the power surges associated with propulsion and manoeuvring. Steady power demands such as supporting onboard domestic power requirements are preferred applications.

A key benefit of the fuel cell is that it presents no moving parts resulting in fewer failure points and, therefore reduced maintenance. However, the emerging nature of hydrogen fuel cells and the lack of prominence of systems on the market, can result in expensive repairs and maintenance.

Some examples of current commercially available technologies include:

- Ballard Power Systems' (Canada) Marine Center: FCwave fuel cell module is the world's first marine type approved (DNV) fuel cell power module. It offers 200kW power and can be stacked to provide a solution in a broad range of marine applications
- Cummins (USA) offer marinized fuel cells. The SeaChange ferry, discussed in the use case, is powered by 360kW fuel cell system by Cummins.
- Genevos (France) offer a range of offshore-certified (Lloyds Register) Hydrogen power modules that are stackable to accommodate 15kW to multi-MW power solutions.

Although the fuel cell presents more upfront capital expense, it offers greater efficiency over a hydrogen ICE. ICEs convert energy multiple times, whereas fuel cells directly convert the chemical energy in hydrogen to electricity, thereby offering greater efficiency. (Laporte, 2015)

Hydrogen as an ICE fuel

A hydrogen ICE uses the conventional principles of an internal combustion engine with hydrogen used as fuel instead of gasoline. The combustion of hydrogen and oxygen results in water and some NOx as a by-product.

It is possible to adapt existing engines to run on hydrogen but, due to material incompatibilities, it is preferred to design and manufacture from scratch. Hydrogen-fuelled ICEs require modifications like; higher voltage ignition coil, stronger connecting rods and larger crankshaft damper, making Hydrogen ICEs comparatively more expensive to manufacture than traditional engines. Hydrogen ICEs still have many moving parts, falling behind fuel cells in this area.

However, traditional engine manufacturers including Cummins and Toyota are developing hydrogen ICEs and looking to adapt their manufacturing infrastructure to support this growing industry.

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hydrogen Fuel** Applicable Sector: Commercial

Technology Group: Energy Storage/Conversion Technology Theme: Alternative Fuel

COMMERCIAL & ENVIRONMENTAL CHARACTERISTICS

<table>
<tr><td>Use Case for Analysis</td><td colspan="2">Ferries
Hydrogen Fuel Cells

4000hrs p.a., 180l/hr consumption</td><td colspan="2">Ocean-Going Vessels
Hydrogen as an ICE Fuel

6960hrs p.a., 1715l/hr consumption</td></tr>
<tr><td>State of Play Data</td><td colspan="4">Application to these use case categories, could see reduction of up to 80% of commercial vessel emissions.</td></tr>
<tr><td>Example of Application</td><td colspan="2">The Sea Change is a 72-foot (approx. 22m), 75-passenger commercial zero emissions ferry. The vessel is of aluminium construction and powered by hydrogen fuel cells and batteries.

Sea Change launched in November 2021 and has been undergoing operational sea trials. It is expected be commercially operational in the San Francisco Bay Area in mid-late 2022, a date which has been flexible owing to the nature of the emerging technology. Final US Coast Guard (USCG) approval is still pending.

</td><td colspan="2">The Norwegian shipping company (Egil Ulvan Rederi), compatriot agricultural cooperative (Felleskjøpet AGRI), and German building materials company (HeidelbergCement) have received NOK 100 million ($11.3 million) in support from Norwegian government enterprise Enova to build the “world’s first zero-emission bulk carrier”. (Prevljak, 2022)

The cargo ship will be equipped with a hydrogen combustion engine, as well as a hydrogen fuel cell and battery, to ensure optimal operation during loading and unloading operations. (Prevljak, 2022)</td></tr>
<tr><td>Readiness / Availability</td><td>CRI-2</td><td>Commercial Trial, small scale</td><td>CRI-2</td><td>Commercial Trial, small scale</td></tr>
<tr><td>CAPEX range</td><td>Exceeding $1m</td><td>Fuel cells, storage tanks, plumbing and other equipment. Design and installation costs.

Little information available due to low CRI and absence of equipment suppliers in New Zealand.

Depends on the size and scale of the vessel being considered.</td><td>Exceeding $1m</td><td>Hydrogen ICE, storage tanks, plumbing and other equipment. Design and installation costs.

Little information available due to low CRI and absence of equipment suppliers in New Zealand.

Depends on the size and scale of the vessel being considered.</td></tr>
</table>

Maritime Decarbonisation Technology Summary Sheet

Technology: **Hydrogen Fuel** Applicable Sector: Commercial

Technology Group: Energy Storage/Conversion Technology Theme: Alternative Fuel

OPEX range	Exceed 20% Increase	Current cost of the fuel is high. Little information available due to low CRI and absence of equipment suppliers in New Zealand.	Exceed 20% Increase	Increased cost of fuel in addition to assumed increased maintenance costs. Little information available due to low CRI and absence of equipment suppliers in New Zealand.
Carbon Impact	High 100%	Tank-to-wake is emissions-free.	High 100%	Tank-to-wake is emissions-free.
Sector Impact	3.4% emissions reduction	Sector contributes 67.6% emissions. Assume technology uptake is 5% of the sector	0.6% emissions reduction	Sector contributes 11.4% emissions. Assume technology uptake is 5% of the sector

BARRIERS AND CHALLENGES

The main barrier and challenges of Hydrogen Fuel Cells and Hydrogen for ICE include:

- Cost and energy required to produce and store Hydrogen
- Cost to the consumer
- Safety and regulation around handling and use of Hydrogen
- Lack of infrastructure to transport, distribute and refuel Hydrogen.

One of the most crucial barriers to hydrogen adoption is storage. For inshore marine applications it is typically compressed but to achieve maximum energy density and reduced storage volume, it should be liquefied and stored cryogenically at -253°C which carries a cost, both in financial and energy terms.

Being the smallest element, hydrogen is tricky to contain and has material incompatibility concerns especially with stainless steels typically used in the marine environment. Careful material selection is required to prevent issues such as hydrogen embrittlement.

Using Ammonia as a hydrogen carrier overcomes issues of embrittlement and extreme cryogenic storage (only requiring -33°C), whilst also being more volumetrically dense. Ammonia is widely used around the world and gaining momentum as an alternative marine fuel, but supply constraints will be an issue in New Zealand. Ammonia is already used as a refrigerant here, but supply volumes will need to be increased to meet the demands of use as a fuel.

Cost is and will continue to be a significant barrier in the production and storage of hydrogen which is passed onto the consumer. The price of hydrogen compared to incumbent diesel can be as much as ten times which is unattractive to vessel owners (Zero Emissions Industry, 2021). As the technology and infrastructure matures, the cost will decline as we can see in California.

Safety is a big concern with hydrogen and due to its infancy, the regulatory environment is still developing worldwide bringing uncertainty in developing compliant designs. However, big classification societies such as Lloyds Register and DNV are starting to Approve in Principle (AiP) large ocean-going hydrogen fueled ships. Additionally, there is a lack of regulations for storage and distribution as a transport fuel in New Zealand.

Maritime Decarbonisation Technology Summary Sheet

Technology:	**Hydrogen Fuel**	Applicable Sector:	Commercial
Technology Group:	Energy Storage/Conversion	Technology Theme:	Alternative Fuel

Retrofit of hydrogen power technology is not a practical approach, especially in an aging fleet like New Zealand. The challenges associated with integration of hydrogen technology mean it is much better suited to new build vessels.

Appendix F – Sector Impact Calculations

EECA Maritime Decarbonisation - Sector Impact Calculations

Status: Issued
Date: 5/09/2022
Job Number: 2931169
By: BECA
Reviewed: Sarah Bacon
Approved: Phil Robson

Technology	Use Case	Operational Profile	CRI	CAPEX	OPEX	Carbon Impact	Sector Impact	% uptake for use case	State of Play Number of users	State of Play tCO2-e p.a.	Per vessel from SOP tCO2-e	Per vessel with carbon impact - Low Range tCO2-e	Per vessel with carbon impact - High Range tCO2-e	Assumptions
Propellor Optimisation	Recreational Medium Petrol Powered Boat Outboard engine	50hrs p.a., 12 l/hr	3	$0-$0.5m	-20-0% Reduction	Medium 9-15%	3.3-5.5% emissions reduction **14,040-23,400 tCO$_2$e/yr**	60	180000	260000	1.444	1.314	1.228	Base case - Assume petrol fuel only
	Commercial Ferries Inboard engine	4000hrs p.a., 180 l/hr	5	$0-$0.5m	-20-0% Reduction	Medium 10-15%	3.9-5.9% emissions reduction **40,800-61,200 tCO$_2$e/yr**	80	250	510000	2040	1836	1734	Assumed 250 vessesls in NZ
Hydrid Drive	Commercial Ferries – Serial Hybrid		6	Exceeding $1m Range $6-12m	-20-0% Reduction	High 70%	12.3% emissions reduction	N/A	N/A	N/A	Not Calculated	Not Calculated	Not Calculated	No calculated as agreed with EECA
	Commercial Ferries – Parallel Hybrid		6	Exceeding $1m Range $6-12m	-20-0% Reduction	Medium 15%	3.7% emissions reduction	N/A	N/A	N/A	Not Calculated	Not Calculated	Not Calculated	No calculated as agreed with EECA
Electrification	Recreational Medium Petrol Powered Boat Outboard engine Retrofit	50hrs p.a., 12 l/hr	5	$0-$0.5m	-20-0% Reduction	High 100%	37% emissions reduction **156,000 tCO$_2$e/yr**	60	180000	260000	1.444	0		200kWh extrapolated from X-Shore and Arc Boats offerings, 3-4 hours of operations
	Recreational Medium Petrol Powered Boat Inboard engine Retrofit	50hrs p.a., 12 l/hr	5	$0-$0.5m	-20-0% Reduction	High 100%	24% emissions reduction **104,000 tCO$_2$e/yr**	40	180000	260000	1.444	0		200kWh extrapolated from X-Shore and Arc Boats offerings, 3-4 hours of operations
	Commercial jet boat Ferries sector from SOP New build	950 hrs p.a., 200 kWh/hr	2	$0.5-$1m	-20-0% Reduction	High 100%	2.5% emissions reduction **12,750 tCO2e/yr**	50	50	25500	510	0		500000L of fuel p.a. per major operator Assume 50 jet boats operating in NZ
	Recreational Personal Watercraft (PWC) a.k.a Jet Ski New build	20hrs p.a., 11.5 kWh/hr	2	$0-$0.5m	-20-0% Reduction	High 100%	10.5% emissions reduction **45,000 tCO$_2$e/yr**	50	93000	90000	0.968	0		Use case -Narke GT95 23kWh will last 2 hours on water
Hydrofoil	Commercial Ferries – specifically catamaran hulls	4000hrs p.a., 180 l/hr (12.5% lower for hydrofoil)	5	0-$0.5m	-20-0% Decrease	Medium 10-15%	2.0-2.9% emissions reduction **20,400-30,600 tCO$_2$e/yr**	40	250	510000	2040	1836	1734	Assumed 250 vessesls in NZ
	Commercial Ocean Going Vessels	6960hrs p.a., 1715 l/hr (12.5% lower for hydrofoil)	4	$0.5-$1m	-20-0% Decrease	Medium 10-15%	0.3-0.4% emissions reduction **2,500-3,750 tCO$_2$e/yr**	50	18	50000	2778	2500	2361	Assumed 18 vessels in NZ
Shore Power	Commercial Fishing Boats		6	$0.5- $1m	-20-0% Decrease	Medium 10-25%	0.4-0.9% emissions reduction	N/A	N/A	N/A	Not Calculated	Not Calculated	Not Calculated	No calculated as agreed with EECA
Biodiesels	Commercial Ferries	4000hrs p.a., 180L/hr	3	$0-$0.5m	0-20% Increase	Low 0-15%	0-7.4% emissions reduction **0-76,500 tCO$_2$e/yr**	100	250	510000	2040	2040	1734	Base case - Assume biodiesel fuel only Emission Factor - Biofuels - Biodiesel B15 Calculated - 2.2865 Assumed 250 vessels in NZ
	Commercial Fishing Boats	7446hrs p.a., 550L/hr	3	$0-$0.5m	0-20% Increase	Low 0-15%	0-5.4% emissions reduction **0-56,250 tCO$_2$e/yr**	100	40	375000	9375	9375	7969	Base case - Assume biodiesel fuel only Emission Factor - Biofuels - Biodiesel B15 Calculated - 2.2865 Assumed 40 vessels in NZ
Hull Coating	Commercial Ferries	4000hrs p.a., 180L/hr	6	$0-$0.5m	-20-0% Reduction	Low 0-4%	0-2.0% emissions reduction **0-20,400 tCO$_2$e/yr**	100	250	510000	2040	2040	1958	Assumed 250 vessesls in NZ
	Commercial Fishing Boats	7446hrs p.a., 550L/hr	6	$0-$0.5m	-20-0% Reduction	Low 0-4%	0-1.4% emissions reduction **0- 15,000 tCO$_2$e/yr**	100	40	375000	9375	9375	9000	Assumed 40 vessesls in NZ
Hydrogen Fuel Cell	Commercial Ferries Hydrogen Fuel Cells		2	Exceeding $1m	Exceed 20% Increase	High 100%	2.5% emissions reduction	N/A	N/A	N/A	Not Calculated	Not Calculated	Not Calculated	No calculated as agreed with EECA
	Commercial Ocean-Going Vessels Hydrogen as an ICE Fuel		2	Exceeding $1m	Exceed 20% Increase	High 100%	0.4% emissions reduction	N/A	N/A	N/A	Not Calculated	Not Calculated	Not Calculated	No calculated as agreed with EECA

Appendix G – Technology Opportunities by Sector

Technology Opportunities – Commercial Sector

Vessel Type	Examples of Typical Use	Estimated Number of Vessels	Use Case Annual Usage (Hrs)	Use Case Fuel Consumption Rate (L/hr)	Estimated Annual Fuel Consumption (L)	tCO_2e p.a. (State of Play)	Technology	Carbon Impact Score	CRI	Sector Impact	OPEX	CAPEX
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Biodiesel (B15)**	Low	3	0-7.4% emissions reduction **0-76,500 tCO_2e/yr**	0-20% Increase	$0-$0.5m
Commercial Fishing Boat	Commercial Fishing	40	7446	550	163,812,000	375000*	**Biodiesel (B15)**	Low	3	0-5.4% emissions reduction **0-56,250 tCO_2e/yr**	0-20% Increase	$0-$0.5m
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Propellor Optimisation**	Medium	5	3.9-5.9% emissions reduction **40,800-61,200 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Hydrofoil (Catamaran Hull)**	Medium	5	2.0-2.9% emissions reduction **20,400-30,600 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Hull Coating**	Low	6	0-2.0% emissions reduction **0-20,400 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Commercial Jet Boat	Tourism operations	50	950	70	3,325,000	25500	**Electrification**	High	2	2.5% emissions reduction **12,750 tCO_2e/yr**	-20-0% Reduction	$0.5-$1m
Commercial Fishing Boat	Commercial Fishing	40	7446	550	163,812,000	375000*	**Hull Coating**	Low	6	0-1.4% emissions reduction **0- 4,000 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Commercial Ocean Going Vessel	Freight and coastal shipping	18	6960	1715	214,855,200	50000	**Hydrofoil**	Medium	4	0.3-0.4% emissions reduction **2,500-3,750 tCO_2e/yr**	-20-0% Reduction	$0.5-$1m
Commercial Fishing Boat	Commercial Fishing	40	7446	550	163,812,000	375000*	**Shore Power**	High	6	0.4-0.9% emissions reduction	-20-0% Reduction	$0.5- $1m
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Hybrid Drive - Parallel**	Medium	6	3.7% emissions reduction	-20-0% Reduction	Exceeding $1m Range $6-12m
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Hybrid Drive - Serial**	High	6	12.3% emissions reduction	-20-0% Reduction	Exceeding $1m Range $6-12m
Commercial Ferry	Passenger transport, Tourism operations	250	4000	180	180,000,000	510000	**Hydrogen Fuel Cell**	High	2	2.5% emissions reduction	Exceed 20% Increase	Exceeding $1m
Commercial Ocean-Going Vessel	Freight and coastal shipping	18	6960	1715	214,855,200	50000	**Hydrogen as an ICE Fuel**	High	2	0.4% emissions reduction	Exceed 20% Increase	Exceeding $1m

For detailed assumptions and calculations refer to Appendix E to Appendix F

* Carbon impact of Fishing Boats is updated from State of Play as a result of more reliable data coming available late in the project. Sector emissions has been assumed at 375,000 tCO_2e per annum with a typical Fishing Boat use case at 7446 hours per annum at a fuel consumption rate of 550L/hr.

Technology Opportunities – Recreational Sector

Vessel Type	Examples of Typical Use	Estimated Number of Vessels	Use Case Annual Usage (Hrs)	Use Case Fuel Consumption Rate (L/hr)	Estimated Annual Fuel Consumption (L)	tCO_2e p.a. (State of Play)	Technology	Carbon Impact Score	CRI	Sector Impact	OPEX	CAPEX
Recreational Medium Petrol Powered Boat (Outboard)	Recreational fishing, watersports, private transport	108000	50	12	64800000	156000	**Electrification**	High	5	37% emissions reduction **156,000 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Recreational Medium Petrol Powered Boat (Inboard)	Recreational fishing, watersports, private transport	72000	50	12	43200000	104000	**Electrification**	High	5	24% emissions reduction **104,000 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Recreational Personal Watercraft (PWC)	Recreational fishing, watersports, entertainment	93000	40	10	37200000	90000	**Electrification**	High	2	10.5% emissions reduction **45,000 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m
Recreational Medium Petrol Powered Boat (Outboard)	Recreational fishing, watersports, private transport	108000	50	12	64800000	156000	**Propellor Optimisation**	Medium	3	3.3-5.5% emissions reduction **14,040-23,400 tCO_2e/yr**	-20-0% Reduction	$0-$0.5m

For detailed assumptions and calculations refer to Appendix E to Appendix F

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Appendix I – References

Title	Author / Source	URL	Date Published / Accessed
Auckland Air Emissions Inventory 2016 Sea Transport	Auckland Council		July 2018
Measuring Emissions: A Guide for Organisations	MfE		Dec 2020
Off-road liquid fuels insights, Survey results and analysis	EECA		May 2021
Oil data monthly tables	MBIE		Nov 2021
Calculation of petrol used in recreational boats in NZ	NZ Marine		Sept 2018
Estimated Stock of Boats in New Zealand	NZ Marine		Dec 2021
NZ Greenhouse Gas Inventory 1990 – 2019	MfE		Oct 2021
Jet Ski registration numbers	Auckland Transport		Mar 2022
Tonnage of cargo by sea around New Zealand	Figure.nz		Mar 2022
Sharrow Engineering Propeller Product Review Video	YouTube - By BoatTEST.com	https://youtu.be/fO862lWuBdE	Oct 2019
Decarbonizing Maritime Transport: The Importance of Engine Technology and Regulations for LNG to Serve as a Transition Fuel	Elizabeth Lindstad, Gunnar S. Eskeland, Agathe Rialland and Anders Valland		Oct 2020
Biofuels for the marine shipping sector	IEA Bioenergy: Chia-wen Carmen Hsieh and Claus Felby		2017
Roadmap for the Decarbonisation of the European Recreational Marine Craft Sector	Carbon Trust - Olivia Burke		2021
Electric and Hybrid Marine EXPO	Multiple Conferences		2021
Decarbonization of Marine Fuels—The Future of Shipping	Jerzy Herdzik	https://doi.org/10.3390/en14144311	Jul 2021
2020 Recreational Boating Survey – Top-line Results	Ipsos (For Maritime NZ) - Jonathan Dodd		Jun 2020
NZ Marine News – Summer 2022	NZ Marine		Jan 2022
Biofuel Insights	Sapere (for EECA) Corina Comendant and Toby Stevenson		Mar 2021

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