Seafood Industry Australia
The Voice of Australian Seafood

FINAL REPORT

Climate Resilient Wild Catch Fisheries

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

Foreword

Our Pledge

We are the Australian seafood industry, and we are committed to putting the best Australian seafood on your table now and for generations to come.

To ensure we do this in ways we are all proud of, we promise to:

- Actively care for Australia's oceans and environment and work with others to do the same;
- Value our people, look after them and keep them safe;
- Respect the seafood we harvest and the wildlife we interact with;
- Be transparent and accountable for our actions;
- Engage with the community and listen to their concerns; and,
- Continually improve our practices.

This is our pledge to you.

To honour this pledge to the Australian public, the seafood industry has committed to completing this project to ensure that our fisheries are not only resilient to climate change, but also a driver of a cleaner, greener, and more sustainable industry.

This project is about finding and adopting emerging technologies that will allow our wild catch fishing fleet to run on cleaner, more renewable fuel sources. It will review the already existing technologies that are suitable for the industry now, and it will seek to assess whether there are any infrastructure gaps that need to be addressed by industry, the Government or the wider community.

The Australian seafood industry enjoys providing fish to customers around the globe. We recognise that our trading partners, and our overseas customers have a desire to source produce from clean and environmentally responsible industries. The project is designed to bring us a step closer to eliminating fossil fuels from our supply chain and meeting our customers' expectations.

We want to bring the people and businesses that make up our industry along with us and present them with better options for their business and for the planet.

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Glossary of Terms

Advanced Biofuels – are drop-in replacement fuels as they have chemical compatibility with their petroleum derived equivalents (e.g. petrol, diesel, kerosene) that are produced from biomass.

Alternative Fuels – The differences between Alternative and Future fuels lies in their current level of technical readiness, usage, and acceptance. Alternative fuels are already in use and have been adopted by some members of industry, while Future fuels are not yet fully developed, available or widely used.

B5 – a blend of diesel with 5% biodiesel.

B20 – a blend of diesel with 20% biodiesel.

Biodiesel – a fuel close in quality to petrodiesel, an example production pathway is using alcohols applied to the fatty acids from biomass to cause production of chemicals similar in nature to petro-diesel, although with an oxygen component which can limit its shelf-life.

Biomass – any organic matter, from plant, algae or animal origin (including waste), which can be used to produce energy.

Bu16 – a blend of petrol with 16% butanol.

Biomass to Liquid (BtL) or (BMtL)

Capex – capital expenditure.

Carbon Border Adjustment Mechanism – the term used to refer to the trade tariff that the EU has legislated to take effect from 2026 in order to adjust the price of imported goods to take into account the GHG emissions in their production and the difference between the EU ETS price and that country's carbon price.

Carbon Capture and Storage Systems – systems designed to capture carbon emissions from industrial processes and make that carbon available for sequestration or commercial use.

Carbon Dioxide Equivalent – a way of expressing any GHG emission in terms of the equivalent amount of carbon dioxide that would deliver the same greenhouse effects.

Carbon Leakage – is a type of spillover effect where producers of products with high GHG emissions choose to move production of those products from countries with strict GHG emissions regulations to ones with less strict regulations, and then importing them to the original countries.

CO_2 equivalent – total GHG emissions expressed as the equivalent amount of CO_2 emissions.

Cold Ironing – Allowing vessels to obtain sufficient power from shore power so they can replace the load normally handled by main engines and auxiliary generators and thus turn those off.

Common Rail – an electronic fuel injection architecture for diesel engines.

Compression Ignition – a type of ignition for Internal Combustion Engines in which the fuel is ignited by the elevated temperature of the air caused by the mechanical compression of the air in the cylinder.

Conventional Biofuels – are not drop-in replacement fuels but are relatively easy to produce from biomass.

Direct Air Capture – technologies that are designed to capture CO_2 from the air and make it available for sequestration or commercial use.

Drop-in Replacement Fuel – any fuel that could be used to replace another fuel without changing the engine or fuel system components.

E10 – a blend of petrol with 10% ethanol.

Electrofuel / e-Fuel – electrofuels, also known as e-fuels, are a type of drop-in replacement fuel. They are manufactured using captured carbon dioxide or carbon monoxide, together with hydrogen obtained from sustainable electricity sources such as wind, solar and nuclear power.

Electrolysers – Hydrogen electrolysers are devices that use electricity to split water molecules into hydrogen and oxygen, a process known as electrolysis. They consist of an anode and a cathode, separated by an ion-conducting membrane, and are typically powered by renewable energy sources, such as wind or solar power to produce Green Hydrogen.

e-Diesel – a synthetic diesel electrofuel which meets the same ASTM D975 and EN 15490 standards as petrodiesel.

Exhaust Aftertreatment and CO_2 Re-use – a way of treating exhaust emissions so that pollutants are removed from it, and the carbon monoxide/dioxide components are captured so the carbon can be re-used in other processes rather than released to the air.

Fuel Cells – a type of equipment that transforms liquid or gaseous fuel into electrical energy.

Future-fuels – The differences between Alternative and Future fuels lies in their current level of technical readiness, usage, and acceptance. Alternative fuels are already in use and have been adopted by some members of industry, while Future fuels are not yet fully developed, available or widely used.

Fossil Fuels – a group of energy-rich hydrocarbon compounds that are formed from the remains of ancient plants and animals. They are called “fossil fuels” because they are formed from the fossils of ancient life that have been subjected to heat and pressure over millions of years. The three main types of fossil fuels are coal, oil (petroleum), and natural gas (methane).

Genset – a generator set that brings together a fixed speed fuel-powered engine and an alternator/electric generator that creates electricity from liquid fuels.

Greenhouse Gas – a gas that absorbs and emits radiant energy within the thermal infrared range, causing a warming effect like that offered by a greenhouse as some of the light of the sun is not reflected, but instead radiated around as heat inside the Earth’s atmosphere (e.g. CO_2, SF_6, CH_4, NF_3, N_2O, HFCs, PFCs).

Homogeneous – a substance that has a consistent composition throughout its volume.

HVO100 – a term used in NSW for renewable diesel at 100% purity.

Hydrofluorocarbons – a group of synthetic gases primarily used for cooling and refrigeration that are potent greenhouse gases.

Iatrogenesis – negative effects that the exercise and institutionalization of modern medicine produce on people and society.

Immiscible – where two substances are not capable of combining to form a homogeneous mixture.

Opex – operating expenditure.

Paraffinic Diesel – another term for renewable diesel.

Perfluorochemicals – a group of chemicals are used within the electronic industry for production of semiconductors and for soundproofing windows that are are potent greenhouse gases.

Petro-diesel – diesel fuel produced from the fractional distillation of crude oil from the remains of fossilised plants and animals.

Power-to-Liquid (PtL) – PtL is a synthetically produced liquid hydrocarbon. Renewable electricity is the key energy source, and water and carbon dioxide (CO_2) are the main resources used in PtL production, which consists of three main steps: 1) Renewable energy powers electrolysers to produce green hydrogen and oxygen from water. 2) Climate-neutral CO_2 captured, for example, by Direct Air Carbon Capture is converted into carbon feedstock. 3) Carbon feedstocks are synthesised with green hydrogen via processes such as Fischer-Tropsch to generate liquid hydrocarbons. They are then converted to produce a synthetic equivalent to liquid fossil fuels such as diesel, methanol, and kerosene.

Power Take-In – when power from an electric motor on a propeller shaft is used to drive the shaft to generate mechanical power.

Power Take-Out – when power from an electric generator on a propeller shaft is used to take energy from the shaft and generate electrical energy.

R99 – a term used in the USA for renewable diesel at 99% purity.

R100 – a term used in the USA for renewable diesel that is 100% pure.

RD100 – a term proposed to be used in Australia for 100% renewable diesel fuel (it is proposed this replaces HVO100 which is only applicable to one processing pathway for renewable diesel).

RD50 – a term proposed to be used in Australia for a fuel blend of 50% renewable diesel fuel and 50% diesel.

Renewable Diesel – diesel created by synthetic means from biomass which meets the same ASTM D975 and EN 15490 standards as petrodiesel, an example production pathway is the hydrogenation of vegetable oil to create HVO (or HEFA). Alternatively, the use of Municipal Solid Waste (MSW) is a feedstock which delivers up to 90% GHG emissions reductions.

Reformed Methanol Fuel Cell (RMFC) – Reformed Methanol Fuel Cell (RMFC) or Indirect Methanol Fuel Cell (IMFC) systems are a subcategory of proton-exchange membrane fuel cells where, the fuel, methanol (CH3OH), is reformed into Hydrogen (H^2), before being fed into the fuel cell.

Seawater-to-fuel (StF) – StF technology demonstrates a method for turning seawater into carbon-neutral liquid fuel that could replace fossil-fuel derived petrochemicals.

Shore Charging – Using shore power to recharge a vessel's batteries while docked.

Shore Power – Providing a connection to onshore sources of electrical power while docked.

Spark Ignition – a type of ignition for Internal Combustion Engines in which spark plugs fire to ignite the fuel and air mixture in the cylinder after they have been mechanically compressed.

Sustainable Development – defined by the United Nations in 1987 as meeting "the needs of the present without compromising the ability of future generations to meet their own needs".

Sustainable Fuels – are fuels that can be produced and used in socially and ecologically sustainable ways that meet the goals of sustainable development, which is generally accepted to include moving towards net zero GHG emissions from the lifecycle of the fuel.

Waste-to-Energy – Waste to energy is a form of energy recovery that involves turning waste material into energy products like heat or electricity. Waste to energy provides an opportunity to get value, in the form of energy, from waste that would otherwise go to landfill.

Abbreviations

AMSA – Australian Maritime Safety Authority

ASTM – American Society for Testing and Materials

CBAM – Carbon Border Adjustment Mechanism

CCS – Carbon Capture and Storage (also known as CO_2 Capture and Storage)

CH_4 – Methane (chemical formula)

CH_3OH – Methanol (chemical formula)

CO_2 – Carbon Dioxide (chemical formula)

CO_2-e – Carbon Dioxide Equivalent

DAC – Direct Air Capture

DF-ICE – Dual Fuel Internal Combustion Engine

EACR – Exhaust Aftertreatment and CO_2 Re-use

EU – European Union

FAME – Fatty Acid Methyl Esters

FOM – Fuel plus Operating and Maintenance costs

GHG – GreenHouse Gas

H_2 – Hydrogen, gaseous (chemical formula)

HEFA – Hydroprocessed Esters and Fatty Acids

HFCs – Hydrofluorocarbons

HT-PEM – High Temperature Proton Exchange Membrane

HVO – Hydrotreated Vegetable Oil

ICE – Internal Combustion Engine

IMO – International Marine Organisation

kW – Kilowatt

Li – Lithium (chemical symbol)

LNG – Liquefied Natural Gas

MeOH – Methanol (industry term)

N_2O –Nitrous Oxide (chemical formula)

NF_3 – Nitrogen Trifluoride (chemical formula)

NH_3 – Ammonia (chemical formula)

NOx – Nitrous Oxides

OEM – Original Equipment Manufacturer

PEM – Proton-Exchange Membrane

PFCs – Perfluorochemicals

PM – Particulate Matter

PTI – Power Take-In

PtL – Power-to-Liquid

PTO – Power Take-Out

PtX – Power-to-Anything

SAF – Sustainable Aviation Fuel

SF_6 - Sulphur Hexafluoride

SIA – Seafood Industry Australia

SO – Solid Oxides

SOx – Sulphur Oxides

SME – Small and Medium-sized Enterprises

TRL – Technology Readiness Level

Executive Summary

The first few years of this decade have made it very clear that the world, individual nations, and all industries must take steps to understand, anticipate, prepare for, and respond to climate change. FRDC created this project to help activate and engage the Australian commercial wild catch fishing industry ('industry') in becoming more resilient with regards to climate change.

The project team was led by Seafood Industry Australia (SIA) as principal investigator; Austral Fisheries as industry experts; Blue-X and Sunshot Industries as technical experts; and Margo Consulting as project managers.

The industry is one of the most exposed to the effects of climate change in terms of harvest predictability, catch sustainability, vessel safety, and economic viability. It is also a significant contributor to greenhouse gas (GHG) emissions. In looking at the challenges most relevant to the industry, seven were considered:

1. National GHG Emissions Targets
2. Fisher Profitability
3. Ecological Changes
4. Fisheries Management Adaptations
5. Consumer Changes
6. Market Access
7. Sea Level Changes

When assessed for immediacy, importance, and addressability the two that stood out were the National GHG Emissions Targets, which have been legislated as a 43% reduction from 2005 levels by 2030, and net zero emissions by 2050, and Fisher Profitability, which is needed to support the ability to adapt to disruptions caused by climate change.

Previous research from FRDC has demonstrated that commercially wild caught fish have a GHG emissions per kilogram of 4.4 kg of CO_2-e (total GHG emissions expressed as CO_2 equivalent), while other fresh and boned proteins like beef has 25.2 kg of CO_2-e, lamb has 19.4 kg of CO_2-e, pork has 6.3 kg of CO_2-e, and only chicken is better with 2.9 kg of CO_2-e[1].

This relative advantage in terms of GHG emissions might cause a level of complacency. However, pockets in the industry are much higher (rock lobster has 11.2 kg of CO_2-e, and prawns 6.7 kg of CO_2-e) and there are good reasons to consider being a leader in climate change resilience. Social licence and potentially market share, especially amongst climate concerned consumers, is only likely to be improved by reducing GHG emissions to become more sustainable as an industry. For example, the MSC's survey of Australian consumers in 2022 identified that:

> "45 percent of Australian seafood consumers are willing to buy more sustainable seafood with just over two in ten (23%) saying they have already made this change in the last year; this represents an opportunity gap to reach consumers who are willing to take action"[2]

[1] https://www.frdc.com.au/fish-vol-30-2/calculating-seafoods-carbon-footprint
[2] https://www.msc.org/docs/default-source/aus-files/msc-consumer-survey-2022-summary.pdf

The Australian Federal and State governments have yet to require the industry to reduce GHG emissions, however this is unlikely to remain the case as we approach 2030. Making progress in reducing GHG emissions both contributes positively to the energy transition and helps put the case that the industry sees this as important. It also gives the industry an opportunity to make the case for government interventions that would best suit fishers.

The project focused on decarbonising the propulsion and auxiliary fuel needs of fishing vessels as key challenges in wild catch fisheries (46% of total GHG emissions[3]) to improve climate resilience, meet the national GHG emissions targets, and protect or improve fisher profitability.

Over 8 months the project team researched and analysed the state of the art in alternative fuels, considering the potential of each to reduce GHG emissions, the technical readiness of both supply and consumption of each fuel, the suitability of that option to use on fishing vessels, deepwater, inshore and estuarine, and the likely degree to which each fuel could be supplied economically in Australia to the industry. Established original equipment manufacturers (OEMs), startups, suppliers, naval architects, fuel industry stakeholders, and fishers were contacted to ensure that both the industry's needs and the commercial difficulties solutions must overcome were understood.

A picture quickly emerged of a chaotic mix of possible options. The result of an uneven application of regulatory stimulus, incomplete research, and immature product development meant that many options appeared to be real solutions, but on closer analysis turned out to either be based on wishful thinking or were years from being ready for deployment. Many of the most promising developments were only being done in very large ships and were driven by strict International Marine Organisation (IMO) regulations, or were being done by very early adopters, enabled by access to local incentives that helped reduce the cost of the project. Reports and analysis emerged during the project that helped eliminate certain solutions from the mix (e.g. ammonia due to safety, liquid hydrogen due to volume constraints, biodiesel and E10 due to oxidation and storage issues). Several options stood out for their maturity, positive impact on reducing GHG emissions and suitability for the industry (see Recommended Energy Carriers).

The suitability of different options was assessed through discussions with industry stakeholders and an understanding developed of the key requirements, and the differences between the needs for those using diesel inboard engines and others using petrol outboard motors. Self-sufficiency emerged as a key characteristic that fishers care about, and especially for single vessel enterprises where there is a single point of failure at the vessel level. Economic analysis using the Austral Fisheries' vessel, Comac Enterprise, as a case study highlighted that the opex of higher fuel prices would far outweigh the capex required to modify vessels for one alternate fuel example, dual-fuel methanol. This demonstrated how significant fuel prices are in assessing the viability of options, especially when fisher profitability is considered.

This also illustrates what has become known as the energy transition paradox. The paradox is that it is easy to hold the view that the transition is impossible to accomplish, and yet at the same time hold the view that it will be inevitable that it occurs. Without a way of breaking the deadlock we cannot progress in one direction without being pulled back in the other. The answer is to make small reinforcing positive

[3] FRDC Project No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April). CC BY 3.0

steps towards the change we would like to see, ensuring that when one of them fails we do not overreact and stop all forward momentum. This principle was applied to the alternate fuels options that are available, with the ones that are most immediately actionable highlighted and future focus being based around the alternatives that provide the greatest amount of optionality – in other words ones where we could most easily compensate if something went wrong.

A range of industry-wide scenarios were created to analyse the effect of different actions and possible technological and/or commercial breakthroughs. These revealed that some promising technologies would be unlikely to make a significant positive impact on reducing GHG emissions, whilst others had far better upside potential. The learnings from these scenarios then informed the creation of energy transition roadmaps for decarbonising fishing vessels.

Energy transition roadmaps have been created for diesel inboard engines and petrol outboard motors, for retrofitting existing vessels, and creating newbuild vessels. In line with the principle of optionality they are designed to be antifragile, to ensure that investment decisions are made in ways that will allow for very positive impacts and limit negative ones. There will be early adopters, forward thinkers and risk takers who are willing and able to step further into the future right now – or who even want to try adopting a solution not on the roadmaps. The roadmaps also provide a way for the industry to feedback to OEMs and fuel suppliers the likely direction of most of the industry in coming years.

Through the scenarios and roadmaps we have identified that in the short-term renewable diesel offers the best hope for large-scale reductions in GHG emissions across the fleet of diesel inboard vessels, and for diesel outboard motors – provided that it is sourced from the right biomass feedstocks – and battery/electric outboards are emerging as the best option for reducing GHG emissions across the boats using petrol outboards. In the medium term there are exciting opportunities with green methanol/biomethanol for inboard engines that should also be pursued. Finally, there are promising signs that emissions capture solutions for small/medium maritime vessels are feasible and could offer the fastest path to decarbonising the fishing fleet of today if focus was put into developing them.

Report Recommendations

The report makes nineteen (19) recommendations as a result of this project's findings. They are intended to help extend this work and especially ensure the focus that the roadmaps can give to investors, government and OEMs is realised.

Fishing Industry Specific

Eleven (11) of the recommendations are specific to the fishing industry:

Recommendation F1

As part of its digitalisation and climate resilience promotion strategies, FRDC should promote and, where necessary, fund the development of digital innovations that can help fishers practice **precision fishing**. These efforts should be coordinated with the recommendations to create a Gear Forum and the Future of Fishing.

Recommendation F2

FRDC should create and maintain an up-to-date and online **fishing gear database** for Australian commercial wild catch fishers to learn from. Innovators and suppliers to the industry should be encouraged to nominate outstanding gear innovations to be included.

Recommendation F3

FRDC should create an **Australian Gear Forum** that works in a similar way to the UK one and seek to connect with Seafish↗ in order to share learnings and knowledge across the UK and Australian commercial fishing contexts. The forum could be promoted to members of the Australian International Marine Export Group (AIMEX)↗, the Advanced Manufacturing Growth Centre (AMGC)↗, and the Blue Economy CRC↗.

Recommendation F4

Early adopters that reduce GHG emissions will find there is an economic cost to this pursuit, even whilst they help clarify the potential roadmaps for the rest of the industry. The FRDC should both help encourage GHG emissions reduction, and early adopters, by promoting ways that more sustainably run fishing businesses can increase the market value of their catch. One possible avenue that should be explored is whether mandatory and consistent **sustainability labelling** on locally sold seafood could help consumers choose to shift from unsustainably harvested imported seafood to more sustainably harvested Australian wild caught seafood.

Recommendation F5

The biannual Seafood Directions conference should have a **Sustainable Gear Innovation Award** to celebrate innovations in commercial fishing gear that promote more sustainable fishing and operational practices. FRDC and Seafood Industry Australia (SIA) could put together prize money and recognition packages (promotion and press releases about the winning innovations) for the winners.

Recommendation F6

FRDC should commission a set of **sustainable vessel design** projects to a) identify the vessel designs of most interest to the Australian commercial wild catch fishing industry, and b) to create a set of concept designs around the use of hybrid diesel-electric, mono/dual-fuel methanol, and battery-electric powertrains.

Because these projects will require local boatbuilding experience, it is recommended that they be promoted in conjunction with the Australian International Marine Export Group (AIMEX)↗, Australian Commercial Marine Group (ACMG)↗, the Australian Division of the Royal Institution of Naval Architects (RINA)↗, Blue Economy CRC↗, and the Advanced Manufacturing Growth Centre (AMGC)↗.

Recommendation F7

FRDC's Capability, Capacity and Culture Change enabling strategy is key to helping drive the **culture change** needed across the Australian commercial wild catch fishing industry.[4] Promotion of Energy Intelligence and encouragement of travel bursaries to relevant maritime and fishing technology conferences and exhibitions should be promoted, and the learnings shared widely with the industry as a whole.

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[4] https://www.frdc.com.au/capability-capacity-and-culture-change

Recommendation F8

SIA and FRDC's Capability, Capacity and Culture Change program should collaborate on creating a **climate adaptation program** to help fishers become more adaptable in terms of the fishing vessels and fishing methods they use, and the fishing grounds/fisheries they target.

Fishers using active fishing vessels or methods that are known to be energy inefficient, should be identified and helped to a) understand their energy use, b) analyse how changes to what they do might impact their profitability and business resilience, and c) access financing and grants to help them make those changes.

Fishers operating in areas or fisheries that might be at risk, from climate changes or fishing restrictions, should be identified and helped to a) understand what the nature of the risks are, b) review how they might change the ways their business operates, and c) access financing and grants to help them make those changes.

Recommendation F9

The FRDC should seek initiators to help launch a **new innovation ecosystem** that can address the climate, technological, social, and economic disruptions facing the commercial wild catch fishing and aquaculture industries. Initiators can fill roles such as orchestrator, sources of funding, and sources of knowledge.

It is suggested that the vision of the innovation ecosystem be explicitly bound to social or sustainability goals rather than GVP or economic return. This can both help address FRDC's key strategic risks of biosecurity, cybersecurity, sustainability, climate change, and ocean planning; and reduce the chance of entrepreneurial iatrogenesis[5] (harmful side-effects).

Most importantly, the orchestrator organisation should be one that can help recruit innovators in the partner, peer consumer, and peer producer roles – implying they have a broad network across the fishing, aquaculture, seafood, venture capital, private capital, AgTech, ClimateTech, and DeepTech industries.

Recommendation F10

FRDC should seek Australian Government support for running an **energy tracking campaign** across the Australian commercial wild catch fishing industry to ensure that every engine or generator on every vessel which can have a fuel flow monitor does so, that every vessel with a large battery have an electrical current data logger, and that training is organised to show fishers how to use the monitors and loggers to help them manage operational use of their vessels to reduce fuel consumption, with the added benefit of reducing GHG emissions.

Recommendation F11

As part of its digitalisation and climate resilience promotion strategies, FRDC should fund an **Energy Intelligence** program that develops processes and digital systems to simplify and where possible automate the process of capturing operational energy use data.

FRDC's Capability, Capacity and Culture Change program should develop energy assessment training to help fishers learn how to do a basic energy assessment that can help them understand better how to apply the relevant outboard motor or inboard engine roadmaps.

Agriculture Industry Related

Two (2) of the recommendations require cooperation with the Agriculture industry:

[5] Montiel, O., Entrepreneurial Iatrogenesis: An Explorative View, SWAM, March 2021.

➔ Recommendation A1

FRDC should support the development of new, and/or integration of existing, digital tools for fishers that can help them record their **carbon footprint** with the AIA's environmental accounting platform, the digital tools should also enable the easy creation of reports to help larger fishers meet their mandatory climate-related financial reporting requirements.

➔ Recommendation A2

Seafood Industry Australia will coordinate with Maritime Industry Australia Ltd (MIAL)↗ to advocate for Australian government action to progress local production of **renewable diesel** and make sure the needs of the Australian commercial wild catch fishing industry are recognised.

Maritime Industry Related

Six (6) of the recommendations require cooperation with the Maritime industry, and others:

➔ Recommendation M1

FRDC should establish connections with efforts by Maritime Industry Australia Ltd (MIAL)↗, the Australian Renewable Energy Agency (ARENA)↗, Blue Economy CRC↗, and iMove CRC↗ to create credible **sustainable future fuel options** for the maritime industry, especially domestic commercial vessels (DCVs).

These efforts should target Methanol Hubs created in response to the Port & Harbour Infrastructure recommendations.

➔ Recommendation M2

FRDC's Capability, Capacity and Culture Change program should work with the Australian Maritime College (AMC)↗, Australian Maritime and Fisheries Academy↗, Batavia Coast Maritime Institute↗, Great Barrier Reef International Marine College↗, and other industry capability and training groups to ensure that the future educational needs of maritime workers to remain **energy transition relevant** can be satisfied.

➔ Recommendation M3

Sustainable energy shore infrastructure and sustainable vessels need to be matched together so that supply and demand ensures investment on either end is not wasted. To that end it is recommended that FRDC works with Ports Australia↗, Maritime Industry Australia Ltd (MIAL)↗, Blue Economy CRC↗, Boating Industry of Australia (BIA)↗, Australian International Marine Export Group (AIMEX)↗, and Australian Commercial Marine Group (ACMG)↗ to create **regional maritime sustainability hubs** where stakeholders across the maritime ecosystem, from harbour managers, to fuel suppliers, DCV operators, unions, equipment manufacturers and government authorities can focus efforts on progressing the effort to improve maritime sustainability.

From this report, two initial focus areas for different hubs would be:

1. Electrification Hub
Exploring shore charging, battery-electric outboards and inboards, hybrid diesel-electric vessels. Fishing vessels, smaller ferries, pilot boats, and offshore support vessels could all be involved.

2. Methanol Hub

Exploring methanol fuels handling procedures, methanol bunkering, grey/green methanol 'last mile' supply issues, AMSA-compliant vessel design, new engine/fuel-cell technologies and economics. Fishing vessels, coastal transport, larger ferries, and offshore support vessels could all be involved.

➔ Recommendation M4

FRDC should work with Seafood Industry Australia (SIA)↗, Maritime Industry Australia Ltd (MIAL)↗, Boating Industry of Australia (BIA)↗, Blue Economy CRC↗, Australian International Marine Export Group (AIMEX)↗, and Australian Commercial Marine Group (ACMG)↗ to promote the uptake of **Australian propulsion innovations** across the Australian commercial wild catch fishing industry.

➔ Recommendation M5

FRDC should work with the Australian Renewable Energy Agency (ARENA)↗, Blue Economy CRC↗, iMove CRC↗, and CO2CRC↗ to identify and promote areas where research, development and commercialisation are needed to create **Emissions Aftertreatment and CO_2 Capture (EACR)** breakthroughs, solutions and products, and also to promote circular economy thinking in the development of sustainable maritime fuels.

➔ Recommendation M6

FRDC should work with the Australian Renewable Energy Agency (ARENA)↗, Blue Economy CRC↗ and iMove CRC↗ to **identify and fund pilot projects** for dual-fuel diesel/methanol retrofit kits, mono-fuel methanol engines, and methanol fuel cells. These projects should consider the full range of operational requirements of offshore maritime operations such as deepsea fishing, offshore supply vessels, coastal transport, and long-distance ferries.

These pilot projects should be connected to Methanol Hubs created in response to the Port & Harbour Infrastructure recommendations.

Summation

This project has made an important step towards helping the Australian commercial wild catch fishing industry gain clarity around what climate resilience means, and the part that transitioning to alternate fuels can play in helping the industry compete globally and contribute towards mitigating the climate change events that resilience is needed to handle.

Keywords

climate resilience – wild harvest fisheries – alternative fuels – propulsion systems – technology adoption – carbon – methanol – diesel – renewable diesel – hydrotreated vegetable oil – hydroprocessed esters and fatty acids – biodiesel – hydrogen – ammonia – hybrid electric – electric drive – batteries

Introduction

Climate resilience is the ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate. Improving climate resilience involves assessing how climate change will create new, or alter current, climate-related risks, and taking steps to better cope with these risks.[6]

This project is intended to activate and engage industry in viable options towards climate resilience by 2030. This includes the need to demonstrate that immediate options exist and are viable and meaningful, while also gaining support for a clear plan to transform the industry and supply chain with support both internally and beyond the sector.

Industry awareness of the problems and solutions around climate change and resilience is below where it needs to be to activate broad transformation[7]. At the commencement of this project, the Australian fishing sector had taken little action towards building climate resilience in comparison to other agricultural sectors.

As an industry, commercial wild catch fishing is vulnerable to negative effects of climate change to the fishing stocks the industry is built on, and the coastal infrastructure used, whilst changing consumer attitudes to protein mean there is no reason to expect a higher return on fishing. There will be increasing competition within the local protein market to validate and promote sustainable practices and positive contributions to the environment and climate. This competition is becoming more apparent in global markets also.

In 2021, the EU announced its legislative proposal for the Carbon Border Adjustment Mechanism (CBAM). The CBAM is a measure to reduce the risk of carbon leakage by charging a carbon price on imports from countries with less strict climate change policies than those of the EU, ensuring a level playing field.[8] The Inflation Reduction Act of 2022 (IRA) in the USA also gives American producers significant help to decarbonise their industry.

This project aims to contribute to the industry's body of work and knowledge that underpins its decarbonisation progress.

Fishing sector leaders and innovators in the industry are acting in isolation with few common resources to support their decarbonisation efforts. The extension of this project has been designed to develop a network of likely industry early adopters of alternate technologies and those interested in decarbonisation. These early adopters and innovators will lead new ways of operating fishing businesses into the future.

[6] https://www.c2es.org/content/climate-resilience-overview/
[7] 53% of participants in the FRDC 2021 Stakeholder Planning Workshop indicated climate change adaptation was a key challenge https://www.frdc.com.au/stakeholder-planning-workshops#toc-2021-workshop
[8] Darvell, A, 'The EU's Carbon Border Adjustment Mechanism - CBAM Draws Strong Oppositions, but it also pouches some Non-EU Countries to take more Climate Action', December 2021.

Individual and isolated achievements by some stakeholders will not deliver the transformation at a scale or pace that is required to meet growing consumer expectations of climate action.

There is a need to bring together the tools, resources and research around climate change and resilience that are available into forms that fishers find usable and valuable.

The key driver in this project was the following question: “how can the fishing industry demonstrate rapid and practical progress to achieve climate resilience by the fisheries, aquaculture and seafood supply chain by 2030?”

Objectives

The objectives of the project are:

1. To understand challenges facing the commercial wild-harvest sector relating to a changing climate.
2. To determine opportunities to respond to those challenges and validate solutions.
3. To engage with industry leaders and innovators to explore and validate viable, feasible and scalable options towards climate resilience.
4. To demonstrate rapid and practical progress towards climate resilience and elements of SIA’s ‘Our Pledge’.
5. To build partnerships and relationships with global leaders to enable advancement of prioritised solutions that will enable improved climate resilience.

Method

The project methodology for assessing key challenges and the opportunities related to them follows a process that filters challenges based on their immediacy of impact, then assesses their importance, and finally looks at the addressability of each challenge to identify ones that opportunities should be developed for[9]:

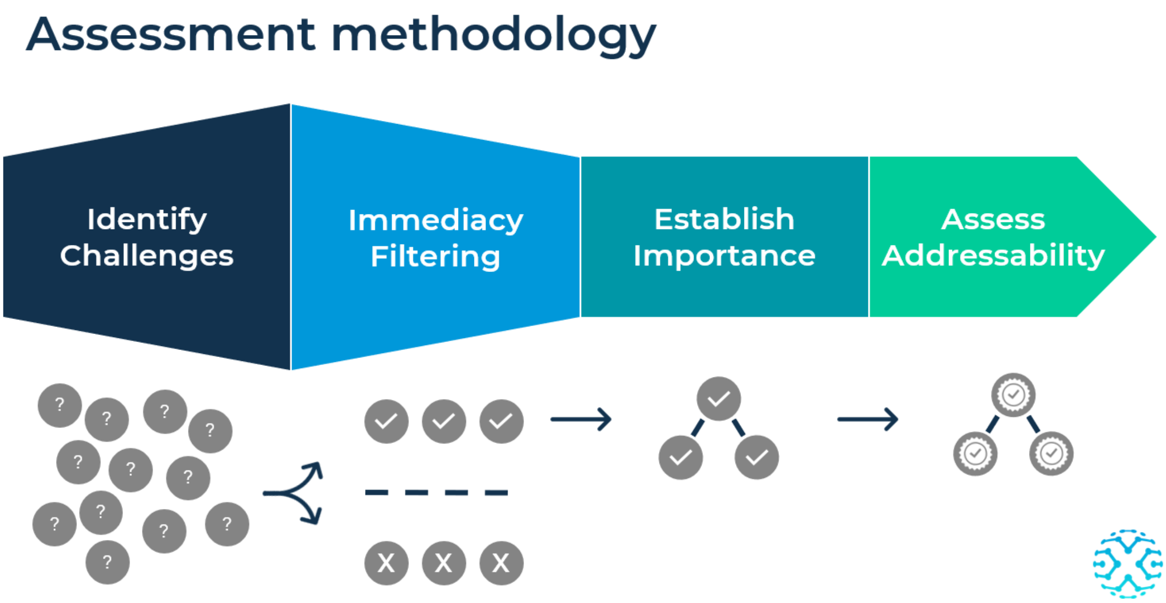

Figure 1: Assessment methodology

The project was conducted in four phases:

1. Develop Intent Statement & Project Plan

A detailed project brief and extension plan was developed at the commencement of the project. These documents set out the project's intent statement, context, and specific needs for the industry.

2. Challenge Assessment

The project set out to conduct a challenge and requirements assessment. This assessment prioritises challenges facing the industry with regards to adoption of technologies with respect to climate resilience. The challenges were filtered to prioritise the ones that had immediacy and were important, which led to a shortlist of three challenges.

3. Opportunity Analysis

The remaining three challenges were assessed based on how addressable each was – from this the challenge C1. National GHG Emissions Targets as identified as the prime one and C2. Addressability of Fisher Profitability as a secondary one, with GHG emissions from fuel for propulsion and auxiliary power being a key item to address, considering the need for fisher profitability to improve resilience.

[9] Rumelt R. 'The Crux: How Leaders Become Strategists'. United Kingdom, Profile, 2022.

In looking at alternative fuels that could provide a reduction in net GHG emissions we originally separated the types of fishing vessels in use into three categories based on length and typical use cases:

1. Tender/dinghy, less than 5m,
2. Inshore, up to 12m, and
3. Deepwater 12m to 24m.

When considering the propulsion and auxiliary power requirements we quickly fell into wondering whether it was more useful to separate vessels that had multiple engines for different purposes (main, boiler, hotel, etc.) from ones that did not, or if the petrol vs diesel divide was more important.

While there are different needs for different purposes, we ultimately found that we largely ended up discussing four categories, which we used throughout the rest of the project:

- Petrol outboard motors
    1. Retrofit
    2. Newbuild
- Diesel inboard engines
    3. Retrofit
    4. Newbuild

The project conducted a detailed technoeconomic evaluation, across a wide variety of options, using a common set of criteria across two primary categories:

1. Energy carrier options
    - Fossil fuels
    - Biofuels
    - Hydrogen based e-fuels
    - Electrons
2. Intervention options
    - Fuel reduction
    - Fuel replacement
    - Fuel system replacement
    - Engine replacement
    - Vessel replacement
    - Emissions capture

The key criteria relied upon for evaluation were:

1. Potential well-to-wake GHG emissions reductions.
2. Marine safety (flammability, toxicity, what a spill would do).
3. Marine suitability (how well does it suit the marine environment, salinity, temperature extremes and turbulence).
4. Suitability to fishing operations.
5. Technology readiness (evaluating technology maturity, supply, and consumption).
6. Supply issues (feedstocks, energy use, refined fuel).

7. Cost (CapEx and OpEx relative to diesel/petrol).
8. Relative energy density (volume and weight).
9. Usability (changes required to use, infrastructure, regulatory and safety maturity).
10. OEM support (support from current or new engine OEMs).
11. Simplicity of implementation/maintenance & workforce readiness.
12. Procurement and speed of deployment.
13. Availability of port and harbour infrastructure (bunkering, shore charging etc).

A detailed breakdown of the evaluation criteria is available in Appendix 3 – Technology Assessment and Recommendations. This evaluation was validated through interviews with fishers.

The set of options to be considered was derived from a combination of literature review; discussions with naval architects, manufacturers, equipment suppliers, alternate propulsion system manufacturers, sustainable fuel supply chain participants (see Objective 5: Partnerships & Relationships); and participation in relevant webinars, conferences, and exhibitions.

Fisher Interviews

A set of interviews were conducted with the following fishers, whereby they were asked about a number of areas of interest:

1. Effects of the rising cost of fuel on their business.
2. Operational changes they have made to maintain profitability.
3. Their awareness and experience of alternative fuels.
4. Their awareness and experience of alternative propulsion systems.
5. Intentions with regards to newbuild vessel(s) vs retrofitting existing vessel(s).
6. Awareness and interest in emissions ratings of engines.
7. Awareness and interest in battery-electric outboard motors.
8. Awareness and interest in hybrid diesel-electric inboard engines.
9. Barriers to adoption of new technologies.
10. Their attitudes towards reducing their carbon footprint.
11. Their customer's interest in their business' carbon footprint.
12. Priority pain points in their business.
13. Interest in being kept up to date with the project.
14. Interest in being involved in pilot projects for solutions.

Since facilitating the SIA Alternate Fuels webinar and creating and running these interviews, the project has evolved considerably, and so a new webinar should be facilitated to bring the broader commercial wild catch fishing industry, their upstream suppliers, and downstream value chain partners up to date, and a survey run to give a broader set of responses from the attendees. This survey has been created but an opportunity to run the webinar has not been given.

Key Industry Discussions

The project connected with maritime innovation, decarbonisation, and ClimateTech organisations and programs, to source cutting edge innovations.

Braid Theory

Program: Zero Emission Shipping Venture Studio

Impact on the project: The following startups were sourced and analysed for relevance:

- FuelWell – Plug-in fuel activator device.
- HeatInverse – Passive Cooling films.
- BlueNav – Retrofitting vessels with electric/hybrid drive.
- BoatMate – Digital marketplace for vessel related services.
- Natrion – Scalable and efficient solid state batteries

Department of Industry, Science and Resources

Program: Accelerating Commercialisation

Impact on the project: A biofouling solution provider named HullBot was identified and contributed key insights to Fuel Reduction Interventions (Both Categories).

ClimateSalad

Program: ClimateTech startup community

Impact on the project: A startup named Kapture was identified, which is developing a solution for capturing emissions from the exhausts of diesel gensets.

Event Participation

The following events were selected because of their relevance and ability to connect with industry players across the broader maritime industry.

MIAL Decarbonisation Summit Series

A series of three summits focused on maritime decarbonisation, organised by Maritime Industry Australia Ltd (MIAL).

Event #1

Date: April 2022
Location: Melbourne
Attended by: Clayton Nelson, Chair SIA
Impact on the project: The presentation and attendees were early in their analysis of viable alternative low carbon fuels, with a focus on LNG or compressed hydrogen.

Event #2

Date: Sept 2022
Location: Sydney
Attended by: Allen Haroutonian, Blue-X
Impact on the project: The industry seemed to have moved on from their LNG focus, much to the

dismay of the engine manufacturers who were still pushing LNG as the silver bullet, the conversation had shifted to Ammonia and Hydrogen as the preferred future fuel options.

Event #3

Date: Oct 2022
Location: Perth
Attended by: Allen Haroutonian, Blue-X
Impact on the project: The fuel-centric focus of the event had dramatically shifted towards Methanol and Ammonia, in line with the rapid progression of orders being placed by almost all the major shipping companies, for dual-fuel methanol powered newbuild ships. In addition to the focus on alternate fuels, there were some great case studies presented which highlighted the real opex savings and emissions reductions being achieved from fuel efficiency interventions.

Hybrid & Electric Marine Expo Europe

A major maritime industry exhibition and conference for Hybrid & Electric drivetrain innovations and projects that attracted a global audience of vendors, suppliers, and customers.

Date: June 2022
Location: Amsterdam
Attended by: Allen Haroutonian, Blue-X
Impact on the project: This exhibition and conference was a very important one as it gave a number of important insights:

- Introduction to the concept of methanol reforming as a potential pathway to fishing vessel decarbonisation.
- Several presentations (all of which were recorded in HD and available on-demand) highlighted the issue of volumetric energy density in relation to gaseous or liquid/compressed hydrogen.
- The TRL's, quantity of reputable vendors and immediate availability of products to aid vessel owners with electrification were impressive, and so, it was immediately clear that Australia does not need to invest in reinventing the wheel, it just needs to trial technology in order to build industry confidence for adoption/implementation.

Shipbuilding, Machinery and Marine Technology (SMM) Hamburg

A major maritime industry exhibition and conference series (Maritime Future Summit, Global Maritime Environmental Congress) for shipbuilding, machinery and marine technology products, innovations and projects that attracts a global audience of vendors, suppliers, and customers.

Date: September 2022
Location: Hamburg, Germany
Attended by: Allen Haroutonian, Blue-X
Impact on the project: This exhibition and conference series:

- Met many more manufacturers and suppliers here than at any other conference.
- A startup stream gave access to 18 early-stage startups.

- Greater clarity on the demand for sustainable fuels such as green methanol as several representatives there were looking to sign offtake agreements for sustainable fuels.
- Insights from GMEC conference as to the scale of the challenge, and that industry were asking IMO to provide better regulatory frameworks and clarity on GHG reduction targets.

NZ Seafood Conference

The peak Seafood New Zealand conference major maritime industry exhibition and conference.

Date: August 2023
Location: Wellington, New Zealand
Attended by: Allen Haroutonian, Blue-X
Impact on the project: The project was given a 20 minute presentation slot on "Decarbonisation and Climate Resilience of Wild Catch Fisheries". Conversations after the presentation showed that NZ fishers have similar problems to Australian fishers. The Sustainable Food and Fibre (SFF) Futures↗ programme is the main way decarbonisation projects are being funded. Slides are available online from the conference.

4. Energy Transition Roadmapping

A series of Energy Transition Roadmaps were created that provide guidance for each category of vessel and that tries to not just embrace resilience but look for opportunities to create antifragility in the commercial wild catch fishing industry.

Sample Vessel

The Austral Fisheries vessels *Comac Enterprise* and *Calypso Star* were used as test cases for obtaining high level information to assist in scoping a conceptual drive design. The *Comac Enterprise* vessel is a 23-metre deepwater trap boat monohull with a power requirement of approximately 450 kW. See Appendix 5 – Comac Enterprise Specifications for more details about the vessel.

Important Note: A decision was made to focus on the monohulled *Comac Enterprise* vessel instead of the *Calypso Star* catamaran, as it carried a closer resemblance to the majority of Australian commercial deepwater fishing fleet.

As a prototypical deepwater vessel, the Comac Enterprise represents one of the more difficult vessel types to decarbonise (with deepwater bottom trawl vessels representing the pinnacle of decarbonisation complexity).

The project team were grateful for the openness and collaboration provided by the Austral Fisheries team, as the high levels of access to sensitive corporate information was instrumental in enabling the project to analyse all the technical information and extrapolate insights which should provide this project with the greatest chance of delivering actionable insights and broad appeal to the industry as a whole.

Results & Discussion

Results are presented as progress against each objective in the project contract, followed by a set of recommendations.

Objective 1: Climate Challenges

Objective 1: To understand challenges facing the commercial wild-harvest sector relating to a changing climate.

The project identified and analysed seven main types of challenges that climate change is likely to bring for the Australian wild catch fishing industry (“industry”):

- **C1.** National GHG Emissions Targets
- **C2.** Fisher Profitability
- **C3.** Ecological Changes
- **C4.** Fisheries Management Adaptations
- **C5.** Consumer Changes
- **C6.** Market Access
- **C7.** Sea Level Changes

Challenge	Immediacy	Importance
C1. National GHG Emissions Targets There is a national target to reduce net GHG emissions to 43% below 2005 levels by 2030.	Soon	While the Government may not impose penalties or mandate change to a small and relatively low GHG emitting industry such as commercial wild catch fishing, there could be consumer behaviour changes if the industry is seen as a laggard. Given the industry is so affected by climate change there is also some value in it leading the way to inspire action by others, and potentially attracting greater government support as an early mover.
C2. Fisher Profitability Operating costs for the industry are forecast to increase as a) other industries decarbonise and pass on costs, b) workers see other opportunities as more attractive so seek higher pay to remain, c) ongoing regulation increases equipment costs, and d) carbon pricing increases costs of fossil fuels. At the same time there appear limited ways that fishers can produce more fish or increase the prices they receive.	Already happening	A key aspect of climate change resilience is the ability for a fisher’s business to be able to afford to make the adaptations necessary to deal with rising input costs, the need to decarbonise, and fisheries management changes. Fishers that have more profitable and more diversified businesses will be able to adapt better than ones who are more constrained in their financial and operational options.

C3. Ecological Changes Climate change is pressuring marine ecosystems through ocean acidification, ocean warming, and other ocean changes and this creates present and future challenges for the industry.	Already happening[10]	The greatest climate challenges for the Australian wild catch fishing industry come from the ecological changes that are already happening due to ocean acidification, ocean temperature change, changes in current strength and oxygenation. These range from significant short-term impacts to fish stocks and the economics of the industry, to the existential threat of whole fisheries being lost.
C4. Fisheries Management Adaptations Fisheries management will need to adapt to climate change impacts on their fishery, and the industry will likely find it challenging to adapt to new rules and regulations.	Already happening	Other FRDC research is already addressing the fisheries management issues, most notably FRDC projects 2016-059 and 2021-104 and the Fisheries Climate Adaptation Handbook. As a result, this area was marked as less important for this project.
C5. Consumer Changes Consumer behaviour changes due to attitudes towards climate change and sustainability will create challenges for the industry.	Soon[11]	Attitudes towards wild-caught protein may become negative, with farmed product preferred, likewise alternative protein sources with lower net GHG emissions may become much more popular (e.g. chicken, insects, lab-grown meat). These are important to address at some point, but do not yet show signs of being significant risks to resilience[12]. Over the medium-term (up until 2028) there is an expectation that the gross value of production of seafood will decline by 0.7% per year[13].
C6. Market Access Countries adding carbon taxes to imports, a growing interest in locally harvested foods over distant ones, and political limitations to trade in response to climate change actions or rhetoric could all challenge the industry's economic future.	Eventually but not soon	As the COVID-19 pandemic showed, losing access to key markets can severely impact part of the industry that rely significantly on exports to a few key markets (e.g. China). Greater resilience requires more diversification of export markets and development of significant local markets. Lower GHG emissions may also defend against future CBAM effects.

10 Fulton, E.A., van Putten, E.I, Dutra, L.X.C., Melbourne-Thomas, J., Ogier, E., Thomas, L. Rayns, N., Murphy, R., Butler, I., Ghebrezgabhier, D., Hobday, A.J. (2021) Guidance on Adaptation of Commonwealth Fisheries management to climate change. CSIRO Report for FRDC. Hobart. CC BY 3.0

11 The MSC found that in 2022 only 23% of Australian consumers had made a change in purchasing behaviour to buy more sustainable seafood – GlobeScan Inc., MSC Consumer Insights 2022: Australia, May 2022.

12 Lenka Malek, Wendy J. Umberger, Protein source matters: Understanding consumer segments with distinct preferences for alternative proteins, Future Foods, Volume 7, 2023, 100220, ISSN 2666-8335, https://doi.org/10.1016/j.fufo.2023.100220.

13 Curtotti, R, Dylewski, Cao, A and M, Tuynman H 2023, Australian fisheries and aquaculture outlook to 2027−28, ABARES research report, Canberra, March, DOI: https://doi.org/10.25814/vzbj-nw33. CC BY 4.0.

C7. Sea Level Changes Sea levels around Australia are predicted to rise over the foreseeable future, with the rate varying with changes in GHG emissions. Specific local areas may experience less rising, or even falling sea levels, but in general the melting of land ice and warming of the oceans means they will rise everywhere. This potentially puts at risk coastal infrastructure that fishers rely upon, such as wharfs, boat ramps and fuel stations. It also could dramatically affect estuarine fisheries.	Already happening[14]	Adaptation to rising sea levels will be important for Australian society as so much of our infrastructure and lifestyles are at risk. The long-time scales of sea level change mean that there is time to act and create more resilient coastlines, but the best mitigation may be limiting our GHG emissions.

Table 1: Challenges Identified

The challenges were assessed using a scoring matrix to identify how to handle each challenge. The score is found by looking first at the Immediacy of each challenge, then its relative importance to the industry, and lastly the addressability.

Immediacy	Importance	Addressability		
		Impossible	Difficult	Simple
Already Happening	Vital	Watch	Prioritise	Just do it
	Necessary	Watch	Prioritise	Just do it
	Should do	Ignore	Watch	Ignore
Soon	Vital	Watch	Prioritise	Just do it
	Necessary	Ignore	Watch	Ignore
	Should do	Ignore	Ignore	Ignore
Eventually But Not Soon	Vital	Watch	Watch	Watch
	Necessary	Ignore	Ignore	Ignore
	Should do	Ignore	Ignore	Ignore

Table 2: Challenge scoring matrix

The actions that result from the score are:

- **Prioritise** - things we should do something about and need to focus efforts on now.
- **Watch** - don't act yet but keep watch in case addressability or immediacy change.
- **Just do it** - important, easy to do, and happening or about to so just do something about it.
- **Ignore** - not something we can do anything about, or not something we need to worry about.

[14] Fulton, E.A., van Putten, E.I, Dutra, L.X.C., Melbourne-Thomas, J., Ogier, E., Thomas, L. Rayns, N., Murphy, R., Butler, I., Ghebrezgabhier, D., Hobday, A.J. (2021) Guidance on Adaptation of Commonwealth Fisheries management to climate change. CSIRO Report for FRDC. Hobart. CC BY 3.0

Assessing these challenges came up with the following scoring, which was then used in filtering the challenges we looked at for Objective 2.

Challenge	Immediacy	Importance	Addressability	Score
C1. National GHG Emissions Targets	Soon	Vital	Difficult	Prioritise
C2. Industry Economics	Already Happening	Necessary	Difficult	Prioritise
C3. Ecological Changes	Already Happening	Vital	Impossible	Watch
C4. Fisheries Management Adaptations	Already Happening	Should do	Difficult	Watch
C5. Consumer Changes	Soon	Necessary	Difficult	Watch
C6. Market Access	Eventually But Not Soon	Vital	Difficult	Watch
C7. Sea Level Changes	Already Happening	Necessary	Impossible	Watch

Table 3: Scoring climate change challenges

Objective 2: Addressing the Climate Challenges

Objective 2: To determine opportunities to respond to those challenges and validate solutions.

Reviewing the challenges that have immediacy and are important to address and that are addressable, gave us two key challenges to focus for opportunities around.

C1. Addressability of National GHG Emissions Targets

With an ageing fishing fleet and limited ability to fund capital intensive expenditures the industry will find this challenging, but it is possible to do something to increase resilience to the challenge. Existing FRDC research into GHG emissions in the Australian fishing and aquaculture industry identified that "the overall ranking of emissions for the fishing industry are: 1) fuel combustion 2) processing and 3) transport (of primary and secondarily processed products)."[15]

Of the top three emissions sources, around 46% of total GHG emissions is from fuel used for propulsion and powering auxiliary systems on vessels[16]. Addressing this with a zero net GHG emissions solution would go a long way to meeting the national target of 43% reduction of net GHG emissions.

However, there was a lack of clarity around which solutions to reach net zero GHG emissions would work in a maritime environment. Multiple types of alternate fuels were being debated, promoted, and dismissed by different organisations – most with some bias towards particular options. In these debates, solutions with very low technology readiness levels (TRLs) were naively compared to mature solutions and hypothetical scenarios were often created from assumptions with little basis in scientific reality.

[15] FRDC Project No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April). CC BY 3.0
[16] Ibid.

When looking at GHG emissions reduction it is important to understand the difference between different emission scopes. Scope 1 emissions are those directly created by the activities of the organisation using its own facilities or vehicles/vessels. Scope 2 emissions are those the organisation inherits by consuming electricity, water and heating or cooling energies. Scope 3 emissions are ones that are either upstream (from suppliers) or downstream (from customers) from the organisation that are caused to be emitted by the interaction of those other parties with the organisation (see Figure 2). For the purpose of this report, it was assumed that all three emission scopes should be reduced evenly, and that the report would focus on reductions to Scope 1 emissions.

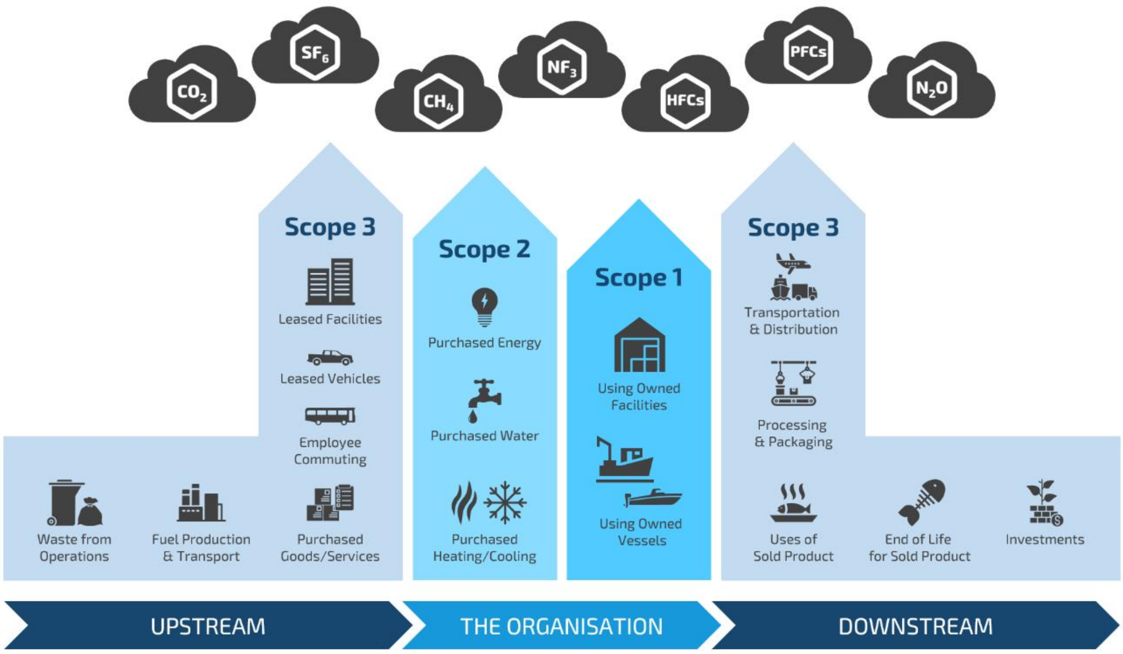

Figure 2: Scope 1, 2 and 3 emissions explained. Source: Blue-X.

The project identified the need to prioritise fisher-centric decarbonisation solutions which simultaneously reduce, or avoid GHG emissions while also:

- Avoiding collateral impacts on ocean, coastal, and estuarine environments (e.g. from potential Ammonia fuel spills);
- Avoiding food security issues, due to interference with the harvest and provision of wild seafood;
- Avoiding job losses and wider community impacts from diminished commercial viability of continued fishing operations, especially in regional Australia;
- Avoiding loss of biodiversity, due to land clearing to plant fuel crops;
- Contributing conservation co-benefits that enhance the resilience of these ecosystems to climate change and other stressors; and
- Facilitating the voluntary adoption of cost-effective, locally appropriate technologies and practices to reduce fuel use and greenhouse gas emissions by fishing vessels and shoreside businesses.

C2. Addressability of Fisher Profitability

Figure 3 shows a profit-tree analysis of fisher profitability with an emphasis on sustainability.

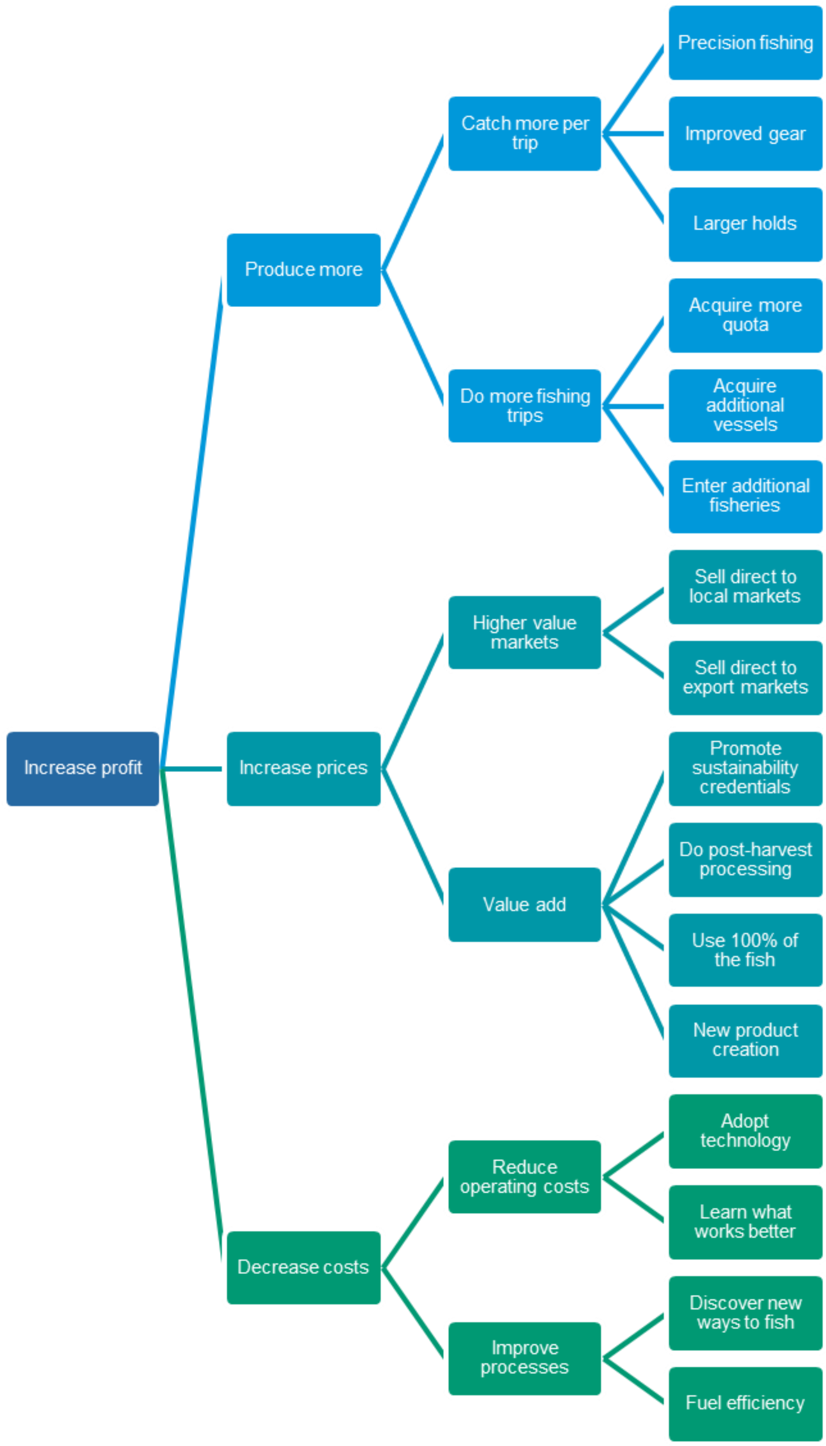

Figure 3: Profit tree for a commercial wild catch fisher.

Climate change puts pressure on fisher profitability by potentially reducing fishing stocks, and at the same time significantly increasing input costs, especially diesel fuel. It is important to consider how to address fisher profitability as a) it ensures the longevity of the industry, and b) producers must be profitable in order to consider becoming more environmentally sustainable[17]. A study into why some Swedish farmers chose to use renewable diesel (HVO) even with a much higher fuel price determined that:

> The findings of this study suggest that "Responsibility" is the most prominent value followed by the values "Self- achievement", "Security", "Satisfaction" and "Legacy". Furthermore, profitability is not mentioned as a motivational factor as to why farmers use HVO in their production, but as a factor that enables the decision.[18]

Producing more by catching more per trip or doing more fishing trips is possible. There is a limit to how much more fish can be caught as most fisheries have quota or effort limits that create an artificial ceiling on the number of fish that can be caught. Diversifying by acquiring more quota and additional vessels, or entering additional fisheries are possible ways a fisher can produce more.

Increasing prices is a harder proposition for many fishers who find they are price-takers, not price-setters. Even when they do set prices, making more money depends on either finding higher value markets or creating extra value within the fisher's own business. Some fishers have managed to increase the price they take by selling their catch directly, and increasing local sales will also help reduce GHG emissions by eliminating transport kilometres. Selling to export markets has the opposite effect on GHG emissions but can be highly profitable with the right product.

Adding value to the catch is how many of the most resilient fishing businesses are setup with vertical integration into fish processing, wholesale sales, and sometimes retail sales. Fishers that take action to reduce GHG emissions can claim promote their sustainability credentials and as a result may attract a premium price for their products in some markets. If processing can be added to the fisher's business then it allows for a greater share of the profits, and enables value capture beyond the fillets with potentially 100% of each fish↗ being usable – for instance a recent ACIAR report with the Pacific Islands Forum Fisheries Agency pointed out a number of ways that high-value products could be created from fish waste[19].

Decreasing costs is an element that fishers can easily address. Reducing operating costs by adopting new technology can help when there is awareness of how it can help, and so education and community shared learnings can help. One of the key issues for the industry is the increasing cost of fuel, particularly diesel. This is difficult to address as all diesel is imported and prices are unlikely to be affected by domestic demand. As a side-effect it may actually make it easier to address C1. National GHG Emissions Targets as the relative price difference between diesel and alternative fuels will narrow.

Cost increases in equipment due to suppliers reacting to climate change themselves is unlikely to be addressable, other than perhaps attempting to create more standardisation across the industry or stimulating domestic supply that has lower transport costs (including less embodied GHG emissions

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[17] Frostgård, L., Svenungsson, E., *Underlying values and motivational factors of farmers - a study of Swedish farmers who use HVO in their productions*. Swedish University of Agricultural Sciences, Uppsala, 2022.
[18] Ibid.
[19] Doan, D., Poole, S., Haroutonian, A., McDonald, A., Cole, S., Wheatley, L., Numilengi, T., Blaha, F., Walton, H., Manley, M., Mangubhai, S., Sarrot, R., *Landscape and Opportunity Analysis in the Pacific Tuna sector*, ACIAR FR2023-033, July 2023.

in the distribution). Identifying where the industry is using gear inefficiently is important, but refrigerant changes are unlikely to be easily addressable. Notably, if there was a more standardisation across fishing vessel designs there might be some advantages in both reducing the cost of new vessels and reducing the cost of creating retrofits for new technology.

Process improvements that consider innovating around how to fish so as to reduce costs, and operational changes to improve fuel efficiency are addressable. Changing processes sometimes requires attracting new talent to the business in order to have people involved who are willing to innovate and work in new ways.

With regards to ensuring the industry can attract talent, there are already some efforts to promote fishing as a career to young people, but the perception of the industry as technological laggards using old vessels and old gear is one that could be helped by addressing C1. National GHG Emissions Targets.

Objective 3: Options to Create Climate Resilience

Objective 3: To engage with industry leaders and innovators to explore and validate viable, feasible and scalable options towards climate resilience.

Based on the project’s analysis of the addressability of the most immediate challenges, it became obvious that the primary challenge this report should address to develop climate resilience for the industry is C1. National GHG Emissions Targets, with a secondary focus on

C2. Addressability of Fisher Profitability.

This report focuses on propulsion and auxiliary fuel needs as key challenges in wild catch fisheries to improve climate resilience and meet the national GHG emissions targets. The project team assessed several fuel reduction options, alternate fuels, and alternate propulsion systems throughout the duration of the project. The need to ensure that fisher profitability was both a key enabler, and a key limitation for option suitability.

Energy Carrier Options

Fossil fuels have held an 80% share of the global energy mix for decades. It has been forecasted that by mid-century fossil fuel use will decrease, but that they still hold a 50% share of the energy mix, a testament to the inertia of fossil energy in an era of decarbonization.[20]

Whatever type of propulsion system is selected there is a need to use some sort of energy carrier. In this section we consider a range of fuels, most of which can be sustainably produced. We also consider how electrical energy might be provided onboard vessels, either on demand from fuels or through battery storage.

Each of the energy carriers includes a table that summarises its characteristics (Appendix 7 – Energy Carriers Summary shows all of them together). The "Suitable Replacement?" row has been used to indicate how suitable that energy carrier is in replacing fossil fuel use with a simple traffic light system (green for "Yes", amber for "Potentially", and red for "No"). The Energy Transition Roadmaps section includes a list of the Recommended Energy Carriers that includes all of the green ones and one of the amber ones (for outboards).

Figure 4 shows a comparison of how the different fuels that might replace diesel fuel in inboard engines compare in terms of suitability and maturity of technology – the size of each bubble is the relative size of the potential reduction in net GHG emissions for each one (actual emission effects will in practice depend on feedstocks, processing, transport, and distribution methods). Dark grey ones are fossil fuels, darker green are biofuels, lighter green are e-fuels.

[20] DNV, 'Energy Transition Outlook 2021 Executive Summary', 2021.

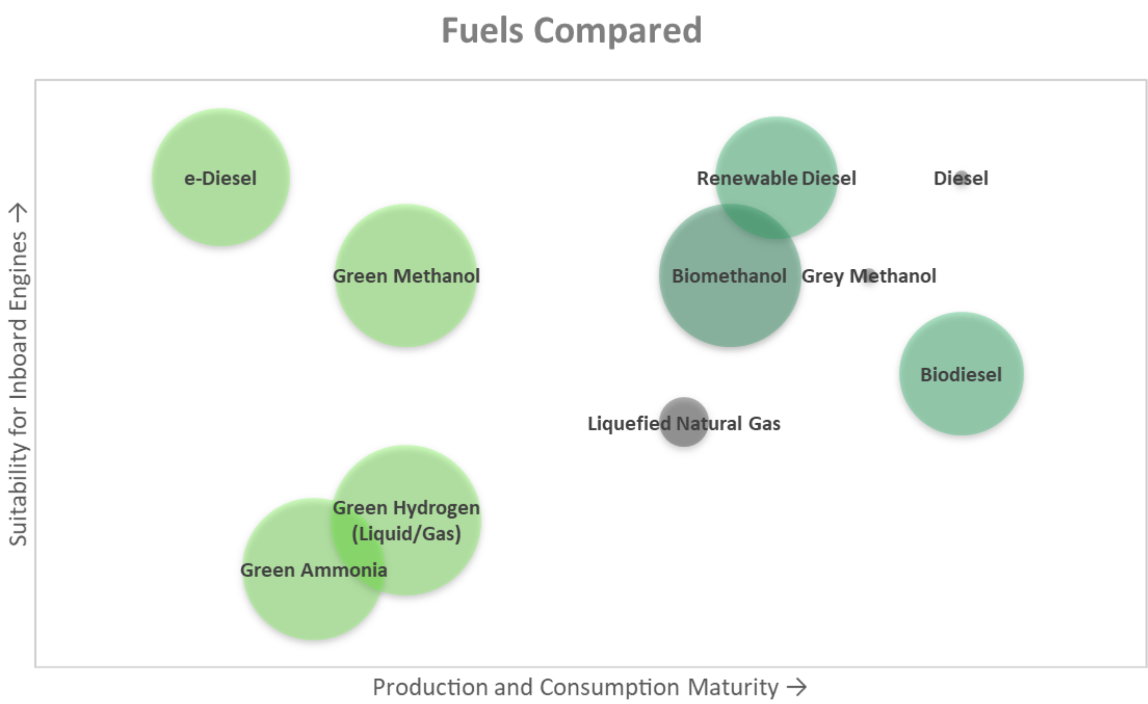

Figure 4: Fuels Compared for Inboard Engine Use. Source: EPA Calculator and FRDC Project 2021-089.

What Makes a Sustainable Fuel?

For a fuel to qualify as sustainable and provide significant benefits in reducing net GHG emissions we must firstly consider the lifecycle GHG emissions (often termed well-to-wake, or WtW) of each fuel, the ability to sustain the production of it (e.g. not impacting food supply, inputs being renewable within reasonably short timeframes, such as years not decades), and then the suitability of it for implementation within the Australian wild catch fishing industry.

In many cases a single chemical fuel has multiple pathways to being produced sustainably. Broadly these can be separated into biofuels, which use sustainably produced biomass as their starting point, and e-fuels, which use sustainably produced green hydrogen as their starting point, and then may add sustainably produced electricity, water, and CO_2 into a variety of sustainable fuels without any need to source a biomass feedstock.

Energy and Volume Densities

One way that the project team evaluated energy carrier options was based on their densities and suitability for fishing vessels (see Figure 5). Different energy sources have different energy densities. To produce a required amount of energy, or marine propulsion, a vessel must both have sufficient space on board for its energy carrier system and be able to handle the extra weight of that energy carrier system. Even when liquified, hydrogen gas is the least energy dense fuel that the project team evaluated, and the current lithium-ion battery storage technologies are even less dense. On the other hand, ammonia, methanol, and renewable diesel are all much closer in density to petro-diesel.

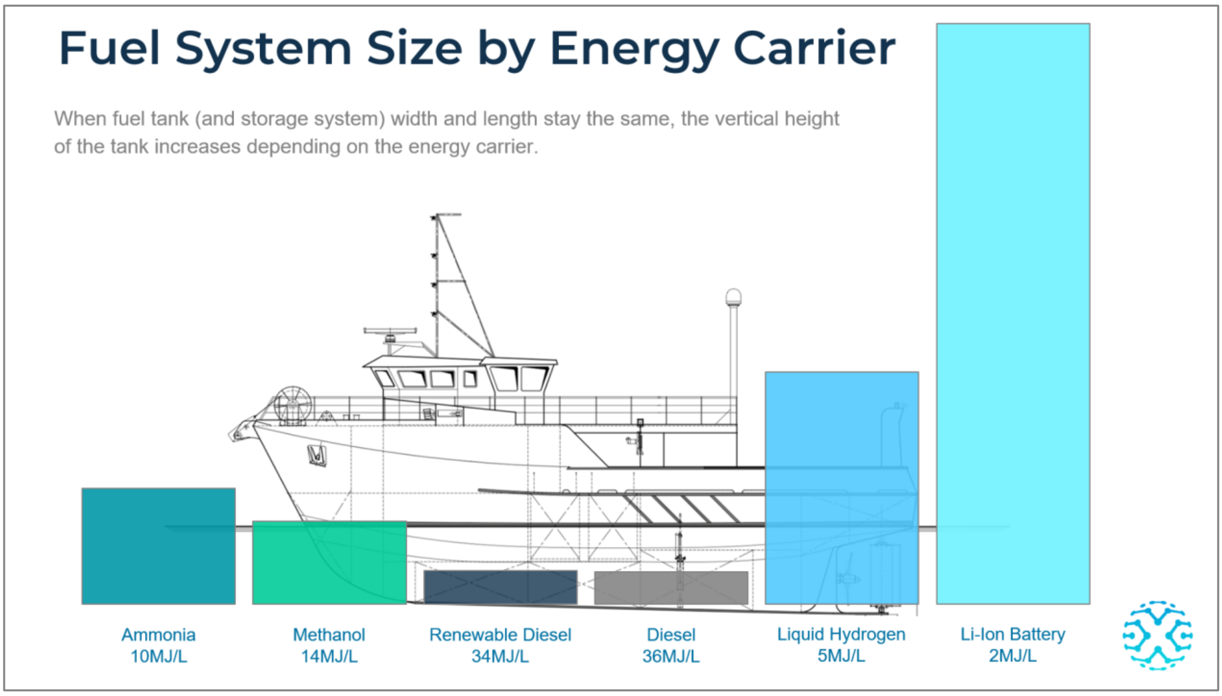

Figure 5: Volume comparisons of different energy carriers (volumetric density).

When we consider the weight of the fuel (gravimetric density) as well as the volume (volumetric density), we can see other differences appear. While initially liquid hydrogen might seem ideal from a gravimetric density perspective, Figure 6 shows how we need to factor in the weight of the storage system too[21].

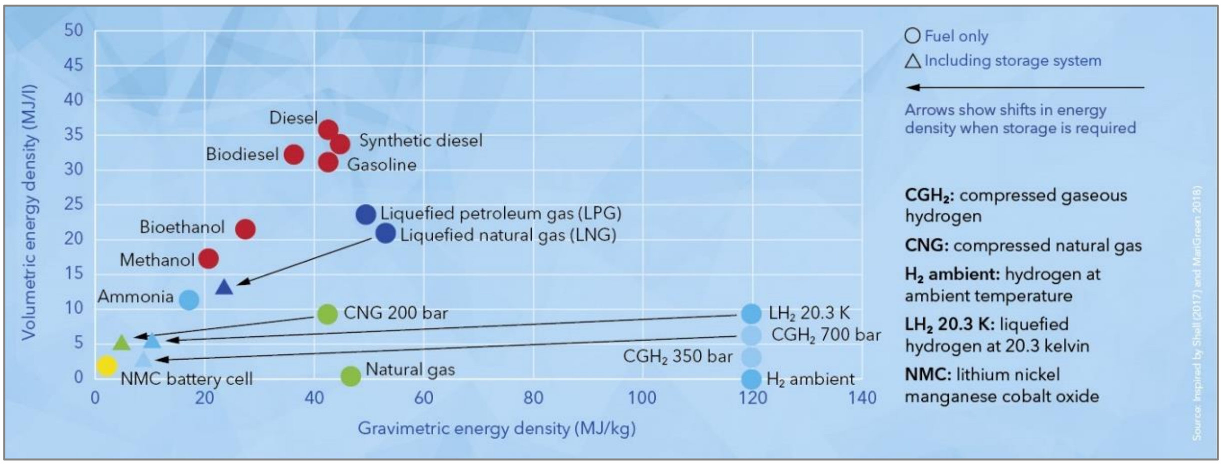

Figure 6: Gravimetric and volumetric storage for alternative fuels. Source: DNV website.

Regulatory Maturity

When considering the suitability of various alternate energy carriers, it is important to also consider how mature the regulations are for onboard use of those alternate fuels. DNV summarised the regulatory maturation timelines for three important alternate fuels (see Figure 7). Of course, these

[21] https://www.dnv.com/expert-story/maritime-impact/How-newbuilds-can-comply-with-IMOs-2030-CO2-reduction-targets.html

timelines are estimates, but they indicate why methanol powered ship orders have received so much press recently[22].

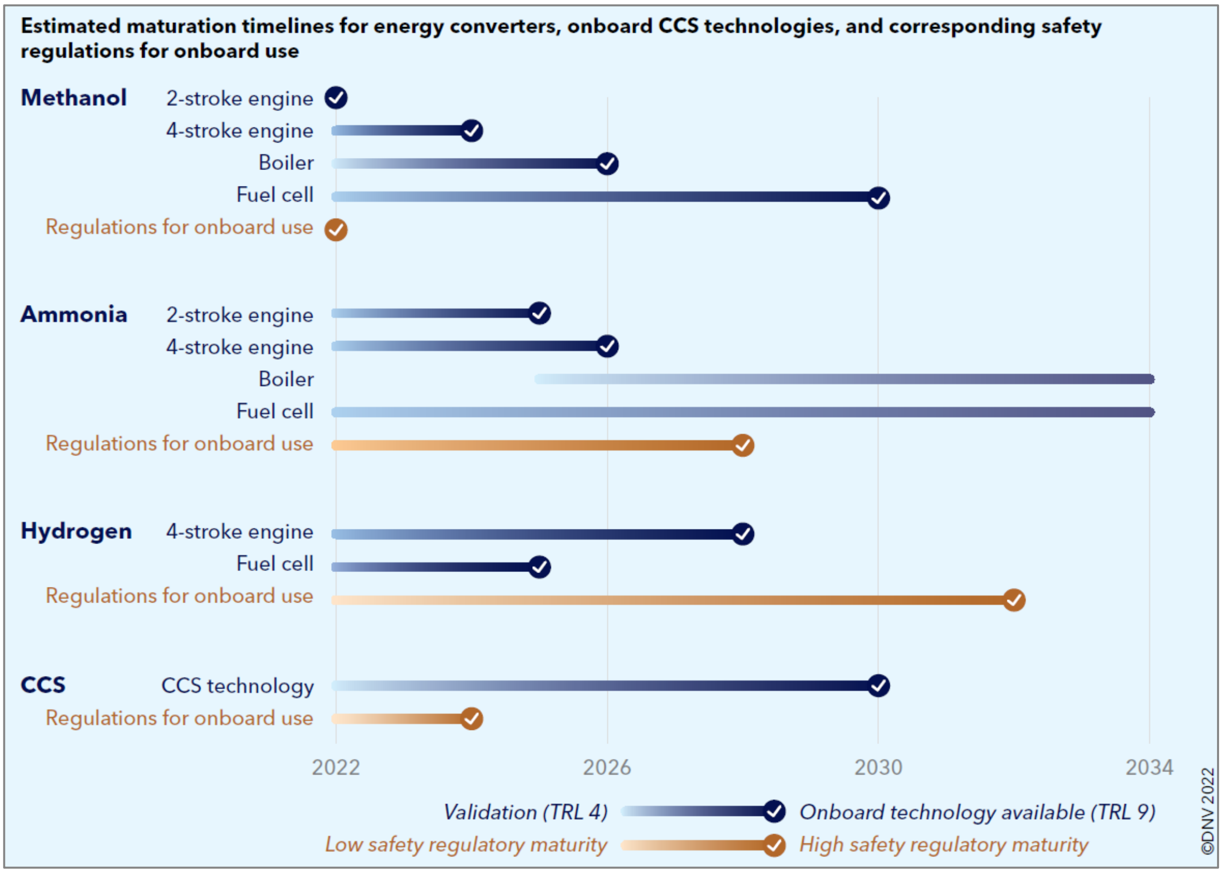

Figure 7: Estimated maturation timelines. Source DNV Maritime Forecast 2050.

Fossil Fuels

While we are looking to move away from fossil fuels, it is worth noting that in the short-term grey methanol may provide a step in the path towards GHG emission reductions as it can support the move towards green methanol. Other fossil fuels have not been considered due to their GHG emissions, but previous FRDC reports have looked at using them from a cost savings perspective[23].

Grey Methanol

Energy Carrier	Grey Methanol
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Slightly worse GHG emissions than diesel when considering well to wake.

[22] http://www.businesskorea.co.kr/news/articleView.html?idxno=118949
[23] FRDC Project No 2006/239. Sterling, Dr D., Goldsworthy, Dr L., Klaka, Dr K., Sterling Trawl Gear Services 2009, *Fishing Energy Efficiency Review for the Fisheries Research and Development Corporation*, Brisbane, (Sep).

Methanol is the simplest form of alcohol, with several ways of creating it (see Figure 8). Grey methanol is a fossil fuel derivative, manufactured from syn-gas derived from reforming of natural gas or coal. As an ICE fuel methanol has similar characteristics to ethanol. In high temperature diesel engines, all the methanol burns up, but in lower temperature engines the incomplete combustion can create formaldehyde a carcinogenic pollutant.

Methanol fuelled engines are currently in use today, although mainly with large cargo ships that transport methanol. Compared to petrol or diesel fuel, methanol is environmentally much safer and less toxic if spilled.[24]

There are also adoption pathways to using methanol. The Methanol Institute has a ready-made safety training package for handling methanol in the maritime sector.[25]

However, the GHG emissions from well-to-wake are worse for grey methanol than for petrodiesel[26]. This means that it is at best a backup fuel source in cases when green methanol is not in sufficient supply.

Marine Safety	Water soluble making spills in large water bodies less dangerous as diffusion is rapid – it also degrades rapidly. Highly flammable (although not as much as diesel), toxic, and lethal if ingested.
Marine Suitability	Not as ignitable as other fuels, requires spark ignition or pilot fuels for compression ignition.
Volumetric Energy Density (including Storage Systems)	Requires fuel tanks slightly more than twice (2x) the size of the same diesel system.
Gravimetric Energy Density (including Storage Systems)	Requires 65% more fuel by weight to provide the same energy as diesel.
Supply TRL	Readily available supply.
Consumption TRL	Few ICE use methanol, but some exist in pilot deployments and OMEs are working on dual-fuel engines.
Potential Supply Issues	Sourced from natural gas and readily available but still has high emissions.
Likely Cost	Priced very similar to diesel at the moment.
Usability	Can retrofit diesel to become dual-fuel engines (ICE), pure methanol ICE developed, methanol reformers can create hydrogen on-vessel, on-demand, or it can be used in solid oxide fuel cells. It is well supported with marine safety systems as it is already a fuel in use and a common cargo.
OEM Support	Engine OEMs are starting to support it, it is already being used very large engines in shipping and bunkered around the world.

[24] https://www.briangwilliams.us/methanol-economy/methanol-and-the-environment.html
[25] https://www.methanol.org/safe-handling/
[26] IRENA And Methanol Institute (2021), Innovation Outlook: Renewable Methanol, International Renewable Energy Agency, Abu Dhabi.

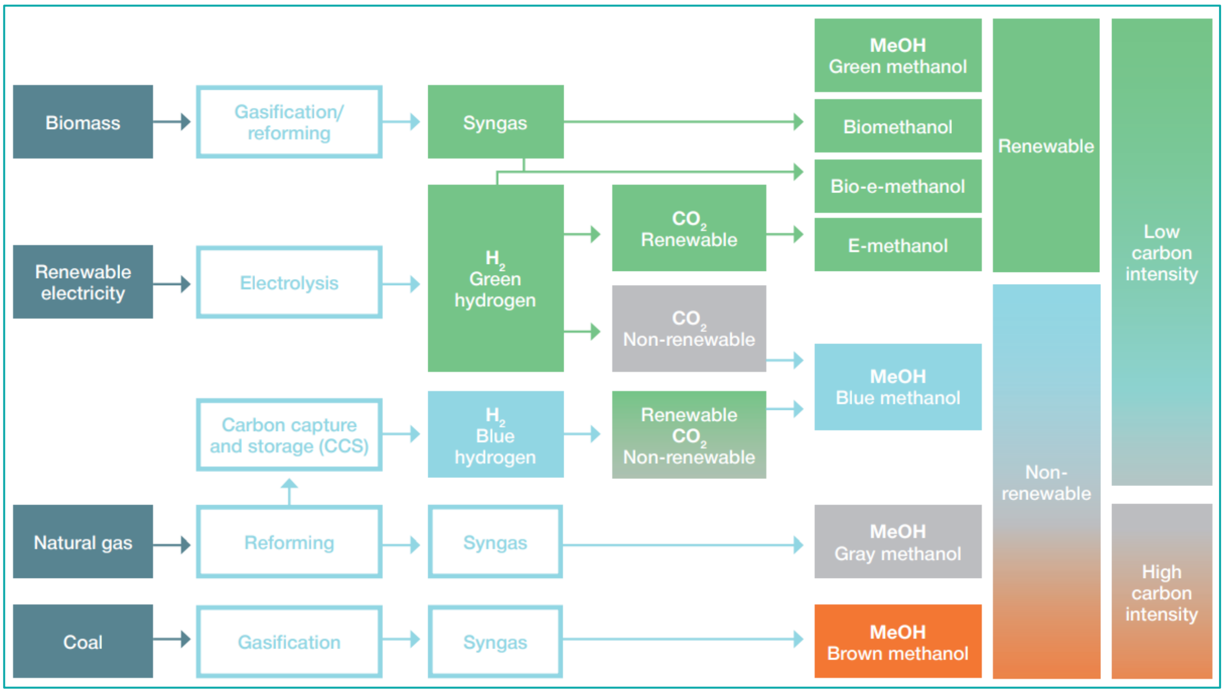

Figure 8: Methanol production pathways. Source: IRENA 2021.

Biofuels

Biofuels use existing biological sources of energy as a starting point for then creating solid, liquid, or gaseous fuels. Sourcing energy from biomass is attractive because the biomass removes carbon from the atmosphere whilst growing which closes the carbon cycle and in theory allowing the fuels created from it to be carbon neutral if certain conditions are met (see Figure 9).

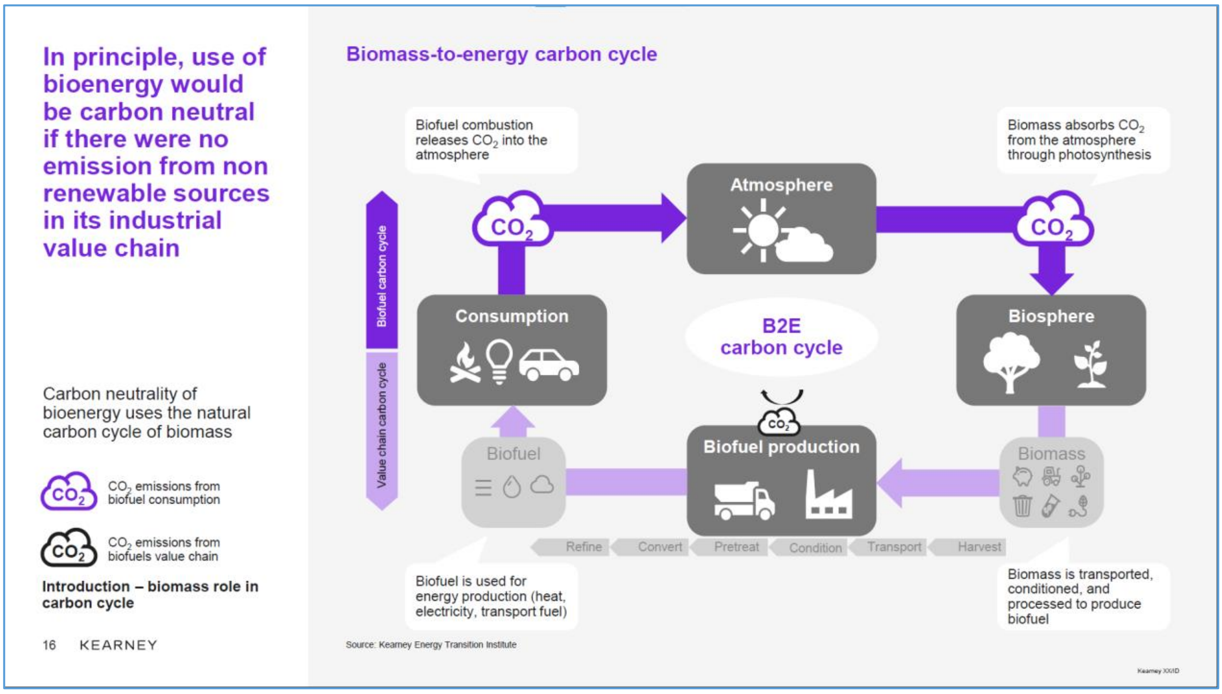

Figure 9: Biomass-to-energy carbon cycle. Source: Kearney Energy Transition Institute's Biomass to Energy Handbook, 2020

ARENA classifies biofuels into conventional biofuels (e.g. ethanol, biodiesel) which are typically not drop-in replacement fuels, and advanced biofuels (e.g. renewable diesel, bio-jet fuel, and bio-gasoline) which have chemical compatibility with their petroleum equivalents.[27] The technology maturity for these range from mature to early stages of research (see Figure 10).

"Advanced biofuels are:

- Referred to as second-, third- and even fourth-generation biofuels, depending on the type of feedstock used
- Produced from non-food feedstocks
- Includes residue from the forestry and agricultural sectors, including straw, cotton trash, sawdust and vegetation removed by agricultural thinning
- Also includes purpose-grown crops such as high-yield grass, woody biomass or algae, typically grown on semi-arable land
- Draws on eligible urban waste streams such as municipal solid waste (MSW) or household rubbish, and food waste streams such as corn stover (stalks, leaves and cobs left over after harvest)
- Compatible with existing fuel infrastructure, these biofuels are widely seen as 'drop-in' biofuels."[28]

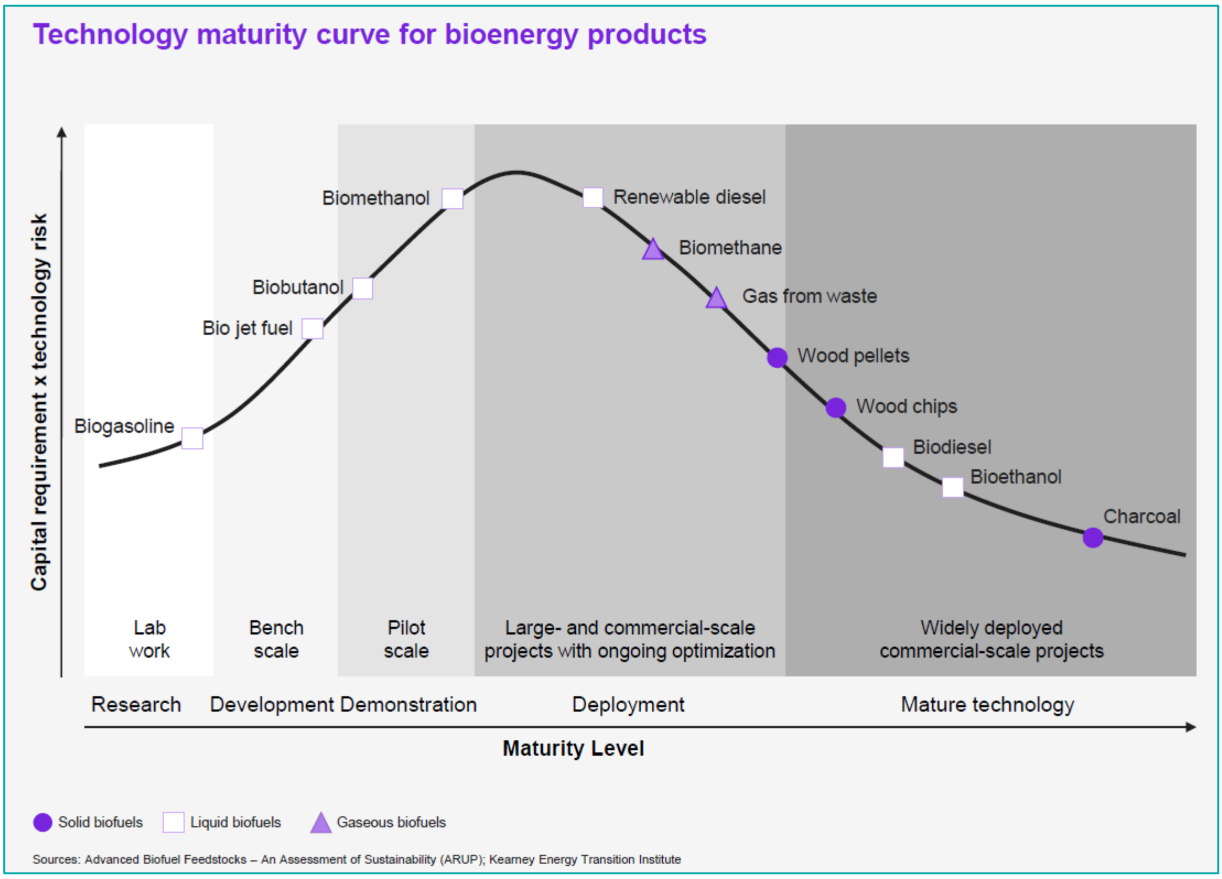

Figure 10: Technology maturity curve for bioenergy products. Source: Kearney Energy Transition Institute's Biomass to Energy Handbook, 2020

[27] 'Biofuels and Transport: An Australian opportunity', ARENA, 2019
[28] Ibid.

Biodiesel

Biodiesel is a renewable alternative to diesel that meets the American Society for Testing and Materials (ASTM) diesel fuel standard, ASTM D6751. Biodiesel is made without petroleum, but it must usually be blended with petrodiesel to be safely used. A common blend is 20% biodiesel to petrodiesel (B20) which is supported by many engine manufacturers.

However, the current Transport for NSW recommendation is that vessel owners avoid these biodiesel fuel blends due to the shorter shelf life of these fuels, B20 tends to oxidise and "an additional fuel stabiliser may be required if biodiesel blends are stored for more than a few months"[29]. There is also the chance of biological growths in the fuel system that may need regular cleaning to remove.

As a conventional biofuel, biodiesel had a lot of early success, but the lack of OEM support for B100 and the characteristics that make it less suitable as a marine fuel mean it is not recommended for the commercial wild catch fishing industry.

Energy Carrier	Biodiesel
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Around 86% for B100. Proportionally less for diesel blends (so B20 is around 17%).
Marine Safety	Is a combustible liquid that burns when heated, but typically becomes flammable when mixed with diesel. Toxic to marine life.
Marine Suitability	Has issues with oxidising around water, biological growths in the tank and long-term storage.
Volumetric Energy Density (including Storage Systems)	Slightly less than diesel, needs about 25% more space – less if blended with diesel.
Gravimetric Energy Density (including Storage Systems)	Requires 18% more fuel by weight to provide the same energy as diesel.
Supply TRL	Supply technology readiness is mature.
Consumption TRL	Consumption technology readiness is mature.
Potential Supply Issues	Relies on biomass feedstocks that will be competed for by other uses.
Likely Cost	Around double the cost of diesel, but that is mitigated by only using 20% of it in a blend.
Usability	Requires fuel system modification even if blended.
OEM Support	Generally supported as a blend with diesel with up to 20% from biodiesel (B20).

In terms of feedstocks, biodiesel can be made from any plant or animal oil, even used cooking oil. As these feedstocks may end up being used for other fuels (e.g. renewable diesel), other feedstocks may need to be considered. Used rubber vehicle tyres is an example for one pilot project, although it has an obvious limitation on availability. GDT Industries turns vulcanised rubber (truck, car & bus tyres) into a bio-oil which can then be refined to a marine grade fuel[30]. The pyrolysis process turns rubber into a 7% diesel product (vapour). The product has been tested and can be suitably turned into marine grade diesel.

[29] https://roads-waterways.transport.nsw.gov.au/about/environment/sustainability/vessel-biofuels.html
[30] https://www.gdtc6.com/tyre-recycling/benefits/

Renewable Diesel

Renewable diesel is a synthetic fuel that recreates the qualities of petrodiesel in a fuel that is sustainably produced. It uses the same, or similar feedstocks to biodiesel, but produces a drop-in replacement fuel for petrodiesel that requires no changes to the diesel engine, fuel system or handling processes, burns cleaner with less NOx emissions, and has exceptional storage stability.

Energy Carrier	Renewable Diesel
Suitable Replacement?	Yes
Potential WtW GHG Emissions Reduction	Between 40% and 80% depending on feedstock, distribution emissions and energy used.
Marine Safety	Has the same safety considerations as normal diesel, although is less toxic and is biodegradable.
Marine Suitability	Has excellent long-term storage properties, even better than normal diesel.
Volumetric Energy Density (including Storage Systems)	Slightly less than diesel, needs about 5% more space – less if blended with diesel.
Gravimetric Energy Density (including Storage Systems)	Slightly lighter than normal diesel.
Supply TRL	Supply technology readiness is at deployment. Australian suppliers are starting up.
Consumption TRL	Consumption technology readiness is mature.
Potential Supply Issues	Relies on biomass feedstocks that will be competed for by other uses. No local suppliers but plants are being built.
Likely Cost	Currently, Neste's renewable diesel imported from Rotterdam is nearly four times the cost of imported diesel. Blending with diesel can reduce costs whilst still getting some GHG emissions reduction.
Usability	No change required to existing engines, tanks, or systems. A true drop-in replacement fuel.
OEM Support	Majority of manufacturers support it.

Currently the most common pathway for renewable diesel is hydrotreating of vegetable and animal fats, oils, and esters. Oceania Biofuels is building a $500 million plant in Gladstone, QLD, that is due to start delivering renewable diesel to customers in 2025[31]. BP Australia has a biorefinery plant at Kwinana, WA that will start producing fuel by 2026[32]. FutureEnergy Australia has a biorefinery planned for Narrogin, WA that is due to produce 500 Ml by 2030[33]. Marr Contracting has sourced renewable diesel (HVO100) from Neste Singapore and has received permission to import the fuel to reduce the net GHG emissions from their entire fleet of cranes.

Another pathway is catalytic upgrading of sugars, and Mercurius Biorefining has a pilot biorefinery in Mackay, QLD that is turning cellulosic biomass (bagasse, cotton waste, wheat and rice straw, food production waste and municipal solid waste) into renewable diesel amongst other products[34].

The Kearney Energy Transition Institute predict that feedstocks for renewable diesel will "shift toward a higher share of cellulosic biomass: agricultural residues, dedicated energy crops (oily), and eventually algae when process maturity will increase"[35]. Algal biofuels were something called out in FISH back in 2014 as a potential direction for the aquaculture industry in Australia[36]. It is vital that the

[31] https://www.statedevelopment.qld.gov.au/news/oceania-biofuels-why-a-world-leading-renewables-company-chose-queensland-for-their-newest-project
[32] https://www.bp.com/en_au/australia/home/media/press-releases/biorefinery-plans-new-milestone.html
[33] https://futurenergyaust.com.au/futureenergy-australia-signs-mou-with-horizon-power/
[34] https://www.mercuriusbiorefining.com/products
[35] https://www.energy-transition-institute.com/insights/biomass-to-energy
[36] https://www.frdc.com.au/fish-vol-22-1/fuel-future

industry targets renewable diesel from feedstocks that minimise secondary impacts such as loss of biodiversity or competition with food crops.

Important note: Renewable diesel and biodiesel are *not* the same fuel. Renewable diesel, previously known as green diesel, is a hydrocarbon produced most often by hydrotreating and via gasification, pyrolysis, and other biochemical and thermochemical technologies. It meets ASTM D975 (USA) specification for petroleum diesel which has led most OEMs to support it (see Figure 11)[37]. Biodiesel is a mono-alkyl ester produced via transesterification.

"Renewable Diesel meets the same ASTM D975 standard for petroleum diesel, making it a true 'drop-in' fuel. It also requires less maintenance costs than other alternative fuels, and there is no warranty risk for using it to power any Volvo model equipped with a Volvo engine."

— Frank Bio, Director - Sales Development, Specialty Vehicles and Alternative Fuels; Volvo Trucks North America

"The use of Renewable Diesel allows customers to minimize their emissions-based footprints without additional capital investment. Plus, they have the comfort of knowing that Cummins conducted a thorough analysis prior to approval."

— Jim Fier, Vice President, Engineering; Cummins

Figure 11: Sample OEM Approval of Renewable Diesel. Source: Neste website.

Benefits of renewable diesel include:

- **Engine and infrastructure compatibility** — Renewable diesel is chemically identical to fossil-derived diesel counterparts which minimizes compatibility issues with existing infrastructure and engines (see Figure 12).
- **Increased energy security** — Renewable diesel can be produced domestically from a variety of feedstocks and contribute to job creation (see Figure 13).
- **More flexibility** — Biofuels such as renewable diesel are replacements for conventional diesel, jet fuel, and petrol, allowing for multiple products from various feedstocks and production technologies.

[37] https://www.neste.us/neste-my-renewable-diesel/product-information/oem-approvals

Figure 12: Simulated harsh environment testing of B5, ULSD and Renewable Diesel. Source: Diesel Presentation to Detroit Advisory Panel 2017.

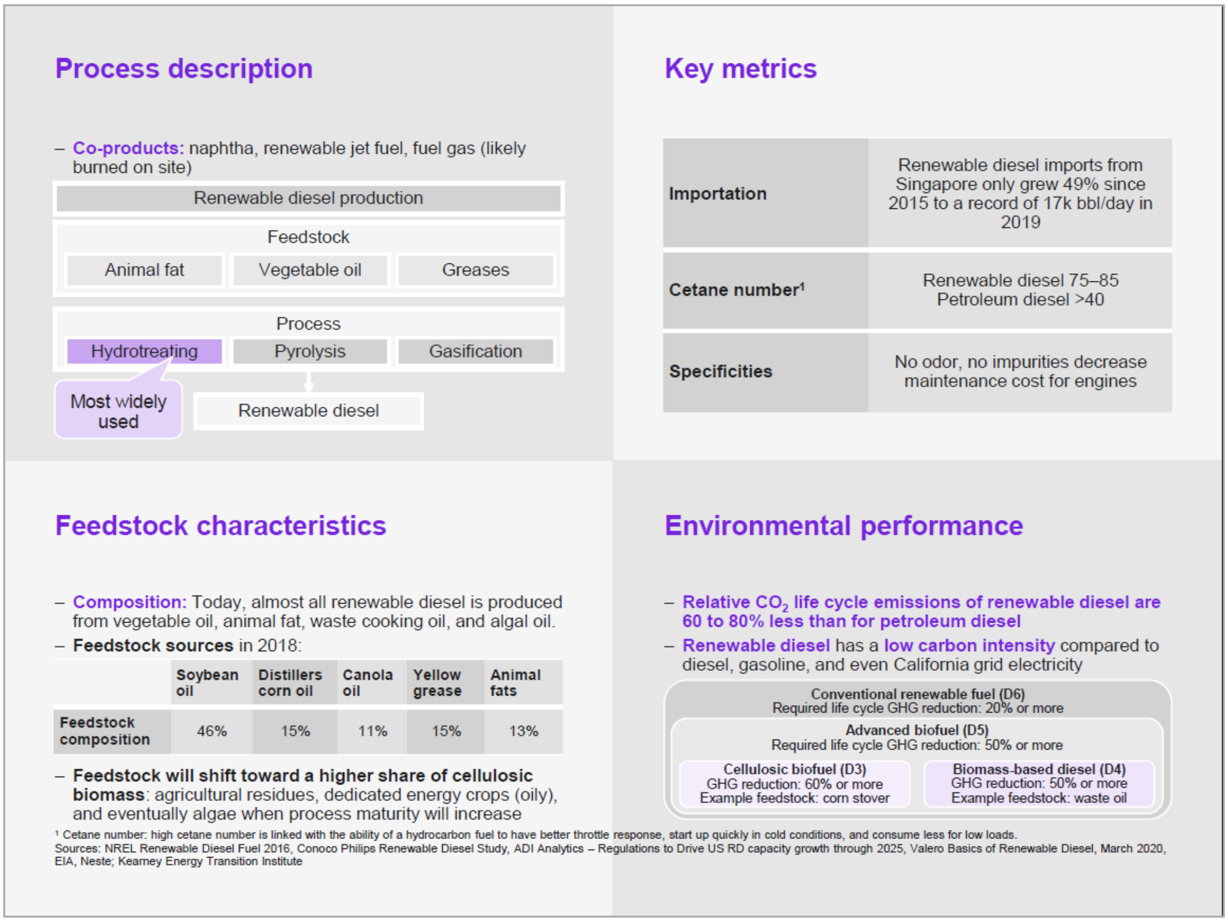

Figure 13: Renewable Diesel Production (USA specific commentary). Source: Kearney Energy Transition Institute's Biomass to Energy Handbook, 2020

One of the issues with renewable diesel is that the costs of creating it are greater than biodiesel, as it is processed further to meet ATSM D975, but it uses the same types of biomass feedstocks. As regulations in California, other USA states and European countries like Norway have started specifying the use of renewable diesel it is expected that the market for biodiesel will stagnate or decline and renewable diesel will significantly grow (see Figure 14).

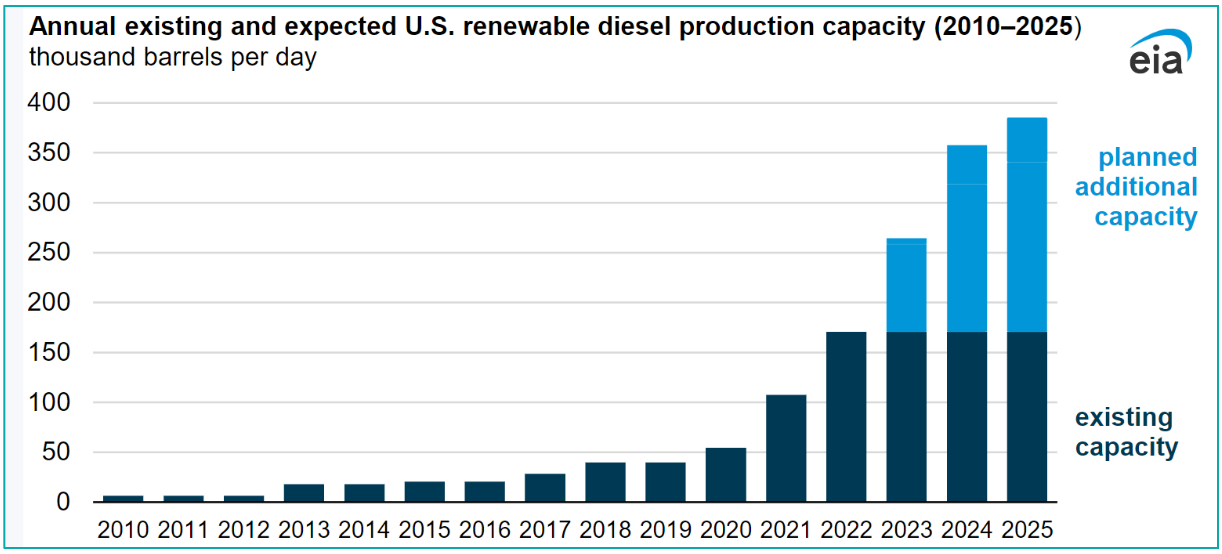

Figure 14: Predicted growth in USA Renewable Diesel production by 2025. Source: EIA.

Some OEMs like Volvo Penta have now started recommending customers use renewable diesel (HVO100) as a way of achieving immediate improvements in sustainability and reducing GHG emissions[38]. They have also pointed out the restricted availability of sustainably sourced renewable diesel:

> HVO fuel cannot be produced in unlimited quantities and only a limited amount can be produced sustainably. This is an industry-wide challenge and we've been selective when it comes to finding suppliers. We encourage Volvo Penta product owners to seek out information on HVO availability in their region.[39]

[38] https://www.volvopenta.com/about-us/news-page/2022/sep/top-5-tips-using-hvo-100-fossil-free-fuel-instead-of-diesel/

[39] https://www.volvopenta.com/about-us/news-page/2022/jun/volvo-penta-case-study-on-hvo-fuel-in-all-demo-and-test-boats/

Biomethanol

Methanol is the simplest form of alcohol, and biomethanol is a biofuel, manufactured by fermentation of biomass or biomethane reforming. As an ICE fuel methanol has similar characteristics to ethanol. In high temperature diesel engines, all the methanol burns up, but in lower temperature engines the incomplete combustion can create formaldehyde: a carcinogenic pollutant.

Methanol's popularity is growing within the marine sector, especially in shipping, as a low carbon fuel. Danish shipping giant, Maersk, has made preliminary steps to off-take green methanol (produced from renewable energy sources such as green hydrogen and captured carbon) for its first carbon neutral vessel. Compared to petrol or diesel fuel, methanol is environmentally much safer and less toxic if spilled.[40]

The Maersk Mc-Kinney Moller Center for Zero carbon shipping presents a simple, interactive overview of readiness across the main alternative fuel pathways as presented in the Shipping Industry's Transition Strategy 2021.[41]

In terms of OEMs that are supporting green methanol, there is a mix between ones that want to use spark ignition (required for pure methanol blends) and others compression ignition enabled by a pilot fuel (between 3% and 30% blend of pilot fuel, depending on fuel and engine load) to help the fuel ignite under compression. Caterpillar Marine, Rolls-Royce Power Systems, and Cummins are all working on methanol fuelled engines[42].

Energy Carrier	Biomethanol
Suitable Replacement?	Yes
Potential WtW GHG Emissions Reduction	Between 50% and 80% depending on feedstock, distribution emissions and energy used.
Marine Safety	Water soluble making spills in large water bodies less dangerous as diffusion is rapid – it also degrades rapidly. Highly flammable (although not as much as diesel), toxic, and lethal if ingested.
Marine Suitability	Not as ignitable as other fuels, requires spark ignition or pilot fuels for compression ignition.
Volumetric Energy Density (including Storage Systems)	Requires fuel tanks slightly more than twice (2x) the size of the same diesel system.
Gravimetric Energy Density (including Storage Systems)	Requires 65% more fuel by weight to provide the same energy as diesel.
Supply TRL	Supply is building due to demand in shipping and power generation where transportability is a major requirement.
Consumption TRL	Few ICE use methanol, but some exist in pilot deployments and OEMs are working on dual-fuel engines.
Potential Supply Issues	A key feedstock in the creation of sustainable aviation fuel (SAF), although there is some use of it as a marine fuel in the USA.
Likely Cost	It is expected to be around double the cost of diesel before subsidies.
Usability	Can retrofit diesel to become dual-fuel engines (ICE), pure methanol ICE developed, methanol reformers can create hydrogen on-vessel, on-demand, or it can be used in solid oxide fuel cells. It is well supported with marine safety systems as it is already a fuel in use and a common cargo.
OEM Support	Engine OEMs are starting to support it, it is already being used very large engines in shipping and bunkered around the world.

[40] https://www.briangwilliams.us/methanol-economy/methanol-and-the-environment.html
[41] https://www.zerocarbonshipping.com/fuel-pathways/
[42] https://www.rivieramm.com/news-content-hub/oems-develop-green-engine-technologies-73326

Biobutanol

When it comes to marine-specific blends of alcohols and petrol, butanol has had the greatest success, as a complex alcohol it is energy dense and is not miscible with water so stays blended in marine contexts. Currently a 16% blend (Bu16) is the recommended alcohol blend for petrol for outboard motors. Biobutanol is an advanced biofuel created from sugar-rich biomass that offers better GHG emissions reduction (around 30% in Bu16 blend[43]) than normal petrol.

Energy Carrier	Biobutanol
Suitable Replacement?	Yes
Potential WtW GHG Emissions Reduction	Around 30% for Bu16 blend vs pure petrol.
Marine Safety	Has the same safety considerations as normal petrol.
Marine Suitability	Is not immiscible in water so has excellent long-term storage potential (better than E10).
Volumetric Energy Density (including Storage Systems)	Slightly less than petrol, needs about 10-20% more space – less if blended with petrol.
Gravimetric Energy Density (including Storage Systems)	Slightly lighter than normal diesel.
Supply TRL	Supply technology readiness is mature.
Consumption TRL	Consumption technology readiness is mature.
Potential Supply Issues	A key feedstock in the creation of sustainable aviation fuel (SAF), although there is some use of it as a marine fuel in the USA.
Likely Cost	Slightly more expensive than E10 fuel.
Usability	No change required to existing engines, tanks, or systems. A true drop-in replacement fuel.
OEM Support	Currently a 16% blend (Bu16) is the recommended alcohol blend for petrol for outboard motors.

Long-term storage of Bu16 has had issues with the butanol levels rising over time due to “vaporization of some of the more volatile compounds in the blend.”[44] This was handled by re-blending the fuel stock before use, so long-term storage of blended fuel will need to be managed (E10 has similar issues).

Biobutanol is also a key feedstock in the creation of sustainable aviation fuel (SAF)[45] and the few pilot programs in Australia are aiming at satisfying that market[46]. However, it is uniquely useful when blended with petrol by creating an outsized reduction of emissions and would be a good option to help outboard users in the commercial wild catch fishing industry reduce GHG emissions.

[43] https://www.marinebusinessnews.com.au/2023/02/sustainable-marine-fuels-in-the-spotlight-at-last-weeks-discover-boating-miami-international-boat-show/
[44] US Coast Guard (2015), *Butanol / Gasoline Mercury CRADA Report CG-D-11-15*, Connecticut, USA (February)
[45] BioEnergy Australia (2022), *Transitioning Australia’s Liquid Fuel Sector: The Role of Renewable Fuels*
[46] https://www.virginaustralia.com/au/en/about-us/sustainability/sustainable-fuel/

Hydrogen Based e-Fuels

These are any fuel that can be created from hydrogen and CO_2 without a biomass feedstock. They are also sometimes referred to as synthetic fuels, and the process of creating them is called power-to-liquid, or power-to-gas, or generically power-to-X (see Figure 15). With fishing vessels, the most useful form is usually a liquid one as that minimises the space required (see Energy and Volume Densities). Because the result is inherently sustainable, the individual fuels are also often termed 'Green' (see Figure 8 for the methanol example).

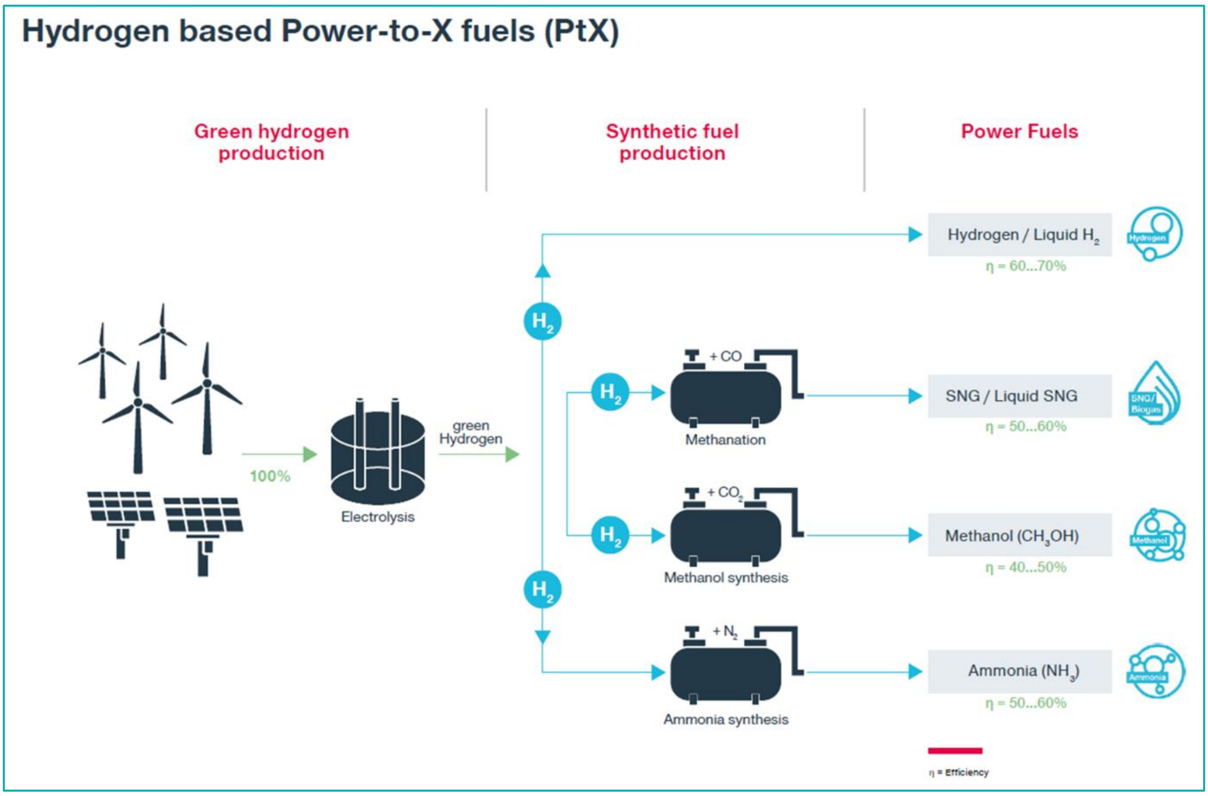

Figure 15: A variety of hydrogen-based Power-to-X fuels. Source: A Maritime Energy Transition, MAN Energy Solutions.

These e-fuels all start with the creation of green hydrogen through electrolysis of water. Australia has a notable advantage in this area which is worth noting when considering alternative fuels for the commercial wild-catch fishing industry:

> Australia is experiencing a remarkable opportunity with the rise of the hydrogen economy. The country is among the leaders with one of the largest hydrogen project pipelines, boasting a capacity of 12 million tonnes per year, 96% of it dedicated solely to green hydrogen projects.
>
> The country's advantage lies in its abundant renewable resources and vast land availability. The region benefits from strong winds and solar irradiance, allowing hybrid onshore wind and solar projects to achieve capacity factors comparable to baseload power generation. This unique advantage enables green hydrogen, produced through hybrid renewables, to project a levelised cost of hydrogen (LCOH) of USD 4 per kilogramme by 2027, eventually reaching cost parity with blue hydrogen, according to WoodMac. In 2050, Australia is predicted to produce

> the fifth-cheapest green hydrogen in the world, according to projections by the International Renewable Energy Agency (IRENA).[47]

There are a number of ways of assessing the climate friendliness of hydrogen, mostly based on the where the hydrogen came from, and whether GHG emissions are a side-effect of its production – a range of colours has been suggested from green to turquoise, blue, pink, yellow, grey, and even brown. One of the key changes being made in Australia is to introduce a Guarantee of Origin scheme (see Figure 16) so that the 'çolour' of hydrogen can be guaranteed:

> The Guarantee of Origin (GO) is a world-class assurance scheme being designed to track and verify emissions associated with hydrogen, renewable electricity and potentially other products made in Australia. Over time, it could expand to include a range of products such as metals and biofuels.

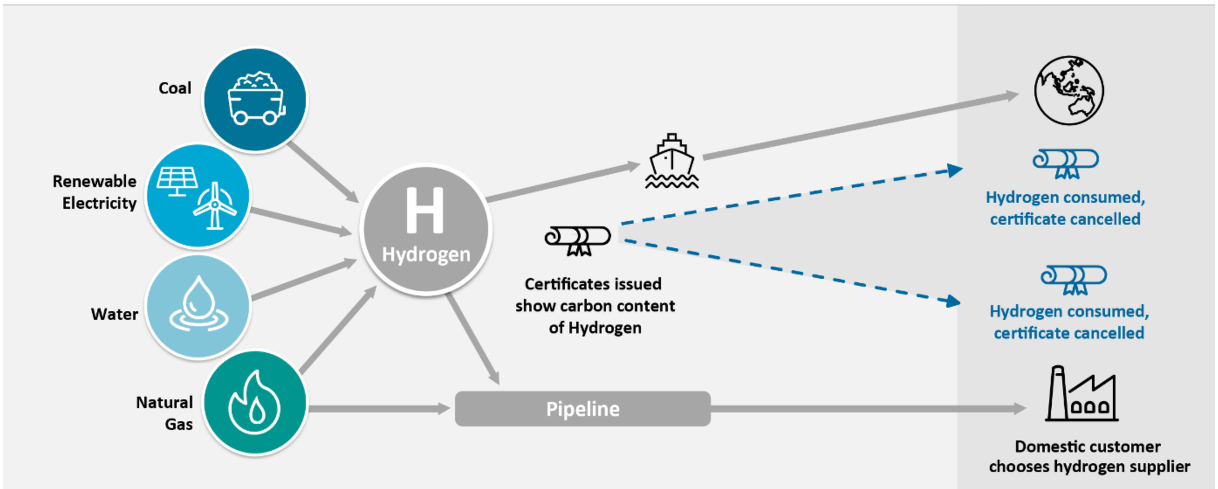

Figure 16: Australia's Guarantee of Origin scheme. Source: Clean Energy Regulator.

This should help make it easier to identify green hydrogen, which is what the rest of this section will assume is the underlying fuel, and which has close to zero carbon emissions associated with it.

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[47] Vasileva, A., *Hydrogen Export Markets – Latest Trends and Development*, World Hydrogen Week, July 2023.

Green Hydrogen (Liquid)

Lower GHG emission hydrogen can be produced by using a fossil fuel (natural gas) and then carbon capture technology to store CO_2 (blue hydrogen) or more sustainably by using renewable energy in a process called electrolysis which converts water into hydrogen and oxygen (green hydrogen, or e-hydrogen).

Liquid storage of hydrogen provides some advantages over gaseous options because the density of a saturated liquid hydrogen molecule at 1 atmosphere is 70 kg/m^3. But conventional liquefaction facilities are very energy intensive with energy demands that consumes more than 30% of the energy content of the hydrogen produced. There is also significant volume and energy requirements for the equipment to maintain the hydrogen at the very low temperatures required.

Current barriers to using hydrogen as a marine fuel include:

- Lack of safety requirements
- Low maturity of technology
- Large onboard storage space
- High investment cost

Energy Carrier	Green Hydrogen (Liquid)
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, energy used and fugitive emissions. Cryogenic equipment reduces the energy available for other uses.
Marine Safety	Very safe for marine organisms as leaks will result in gas venting upward, however marine safety regulations are still being worked on for below deck storage of liquid Hydrogen.
Marine Suitability	Not suitable due to the large volume required for storage of the amount of fuel required.
Volumetric Energy Density (including Storage Systems)	Much less dense than most other options, even in liquid form (which sacrifices 30% of the energy used).
Gravimetric Energy Density (including Storage Systems)	When storage systems are included liquid hydrogen weighs six (5x) times as much as diesel.
Supply TRL	Supply technology readiness is at pilot scale.
Consumption TRL	Consumption technology readiness is at the research stage still.
Potential Supply Issues	Very little supply yet, although new projects are coming online all the time.
Likely Cost	Currently prohibitively expensive, although Australia has lots of green hydrogen projects in the works.
Usability	Completely new engines, fuel systems, refuelling and safety processes are required.
OEM Support	Support is there due to government focus on hydrogen in Japan and Germany, but globally fuel cells and hydrogen derivatives are seen as more feasible for maritime uses.

Maritime classification society DNV has declared that pure hydrogen is not suitable as a maritime fuel for the shipping industry, pointing instead to derivatives of green hydrogen such as green ammonia or green methanol instead[48].

However, while not considered to be an appropriate fuel for inshore or deepwater fishing vessels, green hydrogen may play a crucial role as a feedstock to produce other e-fuels that may assist in decarbonisation of the marine sectors.

[48] https://www.hydrogeninsight.com/transport/dnv-rules-out-pure-hydrogen-as-a-future-long-distance-shipping-fuel/2-1-1325801

Green Hydrogen (Gas)

Lower GHG emission hydrogen can be produced by using a fossil fuel (natural gas) and then carbon capture technology to store CO_2 (blue hydrogen) or more sustainably by using renewable energy in a process called electrolysis which converts water into hydrogen and oxygen (green hydrogen, or e-hydrogen).

Gaseous hydrogen is required to be stored at pressure. Construction of the tanks that are necessary to hold gaseous hydrogen under 700 atmospheres of pressure (700 bar) uses specially designed composite overwrapped pressure vessels (COPVs). Gaseous hydrogen storage tank designs up to 700 atmospheres exist primarily for automotive applications, but the costs to construct these tanks increase significantly for larger scale hydrogen storage solutions.

Energy Carrier	Green Hydrogen (Gas)
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, energy used and fugitive emissions.
Marine Safety	Very safe for marine organisms as leaks will result in gas venting upward, however marine safety regulations are still being worked on for below deck storage of liquid Hydrogen.
Marine Suitability	Not suitable due to the large volume required for storage of the amount of fuel required.
Volumetric Energy Density (including Storage Systems)	Much less dense than most other options. At 700 bar the volume is ten (10x) times larger than diesel fuel tanks.
Gravimetric Energy Density (including Storage Systems)	When storage systems are included gaseous hydrogen at 700 bar weighs six (6x) times as much as diesel.
Supply TRL	Supply technology readiness is at pilot scale.
Consumption TRL	Consumption technology readiness is at the research stage still.
Potential Supply Issues	Very little supply yet, although new projects are coming online all the time.
Likely Cost	Currently prohibitively expensive, although Australia has lots of green hydrogen projects in the works.
Usability	Completely new engines, fuel systems, refuelling and safety processes are required.
OEM Support	Support is there due to government focus on hydrogen in Japan and Germany, but globally fuel cells and hydrogen derivatives are seen as more feasible for maritime uses.

Large storage requirements of bulk hydrogen gas in high pressure COPVs not only necessitate significant and specific storage volume and footprint, but they also incur noteworthy investment capital acquisition expenses. High pressure gas storage systems are also required to be recertified at a five-year mark; this means that after five years of service, the tank(s) must be vented, pressure tested and refilled, which significantly adds to the system's operational expenses. The addition of these capital and operational expenses greatly increases the original cost of hydrogen delivered, which begins at roughly $12 per kg. (2.2 lbs.).

Current barriers to using hydrogen as a marine fuel include:

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However, while not considered to be an appropriate fuel for inshore or deepwater fishing vessels, green hydrogen may play a crucial role as a feedstock to produce other e-fuels that may assist in decarbonisation of the marine sectors.

[49] https://www.hydrogeninsight.com/transport/dnv-rules-out-pure-hydrogen-as-a-future-long-distance-shipping-fuel/2-1-1325801

Green Methanol

Methanol is the simplest form of alcohol, and green methanol (or e-methanol) is an e-fuel, manufactured from syn-gas derived from green hydrogen. As an ICE fuel methanol has similar characteristics to ethanol. In high temperature diesel engines, all the methanol burns up, but in lower temperature engines the incomplete combustion can create formaldehyde: a carcinogenic pollutant.

Methanol's popularity is growing within the marine sector, especially in shipping, as a low carbon fuel. Danish shipping giant, Maersk, has made preliminary steps to off-take green methanol (produced from renewable energy sources such as green hydrogen and captured carbon) for its first carbon neutral vessel. Compared to petrol or diesel fuel, methanol is environmentally much safer and less toxic if spilled.[50]

The Maersk Mc-Kinney Moller Center for Zero carbon shipping presents a simple, interactive overview of readiness across the main alternative fuel pathways as presented in the Shipping Industry's Transition Strategy 2021.[51]

In terms of OEMs that are supporting green methanol, there is a mix between ones that want to use spark ignition (required for pure methanol blends) and others compression ignition enabled by a pilot fuel (between 3% and 30% blend of pilot fuel, depending on fuel and engine load) to help the fuel ignite under compression. Caterpillar Marine, Rolls-Royce Power Systems, and Cummins are all working on methanol fuelled engines[52].

Energy Carrier	Green Methanol
Suitable Replacement?	Yes
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, source of hydrogen, source of carbon, and energy used.
Marine Safety	Water soluble making spills in large water bodies less dangerous as diffusion is rapid – it also degrades rapidly. Highly flammable (although not as much as diesel), toxic, and lethal if ingested.
Marine Suitability	Not as ignitable as other fuels, requires spark ignition or pilot fuels for compression ignition.
Volumetric Energy Density (including Storage Systems)	Requires fuel tanks slightly more than twice (2x) the size of the same diesel system.
Gravimetric Energy Density (including Storage Systems)	Requires 65% more fuel by weight to provide the same energy as diesel.
Supply TRL	Supply is building due to demand in shipping and power generation where transportability is a major requirement.
Consumption TRL	Few ICE use methanol, but some exist in pilot deployments and OEMs are working on dual-fuel engines.
Potential Supply Issues	Relies on green hydrogen feedstocks that will be competed for by other uses. No local suppliers yet.
Likely Cost	It is expected to be around double the cost of diesel before subsidies.
Usability	Can retrofit diesel to become dual-fuel engines (ICE), pure methanol ICE developed, methanol reformers can create hydrogen on-vessel, on-demand, or it can be used in solid oxide fuel cells. It is well supported with marine safety systems as it is already a fuel in use and a common cargo.
OEM Support	Engine OEMs are starting to support it, it is already being used very large engines in shipping and bunkered around the world.

[50] https://www.briangwilliams.us/methanol-economy/methanol-and-the-environment.html
[51] https://www.zerocarbonshipping.com/fuel-pathways/
[52] https://www.rivieramm.com/news-content-hub/oems-develop-green-engine-technologies-73326

Green Ammonia

Green ammonia (NH_3) is produced from nitrogen and green hydrogen via the Haber-Bosch process. Ammonia is liquid at 1 atmosphere and -33°C, or at 8 atmospheres and 20°C. The gravimetric and volumetric energy density is less than a third of diesel which means it takes much more space and weight to get the same amount of energy. Unlike cryogenic fuels, the liquefaction costs of ammonia are less than a percent of the fuel energy content.

Ammonia fuel is difficult to ignite and doesn't sustain combustion well, it also creates more NOx emissions than diesel. Combining ammonia with a liquid pilot fuel such as diesel is required for it to work in ICE engines. In fuel cells ammonia reformers can be used to extract hydrogen from the fuel in a similar way to methanol.

Ammonia is particularly toxic and unlike methanol "There are currently no health, safety or environmental guidelines for ammonia as a shipping fuel, although in discussion."[53] DNV points out that the "key hazard with ammonia is its toxicity; it is harmful to personnel at concentrations well below its lower flammability limit of 15% in air. For example, UK HSE indicates a concentration of 0.36% could cause 1% fatalities given 30 minutes of exposure. Concentrations of 5.5% could cause 50% fatalities following 5 minutes of exposure."[54]

Due to this toxicity, and a lack of compelling differences to green methanol, the project considers green ammonia should not be relied upon to help the commercial wild catch fishing industry decarbonise.

Energy Carrier	Green Ammonia
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, source of hydrogen, energy used, and fugituve emissions. Requires scrubbers to limit NOx emissions when burned.
Marine Safety	Ammonia gas is lighter than air and will rise, so that generally it does not settle in low-lying areas. However, in the presence of moisture, ammonia can form vapors that are heavier than air. Exposure causes immediate burning of the eyes, nose, throat and respiratory tract and can result in blindness, lung damage or death.
Marine Suitability	Ammonia fuel is difficult to ignite and doesn't sustain combustion well, it also creates more NOx emissions than diesel.
Volumetric Energy Density (including Storage Systems)	The energy density is less than a third of diesel, so more than three (3x) times larger fuel tanks, plus safety systems (unknown as yet).
Gravimetric Energy Density (including Storage Systems)	When storage systems are included green ammonia weighs slightly more than twice (2x) times as much as diesel.
Supply TRL	Supply technology readiness is at pilot scale. Once you have green hydrogen it can use the normal mature process for ammonia production.
Consumption TRL	Few ICE use ammonia, but some exist in pilot deployments and OEMs are working on dual-fuel engines.
Potential Supply Issues	Relies on green hydrogen feedstocks that will be competed for by other uses. No local suppliers yet. Will likely be needed to decarbonise agriculture before being used as a maritime fuel.
Likely Cost	Unknown.
Usability	Combining ammonia with a pilot fuel such as diesel is required for it to work in ICE engines. In fuel cells ammonia reformers can be used to extract hydrogen from the fuel first. Requires retrofit kits or new dual-fuel engines (ICE).
OEM Support	No engine OEMs are looking at ammonia for high or medium speed engines.

[53] Coates S, Dawson Dr L, Ware Dr J and Vest L, 'Ammonia as a Shipping Fuel: Impacts of large spill scenarios', EDF, Lloyd's Register, Ricardo PLC, 2022
[54] DNV, 'Hydrogen Forecast to 2050', 2023.

e-Diesel

e-Diesel is a synthetic e-fuel based on raw materials such as water and CO_2 from the atmosphere. e-diesel has its origin in 2014, from an alliance between the German manufacturer Audi and the technology company Sunfire which has since pivoted to target sustainable aviation fuels. This is a common story when looking at the current focus for longer chain e-fuels, which has been dominated by sustainable aviation fuels (SAF), due to the global demand for SAF and lack of other alternatives.

In theory it is a fuel that does not generate GHG emissions though it can still power conventional engines just as diesel does and so creates similar exhaust emissions. The Fischer-Tropsch process is used to take the combined gases and creates a synthetic oil that can be further refined into renewable diesel and other products.[55] It depends on carbon capture and storage (CCS) systems, exhaust aftertreatment and CO_2 re-use (EACR) systems, or direct air capture (DAC) systems to provide the source carbon which then makes the tailpipe emissions sustainable (see Emissions Capture).

Energy Carrier	e-Diesel
Suitable Replacement?	Potentially
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, source of hydrogen, source of carbon, and energy used.
Marine Safety	Has the same safety considerations as normal diesel, although is less toxic and is biodegradable.
Marine Suitability	Has excellent long-term storage properties, even better than normal diesel.
Volumetric Energy Density (including Storage Systems)	Slightly less than diesel, needs about 5% more space – less if blended with diesel.
Gravimetric Energy Density (including Storage Systems)	Slightly lighter than normal diesel.
Supply TRL	No projects currently active.
Consumption TRL	Consumption technology readiness is mature.
Potential Supply Issues	Lack of commercial interest due to cost of production process.
Likely Cost	Unknown.
Usability	No change required to existing engines, tanks, or systems. A true drop-in replacement fuel.
OEM Support	No engine OEMs have discussed e-diesel, but in theory it should be easy to support.

As green methanol is an intermediate product in the creation of e-diesel and there has been a lack of commercial interest in creating e-diesel vs SAF, the project considers that e-diesel should not be relied upon to help the commercial wild catch fishing industry decarbonise.

Important Note: In the USA the term 'e-diesel' is used to refer to diesel blended with ethanol.

[55] https://digismak.com/what-is-e-diesel-the-promising-synthetic-fuel-based-on-water-and-air-compatible-with-conventional-engines/

e-Gasoline

e-Gasoline is a synthetic e-fuel based on raw materials such as water and CO_2 from the atmosphere.

In theory it is a fuel that does not generate GHG emissions though it can still power conventional engines just as petrol does and so creates similar exhaust emissions. The Fischer-Tropsch process is used to take the combined gases and creates a synthetic oil that can be further refined into renewable diesel and other products.[56] It depends on carbon capture and storage (CCS) systems, exhaust aftertreatment and CO_2 re-use (EACR) systems, or direct air capture (DAC) systems to provide the source carbon which then makes the tailpipe emissions sustainable.

HIF Global have plans to create an e-fuels plant in Surrey Hills, Tasmania that is predicted to produce up to 100 million litres of e-fuels annually, starting from mid-2026[57]. They expect to create e-gasoline and/or sustainable aviation fuels (SAF).

Energy Carrier	e-Gasoline
Suitable Replacement?	Potentially
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, source of hydrogen, source of carbon, and energy used.
Marine Safety	Has the same safety considerations as normal petrol, although is less toxic and is biodegradable.
Marine Suitability	Has excellent long-term storage properties, same as petrol.
Volumetric Energy Density (including Storage Systems)	Same as petrol.
Gravimetric Energy Density (including Storage Systems)	Same as petrol.
Supply TRL	Supply technology readiness is at deployment. Australian suppliers are starting up.
Consumption TRL	Consumption technology readiness is mature.
Potential Supply Issues	A key feedstock in the creation of sustainable aviation fuel (SAF), so may be competed for by the aviation industry.
Likely Cost	Unknown.
Usability	No change required to existing engines, tanks, or systems. A true drop-in replacement fuel.
OEM Support	No engine OEMs have discussed e-gasoline, but in theory it should be easy to support.

HIF Tasmania have declared that they will "source wood residues from sustainably managed plantations" to secure biomass for the project[58]. This makes it unclear whether the project is creating an e-fuel or a biofuel as relying on biomass for carbon would theoretically make it more like Renewable Diesel in terms of its reliance on sustainable biomass sources.

As green methanol is an intermediate product in the creation of e-gasoline and there has been a lack of commercial interest in creating e- gasoline vs SAF, the project considers that e- gasoline should not be relied upon to help the commercial wild catch fishing industry decarbonise.

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[56] https://digismak.com/what-is-e-diesel-the-promising-synthetic-fuel-based-on-water-and-air-compatible-with-conventional-engines/
[57] http://www.hiftasmania.com.au/
[58] http://www.hiftasmania.com.au/faq

Metal Hydrides (Pressurised)

As green hydrogen (liquid or gaseous) has low volumetric density, there has been increasing interest in metal hydrides, which are metal alloys that can absorb and desorb hydrogen with a much higher volumetric density. Heat and pressure is applied to the material to encourage hydrogen absorption.

Existing products using this mechanism are predicated on keeping the metal hydride under pressure, around 100 bar which is much less than Green Hydrogen (Gas), so that it can absorb hydrogen, with pressure release being used to desorb hydrogen when needed. CSIRO mentions that one of the current limitations is that "performance often drops, both as a result of deterioration of the hydride, but also deterioration of hydride distribution within the vessel, reducing heat transfer efficiency."[59]

Companies offering pressurised metal hydride solutions in Australia include Lavo↗ and GreenHy2↗.

Because these metal hydrides come as metallic powder kept inside steel pressure vessels there is a lot of weight involved. The gravimetric energy density is lower than liquid or high-pressure gas hydrogen storage options (5kg of hydrogen stored weighs 721kg vs 96.6kg), but the volumetric energy density is higher (5kg of hydrogen stored takes up 141L vs 213.5L)[60].

This makes them a good solution for static hydrogen storage but limits their feasibility as fuel tanks for transport needs.

Energy Carrier	Metal Hydrides (Pressurised)
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Between 60% and 80% depending on distribution emissions, source of materials, energy used and fugitive emissions.
Marine Safety	Unknown. Loss of pressure causes the metal hydrides to desorb hydrogen but they may cause localised marine pollution if the metal salts dissolve in water.
Marine Suitability	When the storage system and solid carrier material weight is included these are prohibitively heavy for maritime use.
Volumetric Energy Density (including Storage Systems)	Much less dense than most other options. At 100 bar the volume is eight (8x) times larger than diesel fuel tanks.
Gravimetric Energy Density (including Storage Systems)	Weighs around fifty (50x) times more than equivalent diesel fuel tanks.
Supply TRL	Supply technology readiness is mature.
Consumption TRL	Consumption technology readiness is mature.
Potential Supply Issues	Not currently being used in maritime environments so available equipment may not be rated for maritime use.
Likely Cost	Unknown.
Usability	Completely new engines, fuel systems, refuelling and safety processes are required.
OEM Support	Support is there due to government focus on hydrogen in Japan and Germany, but globally fuel cells and hydrogen derivatives are seen as more feasible for maritime uses.

[59] https://research.csiro.au/hydrogenfsp/our-research/projects/metal-hybrides-composites/
[60] http://www.awoe.net/Hydrogen-Storage-LCA.html

Metal Hydrides (Ambient)

As green hydrogen (liquid or gaseous) has low volumetric density, there has been increasing interest in metal hydrides, which are metal alloys that can absorb and desorb hydrogen with a much higher volumetric density.

These are mostly new innovations that seek to establish hydrogen storage at ambient or close to ambient pressures and temperatures. This simplifies storage and transport of the metal hydrides, but most solutions cannot be filled with hydrogen again without specialised equipment and sometimes additional materials.

There are a number of Australian companies investing in commercialisation of ambient metal hydride solutions, such as Hyrea↗ and Hydrexia↗, and a number of universities still actively researching metal hydride improvements.

Because the pressures and temperatures are much lower there is less equipment needed by these solutions. However, even taking their marketing at face value, the most advanced solution from Hydrexia still needs nearly six times the volume and mass that diesel requires.

Energy Carrier	Metal Hydrides (Ambient)
Suitable Replacement?	No
Potential WtW GHG Emissions Reduction	Between 60% and 80% depending on distribution emissions, source of materials, energy used and fugitive emissions.
Marine Safety	Unknown. Heat or catalyst application while in water will cause the hydrogen to desorb in an exothermic reaction which may cause localised pollution.
Marine Suitability	Unknown. The industry has not worked out how used metal hydride fuel would be removed from vessels efficiently.
Volumetric Energy Density (including Storage Systems)	Unknown. Does not require (much) pressurisation but will still take up much more volume than diesel, especially as spent fuel must be stored separate to fresh fuel.
Gravimetric Energy Density (including Storage Systems)	Unknown. Requires minimal pressurisation, but only small percentages by weight (5-7%) of hydrogen have been stored.
Supply TRL	Supply technology readiness is at the research stage still.
Consumption TRL	Consumption technology readiness is at the research stage still.
Potential Supply Issues	Many research projects, only one looking at maritime uses.
Likely Cost	Unknown.
Usability	Unknown.
OEM Support	Support is there due to government focus on hydrogen in Japan and Germany, but globally fuel cells and hydrogen derivatives are seen as more feasible for maritime uses.

H2Ships↗ are running a pilot project to test an ambient metal hydride solution in a saloon boat (*Neo Orbis*) being built for the Port of Amsterdam. The fuel preparation and spent fuel regeneration processes demonstrate that the pilot has many issues to manage, not the least of which is that spent fuel must be kept separate to fresh fuel, which doubles the volumes required for storage (see Figure 17).

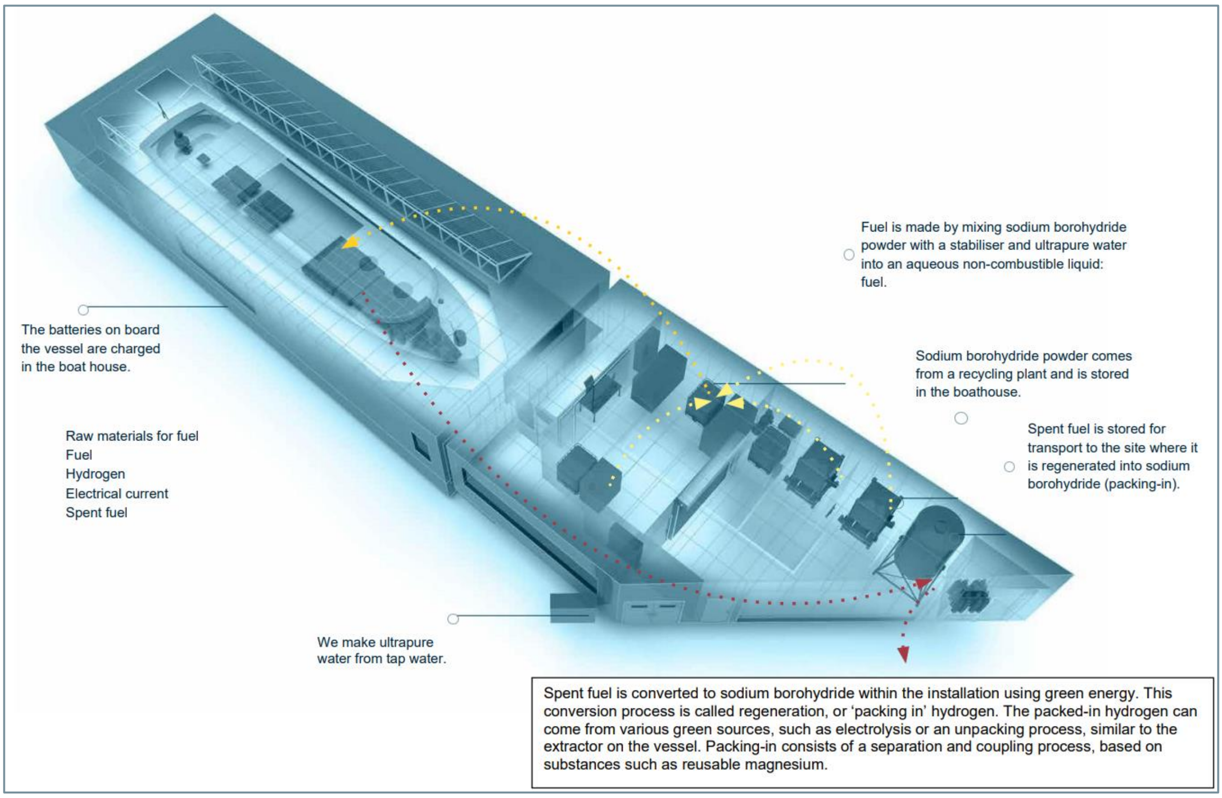


Figure 17: Neo Orbis Fuel Processes, On-Vessel and Shore Installation[61]

[61] https://vb.nweurope.eu/media/16834/neo-orbis_en.pdf

Electrons

As well as liquid and gaseous fuels, there is of course the relatively new idea of using electrons directly as a way of carrying energy for maritime propulsion systems.

Batteries

Lithium-ion battery volumetric energy density is approximately 18 times poorer than diesel. This means that a given amount of stored energy requires 18 times the volume. The poor gravimetric energy density compounds this problem with lithium-ion batteries requiring 50-100 times more weight. This is slightly improved by the fact that electric engines are generally smaller and lighter than internal combustion engines, but the battery-electric powertrain is still much larger and heavier.

Energy Carrier	Batteries
Suitable Replacement?	Potentially
Potential WtW GHG Emissions Reduction	Potentially 100% (depends on battery suppliers, and shore electricity characteristics)
Marine Safety	Marine vessels have used batteries for decades, they are reasonably safe and solid batteries (like lithium-ion) pose little threat to marine life.
Marine Suitability	Limited applications as a sole source of energy because of the much larger volume (and weight) required for storage of the energy. Is being considered because it wastes the exergy less than ICE or fuel cell systems.
Volumetric Energy Density (including Storage Systems)	The least dense form of energy storage considered, the volume required is around twenty (20x) more than diesel fuel. However, lots of R&D is occurring around more dense battery technologies.
Gravimetric Energy Density (including Storage Systems)	Weighs around fifty (50x) times more than equivalent diesel fuel tanks. Although less energy may be required.
Supply TRL	Supply technology readiness is at deployment.
Consumption TRL	Electric drivetrains are mature and available with a range of options.
Potential Supply Issues	Fairly easy to gain access to marine use batteries, but modular, maintainable and large scale solutions are just being produced.
Likely Cost	Much more expensive than the equivalent sized diesel fuel system, but the unit cost per energy unit should be much cheaper.
Usability	Requires electrification of ship propulsion. Completely new fuel systems, refuelling and safety processes required for shore charging.
OEM Support	There is significant support for batteries, although mostly as a backup to generated electricity.

Those figures are for what is currently the densest lithium-ion battery chemistry, which is Lithium Nickel Manganese Cobalt Oxide (NMC). Many maritime users prefer Lithium-Iron-Phosphate (LiFePO4) because it has a better safety record than NMC and longer lifespan. A cheaper safe option is Lithium Titanate (LTO), which is even less dense, but still safer than NMC, with the trade-off that it is the heaviest option.[62]

Where batteries on their own work best is for short day trips where the extra space and weight for batteries is easy to absorb, and nightly charging from shore stations is possible. The boom of new electric outboard motors is a sign of this, and is the area where batteries are best suited as the primary energy carrier for a vessel.

Where batteries have a role in larger vessels is the provision of immediately available power while a generator or fuel-cell starts up. They can also act as a sink into which to put spare

[62] https://plugboats.com/plugboats-guide-to-electric-boat-batteries/

power in cases where a generator, fuel cell or regenerative braking system is creating power in excess to current requirements.

PEM Fuel Cells

When it was first suggested to use liquid hydrogen as a marine fuel, the obvious use was to consider using fuel cells that could turn hydrogen into electrons. The most mature option is the proton exchange membrane fuel cell (PEM) which typically operates at around 70°C, relying on a platinum catalyst to help drive the reaction that produces electrons. They are sensitive to fuel impurities, so it is important that the hydrogen supplied meets strict guidelines, usually being 99.9% pure hydrogen.

That purity also applies to the waste stream, which is mostly pure water vapour. Some of the water is likely to condense and need to be stored or disposed of. Unfortunately, the water cannot be just released to the ocean as it is too pure and too low in oxygen, so marine fuel cells are likely to need to both filter the water for toxins, add salts and minerals, and re-oxygenate it before releasing to the ocean[63].

Unfortunately, the PEM fuel cells have the same issue as green hydrogen ICE – the weight and volume of the fuel is problematic for most commercial fishing applications. A more feasible pathway is to use green methanol as the primary fuel, and reform the methanol into hydrogen using water (this releases CO_2, but at a point close to it being captured). Once the gas created is purified then the hydrogen is used normally by the PEM fuel cell.

Energy Carrier	PEM Fuel Cells
Suitable Replacement?	Potentially
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, hydrogen source and fugitive emissions.
Marine Safety	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Marine Suitability	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Volumetric Energy Density (including Storage Systems)	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Gravimetric Energy Density (including Storage Systems)	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Supply TRL	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Consumption TRL	PEM fuel cells have been used for decades and are mature. Methanol reformers and DMFCs are less ready.
Potential Supply Issues	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Likely Cost	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Usability	Requires electrification of ship propulsion and the fuel cells being essentially black boxes. Green hydrogen requires completely new fuel systems, refuelling and safety processes. Green methanol is well supported with marine safety systems as it is a common cargo and fuel.
OEM Support	Support by traditional OEMs is picking up, and there are PEM fuel cell OEMs that do support the marine market.

The key disadvantages of methanol reformers are low tech readiness, low efficiency, and currently high commercial costs. Solutions to making these more commercially available are being created by

[63] Juan E. Tibaquirá, Kiril D. Hristovski, Paul Westerhoff, Jonathan D. Posner, *Recovery and quality of water produced by commercial fuel cells*, International Journal of Hydrogen Energy, Volume 36, Issue 6, 2011.

e1 Marine[64] and RIX Industries[65] who have cooperated to bring their M2H2 solution to the USA market. M2H2 systems are an on-demand, on-vessel hydrogen generation system that provides high purity, fuel cell grade hydrogen as needed to low-temperature PEM fuel cell stacks/modules. When combined with PEM fuel cells, M2H2 systems reduce emissions, and in particular have no NOx, no Sox, and no Particulate Matter (PM) emissions.

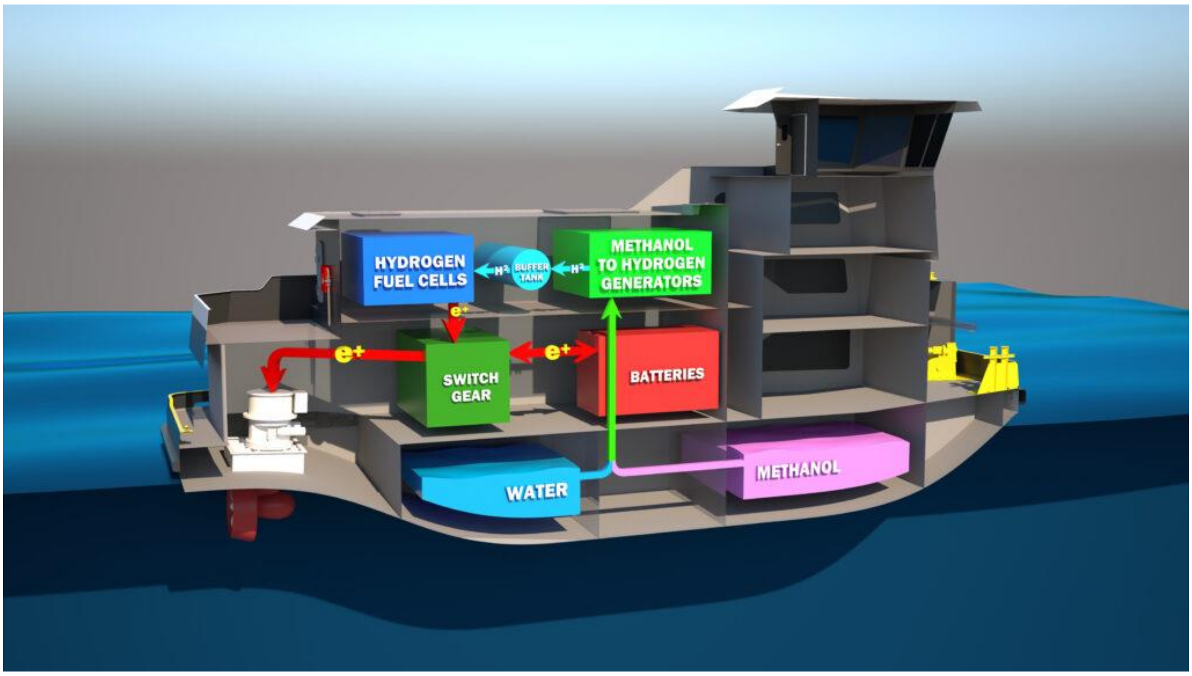


Figure 18: Logic Diagram of a Methanol-Reformer Powered Towboat. Source:Elliott Bay Design Group.

The methanol-water reforming process maintains a critical advantage of being able to release three – rather than two – moles of hydrogen per mole of methanol because water provides one mole of hydrogen in the reforming reaction. This reforming reaction uses approximately 7.15 kg. of methanol-water mixture to create 1 kg of hydrogen.

Reformed methanol fuel cells systems offer advantages over direct methanol fuel cell (DMFC) systems including higher efficiency, smaller cell stacks, no water management, and better operation at low temperatures. DMFCs get their water by recirculating the water emissions from the reaction back to help the catalyst extract electrons from the methanol directly. They suit small portable use cases better than reformed methanol fuel cells, and SFC Energy has created several military, industrial and home/leisure applications with their DMFCs[66]. For this reason, they are a possible option for Petrol Outboard Engine Replacement when combined with an electric outboard motor.

[64] https://www.e1marine.com/technology
[65] https://www.rixindustries.com/hydrogen-generation-systems
[66] https://www.sfc.com/en/technology/direct-methanol/

HT-PEM Fuel Cells

High-temperature PEM (HT-PEM) fuel cells were developed to address the sensitivity to fuel impurities that had made PEM fuel cells problematic in some environments. By operating at a higher temperature (between 120 and 200°C) they can use hydrogen rich gases that are less pure with 50 to 75% hydrogen by volume.

The waste stream is mostly pure water vapour. Some of the water is likely to condense and need to be stored or disposed of. Unfortunately, the water cannot be just released to the ocean as it is too pure and too low in oxygen, so marine fuel cells are likely to need to both filter the water for toxins, add salts and minerals, and re-oxygenate it before releasing to the ocean[67].

This also makes HT-PEM a better match for methanol fuel, as the methanol reformer can be linked directly to the HT-PEM fuel cell without needing a purification step in between. For example, Blue World Technologies have developed a HT-PEM fuel cell with an inbuilt methanol reformer for marine use[68]. They supply their solution in 200 kW modular cabinets in either a cubic or flatpack arrangement that can be combined to provide the desired energy load.

Excess heat from HT-PEM fuel cells can be used in the reformation process and/or used for additional energy recovery using the heat, for example in refrigeration systems where the excess heat can be usefully used to reduce auxiliary power needs (see Figure 19).

Energy Carrier	HT-PEM Fuel Cells
Suitable Replacement?	Potentially
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, hydrogen source and fugitive emissions.
Marine Safety	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Marine Suitability	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Volumetric Energy Density (including Storage Systems)	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Gravimetric Energy Density (including Storage Systems)	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Supply TRL	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Consumption TRL	HT-PEM fuel cells have been used for decades and are mature.
Potential Supply Issues	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Likely Cost	See Green Hydrogen (Liquid), Green Hydrogen (Gas), or Green Methanol.
Usability	Requires electrification of ship propulsion and the fuel cells being essentially black boxes. Green hydrogen requires completely new fuel systems, refuelling and safety processes. Green methanol is well supported with marine safety systems as it is a common cargo and fuel. HT-PEM supports green methanol in particular as hydrogen purity is less of an issue.
OEM Support	Not supported by traditional OEMs, there are HT-PEM fuel cell OEMs that do support the marine market.

[67] Juan E. Tibaquirá, Kiril D. Hristovski, Paul Westerhoff, Jonathan D. Posner, *Recovery and quality of water produced by commercial fuel cells*, International Journal of Hydrogen Energy, Volume 36, Issue 6, 2011.
[68] https://www.blue.world/markets/maritime/

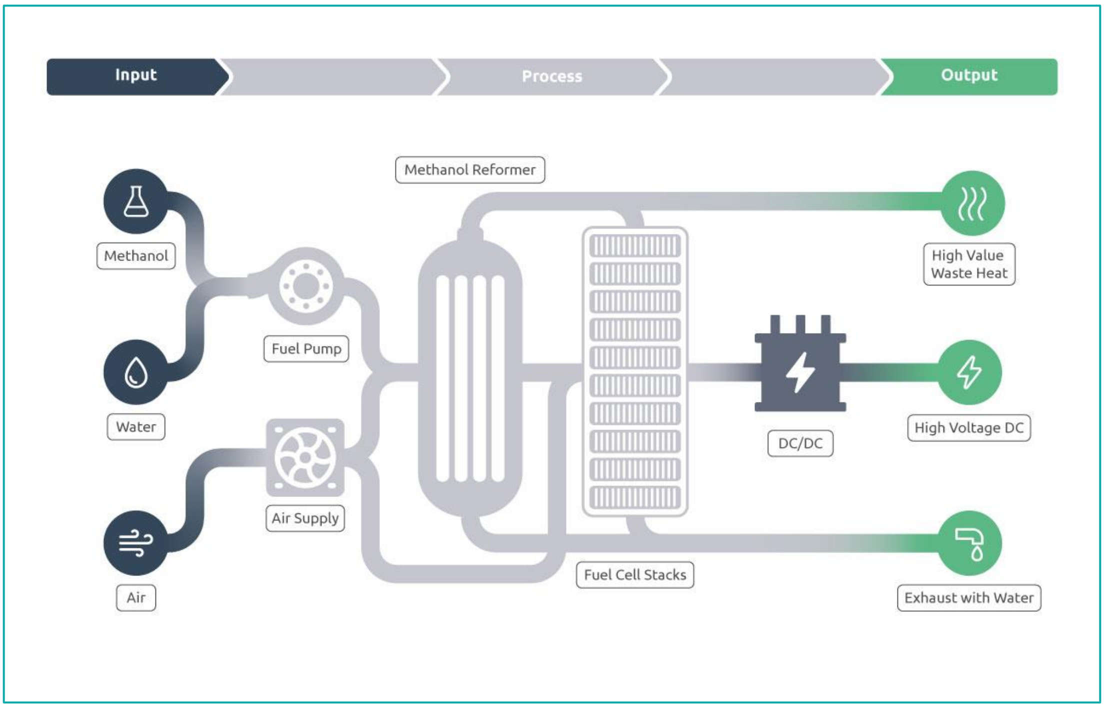


Figure 19: Methanol Fuel Cell Auxiliary Power Unit. Source: Blue World Technologies

SO Fuel Cells

One solution to the bulkiness of green hydrogen is to use it as a feedstock for green methanol and then use that more compact fuel as the source of electrons. One pathway that is being investigated are fuel cells that work on methanol directly, the solid oxide fuel cell (SOFC) does this by operating at a very high temperature between 700-1,000°C which removes the need for a platinum catalyst. As well as methanol, they can use ammonia, hydrogen, LNG, LPG, ethanol, (renewable) diesel, and other biofuels.

Energy Carrier	SO Fuel Cells
Suitable Replacement?	Potentially
Potential WtW GHG Emissions Reduction	Between 80% and 90% depending on distribution emissions, methanol source and fugitive emissions.
Marine Safety	See Green Methanol.
Marine Suitability	See Green Methanol.
Volumetric Energy Density (including Storage Systems)	See Green Methanol.
Gravimetric Energy Density (including Storage Systems)	See Green Methanol.
Supply TRL	See Green Methanol.
Consumption TRL	SO fuel cells are at pilot scale maturity, with the biggest issues being long-term reliability, startup times and efficiency.
Potential Supply Issues	See Green Methanol.
Likely Cost	See Green Methanol.
Usability	Requires electrification of ship propulsion and the fuel cells being essentially black boxes. Green methanol is well supported with marine safety systems as it is a common cargo and fuel.
OEM Support	Very little support for green methanol SO fuel cells, however it is seen as having greater potential than hydrogen fuel cells.

Most of the layers of a solid oxide fuel cell are solid, hence the name, and use fairly low-cost materials. The current research in these is targeting mechanical issues that arise over time due to the high operating temperature causing the solid components to crack, delaminate and have other issues that affect efficiency and operating lifetime.

When looking at marine use, the absence of a methanol reformer is the main advantage of a SO fuel cell compared to a PEM fuel cell. This means less hardware to install, higher efficiency, cheaper fuel cells and less things to go wrong at sea. Unfortunately, the technology is still very much at pilot stage and the concerns about degrading efficiency and operating lifetimes make it still too early to pick these as a winner amongst other fuel cells.

An interesting innovation was recently announced by Expleo who have designed a solution that allows a vessel to take on green hydrogen, using CO_2 on the vessel to synthesise green methanol, which is then used to power a SO fuel cell. The CO_2 emitted by the fuel cell reaction is then captured for re-use in synthesising green methanol when refuelling hydrogen in port[69]. This closed loop CO_2 system addresses one of the drawbacks of using methanol in fuel cells – which is that there are CO_2 emissions from the fuel cell (or methanol reformer if using that). This possibility is covered in Emissions Capture.

[69] https://expleo.com/global/en/insights/news/expleo-green-marine-innovation/

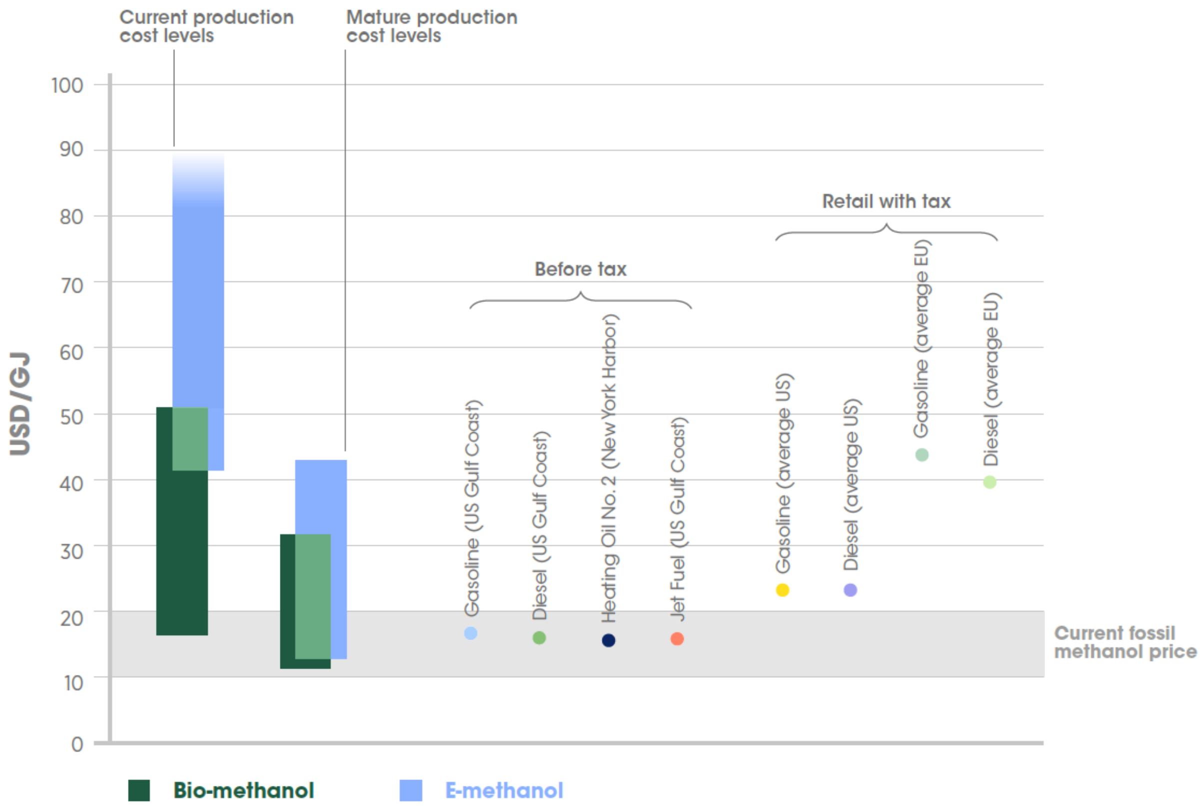
Recommended Energy Carriers

The most promising sustainable energy carriers in the short-term have relatively high TRLs, are relatively easy to introduce, can be produced easily, and can fit into existing regulatory frameworks. These have been marked as "Yes" in the *Suitable Replacement?* field for each energy carrier. The recommended list of energy carriers is:

- Drop-in (alternative) fuels like:
  - Renewable Diesel
  - Biobutanol
- Future fuels like:
  - Biomethanol
  - Green Methanol
- For inshore fishing:
  - Batteries

Batteries are the only energy carrier marked as "Potentially" which is included in the recommended list, this is because they are a "Yes" for inshore fishers who do short trips with the ability to recharge daily but are (currently) a "No" for fishers that do longer trips or need more power.

Figure 20 shows expected future prices for biomethanol and green methanol (e-methanol) and demonstrates that the operating cost of the recommended future fuels is likely to be prohibitive.



Note: *Exchange rate used in this figure USD 1 = EUR 0.9. Fuel costs and prices are averaged over 10 years. See annex 3 for details.*

Figure 20: Renewable methanol vs other fuels on a price per unit of energy basis. Source: IRENA 2021.

Intervention Options

In looking at alternative fuels that could provide a reduction in net GHG emissions we separated the types of fishing vessels in use into four categories:

1. Petrol outboard, retrofit
2. Outboard, newbuild
3. Diesel inboard, retrofit
4. Inboard, newbuild

There are numerous ways of driving GHG emissions reduction via greater fuel efficiency, from just using newer model diesel engines, through to using bubbles to reduce hull drag[70], adding Flettner rotors[71] or self-furling sails[72] to use the wind when steaming, proactive in-water hull grooming to minimise slime biofouling[73], or even just different hull shapes. However, the project team decided that tackling the fact that fossil fuels are still the ones relied upon by the industry was a worthy target and something that greatly improves the climate resilience of the industry. Note: The most promising non-engine/non-fuel based solution encountered was created by an Australian Startup named Hullbot (www.hullbot.com)

For each engine category we then considered the smallest possible financial intervention, through to the largest possible intervention, from simple fuel reduction through to a change that needed a completely new vessel. From a technical and operational sense, a vessel replacement might be one of the simpler interventions, but we recognised that from an industry viewpoint the degree of financial cost was the right way to scale the intervention.

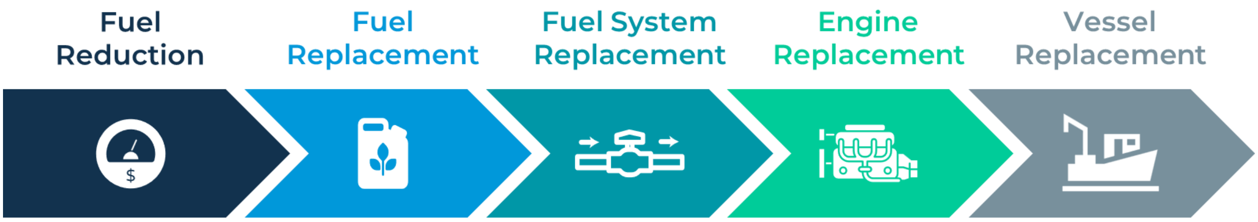


Figure 21: Intervention Escalation

Fuel Reduction Interventions (Both Categories)

There are several possible ways that fishers could optimise their operations to increase their fuel efficiency without changing much about their boats. These are largely the same for boats of all sizes and using all types of engines, so are introduced separate from the Petrol Outboard Interventions and Diesel Inboard Interventions sections.

70 https://harwoodmarine.com.au/services/gills/
71 https://www.marineinsight.com/naval-architecture/flettner-rotor-for-ships-uses-history-and-problems/
72 https://www.frdc.com.au/project/2011-229
73 GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety, 2022, Analysing the Impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures

FRDC has published a Knowledge Hub article on "Energy Efficiency and Renewables"[74] which highlights ten FRDC projects (this project being one of the ones listed) and eight partnerships dedicated to helping deliver fuel efficiency gains for the fishing and aquaculture industries.

One of the earliest of the projects detailed a number of immediate solutions that fishers could implement to decrease their fuel consumption; these are still relevant today. They listed them under two categories[75]:

1. **Hull drag**
   - Reduce speed
   - Maintain hull smoothness
   - Trim monitoring
   - Remove cooling water pipe drag
   - Change of rudder section
   - Fit high aspect-ratio bilge fins

2. **Vessel motion stabilisation**
   - Comparison of existing roll stabiliser devices
   - Fit high aspect-ratio bilge fins

The Alaska Fisheries Development Foundation (AFDF) has published a set of Energy Conservation Measures specifically for fishers[76]:

1. **Improving Diesel Engine Performance (document↗)**
   - "Right size" the engine for the anticipated load. Diesel engine efficiency decreases quickly at loads less than 20% of their rated horsepower. Where possible, match auxiliary load to the correctly sized engine.
   - Modern electronically governed diesel engines can be more fuel efficient than mechanically governed engines, especially at light loads.
   - Minimize parasitic loads—de-clutch hydraulic pumps and deck hoses whenever possible.
   - Keep engine rooms well ventilated.

2. **Propulsion Opportunities (document↗)**
   It's common knowledge that slowing down or cleaning the hull can reduce fuel consumption. This document quantifies how much of an impact those measures can have, and presents results from some less established drag reduction methods like retrofitting a vessel with a bulbous bow.

3. **Improving Deep Freeze System Performance (document↗)**
   There are many types of freezer systems used on Alaskan fishing vessels—from hydraulically driven plate freeze systems to AC powered blast freeze systems. Hold conditions also vary

[74] https://www.frdc.com.au/energy-efficiency-and-renewables
[75] FRDC Project No 2006/239. Sterling, Dr D., Goldsworthy, Dr L., Klaka, Dr K., Sterling Trawl Gear Services 2009, *Fishing Energy Efficiency Review for the Fisheries Research and Development Corporation*, Brisbane, Australia, (September).
[76] https://afdf.org/research-and-development/vessel-energy-solutions

widely between vessels. The following are some practical operational and equipment-related strategies to improve refrigeration performance and save fuel.

4. **Engine Performance (document↗)**
   Brake specific fuel consumption (BSFC) is a measure of the efficiency of an engine. It defines the amount of fuel required to produce a specified amount of work. A higher BSFC implies a lower engine efficiency.

5. **Improving RSW System Performance (document↗)**
   The following are some practical operational and equipment related strategies to improve refrigerated sea water (RSW) system performance and save fuel.

6. **Improving AC and DC Electrical System Performance (document↗)**
   The efficiency of the AC & DC electrical systems on a vessel depend on the efficiency of the alternator in generating electrical power, and the efficiency of the lights and equipment that use the electrical power. The following are some practical operational and equipment-related strategies to improve system performance and save fuel.

7. **Improving Hydraulic System Performance (document↗)**
   The efficiency of the hydraulic system depends on the condition of the hydraulic pumps and motors, and the amount of heat the system generates when circulating hydraulic fluid. The following are some practical operational and equipment-related strategies to improve hydraulic system performance and save fuel.

A simple guide for fuel optimisation from Cetasol, a Swedish manufacturer of engine optimisation solutions for both petrol outboards and diesel inboards suggests[77]:

1. **Plan your operation ahead of time.**
   They observe that in most cases the most significant fuel increase is due to a late start of the operation, which leads to pushing the engine harder to do things faster.

2. **Balance weight distribution.**
   They point out that monitoring the vessel's trim can help maximise the efficiency of its operation by avoiding incorrect list or trim, or inducing trim when it will help the vessel plane more easily.

3. **Avoid any transients and swift actions.**
   They recommend that in the same way that eco-driving in a car can save fuel, the skipper of a boat needs to think the same way. So avoiding swift changes in speed and smoothly ramping up and ramping down.

4. **Monitor your electrical consumption.**
   For some vessels the auxiliary energy uses for refrigeration, air-conditioning, lighting and similar can have a significant effect on your fuel consumption.

[77] https://cetasol.com/saving-fuel/

5. **Use an energy optimiser.**
   They obviously recommend the use of an energy optimisation tool to help save fuel by giving the skipper of the vessel feedback about how their use of the vessel affects fuel consumption. These can be easily plugged into a modern engine using NMEA 2000[78], but even older models using NMEA 0183, SAE J1939, or Modbus protocols or bus standards can be optimised.

The Great Barrier Reef Marine Park Authority has put out a guide on Reducing Outboard Emissions[79] which has more good recommendations:

1. **Look for the 'stars' at your outboard supplier.**
   The Outboard Engine Distributors Association (OEDA) has an emissions rating system known as the Voluntary Emissions Labelling Scheme (VELS). By looking for outboard engines that have more stars you can easily identify lower emissions engines.[80]

2. **Match engine horsepower to vessel size.**
   They point out that you should match the horsepower of the engine to the ways you want to use the vessel in terms of payload and usual speed needed.

3. **Don't forget your prop!**
   Getting a prop that matches the operational requirements of your outboard engine is also vital to reducing fuel consumption. Ensuring that damaged props are fixed or replaced will also help as even a small nick in a prop can significantly affect the fuel consumption.

4. **Follow maintenance and operation tips.**
   A well serviced outboard engine will use less fuel and following operation tips like the ones below can help minimise fuel use as well:
   a. Driving the boat conservatively without sudden stops and starts.
   b. Reducing weight by removing unnecessary items.
   c. Eliminating unnecessary engine idling when it is not needed.
   d. Trim engines to sea conditions and load on the vessel.

Amongst other possible solutions to improve fuel economy are technologies that directly impact the vessel's drag. One that is seeing a degree of acceptance amongst large ship operators are air lubrication systems that use a thin layer of air bubbles between the ship's hull and the water to reduce drag and this fuel consumption[81]. They have the side effect of also reducing underwater noise and inhibiting biofouling. The vessels currently using them are large flat-bottomed ships which may mean there is less utility in fishing vessel hulls.

[78] https://en.wikipedia.org/wiki/NMEA_2000
[79] https://elibrary.gbrmpa.gov.au/jspui/retrieve/9ec043fd-7703-4998-9088-770d762a4526/Tourism-operators-responding-to-climate-change-Reducing-outboard-emissions.pdf
[80] OEDA members have ceased the use of VELS since 2-stroke engines were banned from sale in 2020.
[81] https://safety4sea.com/cm-how-blowing-bubbles-under-ships-can-reduce-emissions/

Figure 22: Silverstream Technologies' air lubrication solution

Another innovation that has taken hold in a significant minority of international shipping is the harnessing of wind power to boost the efficiency of long voyage legs. Whilst most of these solutions are designed for much larger, and more stable, vessels than the typical commercial fishing vessel, there is some potential for innovation in this area. One prawn trawler in the Northern Prawn Fishery frequently uses sails to help supplement diesel power, see Figure 23 for a photo of it in action. FRDC project 2011-229 reviewed the energy savings and concluded:

> "It was found that up to 13% fuel savings could be made under certain conditions. If this data is extrapolated out over a normal 24 hour operating period, savings of up to 7.3% could be made on the total fuel usage per day."[82]

Introducing sail power can create more complexity for fishers to manage, especially as most fishing vessels will not have the hydrodynamics to make best use of sails except when running before the wind or on a broad reach. FRDC project 2011-229 also noted that:

> "There are constraints on when the sails on the FV Sea Lion can be used. With only two crew on-board the deployment of the sail requires significant effort and is generally only done for large transits. With the addition of either a manual or hydraulic winch, and rerouting the furling lines this could be changed to allow easier deployment and recovery, and hence increased usage and thus fuel savings."[83]

[82] Thomas G., Frost R. (2012). *Empowering Industry: Energy Audit of Prawn Trawler with Auxiliary Sail Power*, FRDC Project No 2011-229.
[83] Ibid.

Figure 23: FV Sea Lion under sail

Another example of wind-assisted propulsion technology is the rigid eSAIL from Bound4Blue that uses active boundary layer control using wind suction[84]. A pilot project saw it installed on the longliner vessel Balueiro Segundo (see Figure 24) which reportedly had significant fuel savings from using the technology during sailing trips[85]. Unlike soft sails this sort of rigid tubular installation has the advantage of requiring less effort from the crew to setup. Because it relies on active suction to create the majority of the effect, it also can be turned off when not required. However, significant room on deck is required, and a naval architectural analysis of the effect of adding extra thrust through that part of the vessel. Beyond4Blue are targeting much larger vessels than even large fishing vessels, so it is not likely that many of these systems will be seen anytime soon. Similar technology is bring brought o market by Yara Marine, with the WindWings product[86].

[84] https://bound4blue.com/en/esail

[85] https://bound4blue.com/upload/media/technology/0001/02/b0e9d2f77862aeb0ed68fb94142e11cacdc49a77.pdf

[86] https://yaramarine.com/windwings/

Figure 24: Balueiro Segundo with eSAIL installed

Regardless of the fuel reduction strategies implemented, the first step should be to obtain accurate data on existing fuel use, either by taking an energy audit – or if the 24 months of historical data is not available, by starting to record fuel used for specific operations (e.g. steaming from port to fishing grounds, or performing a trawl, etc) and then allocating that fuel use to outputs, such as kilograms of catch. This can both make obvious the ways that fuel is being consumed, but also will help in the future to assess the benefits of the fuel reduction strategies implemented.

If the current engine for the vessel does not provide fuel flow monitoring, then third-party fuel flow meters are available. If a physical fuel flow meter is thought to be too likely to create a blockage, then a recent innovation from Cetasol might help. They have created a virtual fuel flow monitor which can provide fuel usage with 97%+ accuracy by monitoring other common engine indicators (e.g. RPM, torque, and temperature)[87]. It has the advantage of offering to record the data in a cloud app that can be accessed through a web browser to see historical fuel usage.

Finally, it is important that operational efficiency changes do not lead to fuel efficiency problems. A previous round of energy audits on seven Australian fishing vessels found issues when fishing efficiency got in the way of fuel efficiency.

> "Fishing companies contemplating changes to become more energy-efficient harvesters also need to consider whether such changes will impact favorably on their catch rate and profitability; in the case of FV Torbay energy efficiency (L/hr) was sacrificed (by towing faster) post 2010 in an endeavor to raise the catch rate (kg/hr) and gain more revenue per unit time

[87] https://cetasol.com/cetafuel/

($/hr), yet according the latter quantity this was a fruitless exercise, and consequently the fuel expense as a ratio of revenue reached 0.3."[88]

Petrol Outboard Interventions

Most of these vessels are tenders or dinghies, but some are larger, using one or more outboard petrol motors. Typical use cases are frequent if not daily use, and short trips of a few hours or at most a day from a home port.

Fuel Replacement

The initial focus for fuel replacement was on identifying if there were new drop-in replacement fuels that could simply replace petrol with no, or minimal changes, to the outboard motor. In many ways we are already seeing this happen with the popularity of E10 ethanol and petrol mixes for cars, or B20 biodiesel and diesel blends for heavy vehicles.

However, the current Transport for NSW recommendation is that vessel owners avoid these fuel mixes due to the shorter shelf life of these fuels, with E10's ethanol tending to absorb water and separate from the petrol leading to pure ethanol damaging the engine (as it is a strong solvent)[89].

If the engine's manufacturer recommends that E10 can be used, then provided the right equipment and processes are followed it should be safe to do so. Whether this will suit fishers will depend on their willingness and ability to follow the processes. Indonesia has considered introducing A20, a blend of 80% petrol, 15% methanol and 5% ethanol as a way of improving their fuel quality and slightly reducing emissions[90]. Methanol acts very much like ethanol in that it can react with water and separate from the petrol – then damage fuel lines and engines.

For petrol mixes there is another option that the US Department of Energy proposed, which is butanol. "Butanol at 16 percent blend level works as well as ethanol at 10 percent under tested conditions."[91] One of the advantages that Bu16 butanol blend has over E10 ethanol blend is that it is immiscible in water, meaning the storage problems with E10 in a marine environment do not occur. There has been agreement in the USA from the National Marine Manufacturers Association (NMMA) that Bu16 fuel can be used as a drop-in fuel replacement for marine petrol engines. Patents on the biological production of butanol are owned by Gevo, Inc. a US company that is primarily using it for sustainable airplane fuel (SAF). Synthetic pathways to produce butanol ('e-butanol') are being investigated but have yet to be industrialised.

Most outboard motor manufacturers will support E10 fuel, although older boats may have issues with other parts of the fuel system such as fuel tanks made of fibreglass or aluminium. Fuel stabilisers are recommended to delay the fuel separation in the presence of water but even then, a few weeks is likely to cause a problem, and a 'mostly' empty tank just has more room for water vapour to

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[88] Wakeford, J., Bose, N., *Energy Audits on Australian Fishing Vessels*, 2012.
[89] https://www.transport.nsw.gov.au/operations/roads-and-waterways/environment-and-heritage/vessel-biofuels
[90] IESR (2021). Critical review on the biofuel development policy in Indonesia
[91] https://www.anl.gov/article/argonne-works-with-marine-industry-on-new-fuel

encounter any fuel that remains – helping separate the ethanol solvent out of the fuel and causing problems.

Research in the US has shown that butanol/petroleum blends are better suited to marine environments, but no distributors are currently selling these fuels. Manufacturers that could create green butanol would likely just create renewable diesel, sustainable aviation fuel (SAF) or green methanol as there are more mature markets for these.

However, both Bu16 and E10 can only partly address the GHG emissions from fuel use, with E10 being much less useful than Bu16. In addition, butanol and ethanol are less energy dense fuels compared to petrol, which could lead to a degree of increased fuel consumption and costs for the vessel operator.

Fuel System Replacement

Not many options exist for changing fuel systems in outboard motors as most fuel system changes (e.g. to methanol or diesel) would require replacement of the entire outboard motor rather than retrofitting.

One novel solution comes from E-Class Outboards in Kiama NSW.[92] You send your existing outboard motor to them, they remove the petrol engine, but retain and reuse the shell structure, housing, wiring elements and propeller. This effectively changes the fuel from petrol to batteries and is an example of a circular economy solution. They have also managed to train mechanics in Africa to use their electric rePOWER kits to do the same thing[93].

Engine Replacement

When buying a brand-new outboard motor there are a few options to reduce net GHG emissions. For small vessels that do not need to run for long periods of time, electric drives are an excellent solution for reducing net GHG emissions. There are several market ready solutions being delivered by large players and startups in the outboard industry. Suppliers include eClass Outboards↗, ePropulsion↗, Rad Propulsion↗, ACEL Power↗, Evoy↗, Mercury Avator↗, Pure Watercraft↗, Flux Marine↗, Elco↗, TEMO↗, Remigo↗, Vision Marine Technologies↗, and Torqueedo↗.

In addition to the reduction of emissions, the conversion from petrol to electric uses circular economy principles, which could provide added benefits from a social licence perspective. While there is some concern over access to batteries, given the rate electric vehicles are surging, there is an option to choose reclaimed/reused/repurposed batteries from electric vehicles like the Toyota Prius, Nissan Leaf, and Mitsubishi iMiev. The reused batteries are tested, and quality checked by the startup company running that business, before being offered to customers of eClass Outboards at a lower price than a brand-new battery pack.

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92 https://eclassoutboards.com.au/

93 https://www.aimex.asn.au/news/electey-marine-electric-project-success/

Figure 25: ePropulsion Navy Outboard and Batteries. Source: ePropulsion.

EFOY have done a pilot project with ePropulsion to test the use of one of their direct methanol fuel cells as the power source for an ePropulsion outboard motor[94]. As green methanol becomes more plentiful and electric outboards more powerful, this combination is likely to become more attractive.

Figure 26: ACEL Power outboard and modular battery system. Source: ACEL Power.

As manufacturers advance in the electric outboard space it is increasingly their handling of battery power concerns, especially range, that is differentiating the solutions that exist. One area that Mercury has struggled in is to make their Avator products compete with ePropulsion on range, despite being heavier and more elegant in design.

[94] https://www.sfc.com/en/sfc-energy-cooperates-with-epropulsion-in-the-field-of-electric-boat-drives/

There are some diesel outboards now available which could be fuelled in the future by renewable diesel, see the Diesel Inboard Interventions for more information on that option. Many of those already offer greater efficiency than petrol motors and could be a worthwhile short-term replacement for petrol outboard motors[95]. Manufacturers offering diesel outboards in Australia include Oxe Marine↗, Cox Marine↗, and Neander Marine↗ (Dtorque); Mercury also has a diesel outboard, but unfortunately in Australia they only offer diesel outboards to government clients.

Vessel replacement

Given that the majority of the GHG emissions for this category of vessel come from the outboard motor, there is not much value in looking at fully replacing these vessels. If a vessel operator wanted to move to electric outboard motor but lacked the appropriate space for batteries, then purchasing a new vessel might be warranted.

However, it should not be ignored that significant savings can result from downsizing the fishing vessel in order to better use an electrified drivetrain. In the West Highlands of Scotland two fishermen have changed to use smaller electric powertrain boats for their fishing with surprising results:

> "Douglas shared his experience of transitioning from a large diesel-powered catamaran to a small, more efficient electric vessel. He noted that he used to burn 50 gallons of diesel per trip but now can sometimes return to shore having effectively the same amount of fuel as when he left thanks to an on-board solar panel charging the battery which drives his motor whilst he is out at sea." [96]

> "Hans expects that fishing 2-3 days per week on his newly refitted electric <8m vessel will be almost as cost efficient as fishing daily when he relied on diesel. Catching less and making the same money is a model that will work well for him and the restaurants he supplies."[97]

Diesel Inboard Interventions

Most of these vessels use inboard diesel engines that run at relatively high speeds and for long periods of time. Some of the larger inshore fishing vessels fit this category, and interviews and discussions with fishers have generally shown us that these were the oldest vessels we came across. Other vessels in this category are the larger (up to 24m long) deepwater fishing vessels that operate for weeks at a time at sea.

Fuel Replacement

Again, the project's initial focus was on identifying if there were new drop-in replacement fuels that could simply replace diesel with no, or minimal changes, to engines, generators, or boilers. As well as the option of using B20, since 1 March 2009 all diesel fuel in Australia is permitted to have up to 5 percent biodiesel (B5) *without* being labelled as such.

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[95] https://boattest.com/cox-cxo300
[96] https://fisorg.uk/net-zero-vessels-clyde-workshop/
[97] Ibid.

However, the current Transport for NSW recommendation is that vessel owners avoid these fuel mixes due to the shorter shelf life of these biodiesel blends as they can oxidise and "an additional fuel stabiliser may be required if biodiesel blends are stored for more than a few months"[98].

If the engine's manufacturer recommends that a biodiesel mix greater than 5% (B5) can be used, then provided the right equipment and processes are followed they should be safe to do so. Whether this will suit fishers will depend on their willingness and ability to follow the processes.

In recent years an advanced biofuel has become available that does not have the disadvantages of biodiesel. Renewable diesel differs from biodiesel in that it is synthetically refined rather than biologically created and so better meets fuel standards despite using the same feedstocks. The California Air Resources Board has modified their Commercial Harbor Craft Regulation to mandate the use of renewable diesel fuel (R100 or R99) by all vessels, including commercial fishing vessels – with it becoming mandatory in the 2030-2032 timeline (depending on age of engine)[99].

From the perspective of net GHG emissions the best option in this area is to use renewable diesel as it offers a GHG emission reduction of between 40% and 90%[100], depending on the source of the feedstock and the way the fuel is produced. However, it is expected that supply of renewable diesel will be constricted until close to 2030[101] so price and availability may well be an issue. It is also vital that the right feedstocks be promoted, and the wrong ones discouraged – the legacy of early biofuels like ethanol was competition between crops for food and for fuel which led to an increase in the price of corn-based foods for the poorest and most vulnerable people.

Fuel additives could possibly be a useful avenue to gain some fuel efficiency, although studies of different ones have shown varying levels of effectiveness on fuel consumption, and frequently differences between manufacturer's claims and provable results[102].

Fuel System Replacement

Fuels that are not mixed but are 100% composed of alternate fuels need changes made to the fuel system. Likewise, some marine-friendly dual or triple fuel mixes also require fuel system changes. In these cases, both the fuel and the fuel system need replacement, or significant modification.

Ethanol fumigation of diesel engines (e.g. atomised insertion into the air intake) has previously been reviewed for FRDC. That study concluded that "Addition of ethanol by fumigation is a relatively simple way of introducing a biofuel to a diesel engine, while at the same time reducing NOx emissions and potentially increasing thermal efficiency." [103] Sourcing green ethanol, seeing less diesel

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[98] https://roads-waterways.transport.nsw.gov.au/about/environment/sustainability/vessel-biofuels.html
[99] https://ww2.arb.ca.gov/resources/fact-sheets/chc-factsheet-renewable-diesel-r100-or-r99
[100] https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities and https://www.neste.com/products/all-products/renewable-road-transport/neste-my-renewable-diesel
[101] 'Biomass to Energy Handbook', Kearney Energy Transition Institute, 2020
[102] V Mihaylov et al (2021), *Experimental evaluation of the effectiveness of a diesel fuel additive*, IOP Conf. Ser.: Mater. Sci. Eng. 1031 012017, and
Elwardany, Ahmed & Marei, Mohamed & Ismail, Mohamed & Eldariny, Y. & El-Kassaby OR ELKASABY, Mohamed. (2017). *Effect of ferrocene nanoparticles as additives on diesel engine performance and emissions.*
[103] Goldsworthy, Dr L., 2007/200 *SESSF Industry Development Subprogram: Alternative Fuels for Fishing Vessels*

used and lower NOx emissions would provide some benefit. Storage of ethanol has some issues, but the actual fumigation process is straightforward and could work with older diesel engines.

Many of the options for sustainable replacement fuels, such as methanol, require modifying the ignition system from compression ignition to spark ignition. The commercial wild-catch fishing industry has been considering this sort of change for more than 40 years[104], but it has always been resisted by fishers due to the need for self-sufficiency whilst at sea (see The Importance of Self-Sufficiency). To accommodate this, a fuel system level change could consider introducing both a new base fuel (e.g. methanol) and a pilot fuel that could help achieve compression ignition. One project that retrofitted a Volvo Penta diesel engine to run dual fuel methanol and diesel substituted a maximum of 74% by volume of the normal diesel used with methanol[105].

One company that is trying to address the alternative fuel problem in an innovative way is ClearFlame, who manufacture retrofit kits for specific common engines that use high temperature mixing controlled compression ignition (MCCI) to allow sustainable fuels like methanol, ethanol, or others to ignite under compression. This does not require any pilot fuel and allows the use of 100% sustainable fuels. However, their technology is still nascent and their initial target markets are trucking, agriculture, and power generation[106].

Another problem with retrofitting for dual-fuel or alternative fuel use is that engine manufacturers are unlikely to provide such retrofit kits and will not warrant the engine for faults while retrofitted. In older boats with engines out of warranty this may not be a concern, but the fact that any retrofit is likely to increase maintenance costs and engine durability needs to be considered.

Finally, the lower flashpoint of alternative fuels such as methanol (11°C) or ethanol (17°C) means that there are issues with converting fuel tanks designed for diesel (above 60°C) as those fuel tanks are often not designed for holding fuels with such flammable vapours. Australian Maritime Safety Authority (AMSA) regulations provide that non-portable fuel tanks for low flashpoint fuels must be contained within a liquid and vapour tight compartment (see Figure 27: Example of an under-floor fuel tank installation for fuel less than 60°C flashpoint (informative))[107]. This means that existing fuel oil spaces must be modified, sometimes significantly, in order to be able to hold methanol. It also means that the volume of methanol will be lower (due to the extra space around the new fuel tank) despite there being a need for a greater volume of methanol than diesel to give the same energy output. If there is an excessive amount of current fuel storage, and if the fuel tank can be modified cost effectively, then this may not be a great concern – but in the case of many of the fishing vessels the project team know of it would be a very expensive process.

[104] https://www.frdc.com.au/sites/default/files/products/1983-065-DLD.pdf
[105] https://www.sciencedirect.com/science/article/pii/S2666052021000030
[106] https://www.clearflame.com/solutions/
[107] Australian Maritime Safety Authority, *National Standard for Commercial Vessels, Part C – Design and Construction, Section 5 – Engineering, Subsection 5A – Machinery*, November 2017

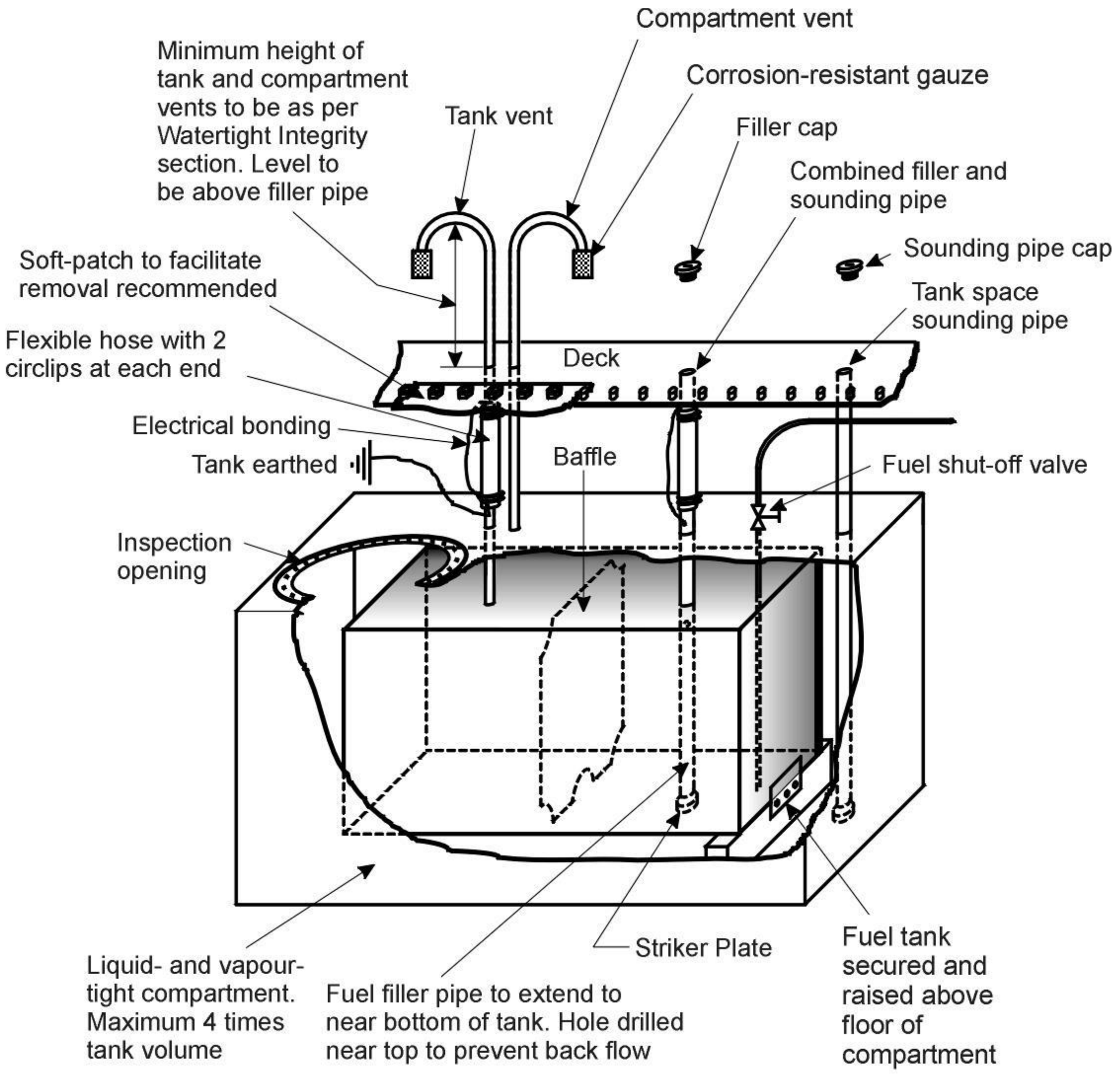

Figure 27: Example of an under-floor fuel tank installation for fuel less than 60°C flashpoint (informative)

Engine Replacement

One way to get around the issue with engine manufacturers' reluctance to warrant or support retrofit fuel systems is to replace the entire engine with one designed to run on sustainable alternative fuels. There is always a risk with conversions like this that the wrong alternative fuel is selected, and the vessel owner is left on an evolutionary dead-end without a reliable fuel supply (a little like owning a Betamax video cassette recorder when VHS took off).

To help remove this uncertainty engine manufacturers like Cummins have been working on new engine platforms designed to support a variety of fuel types, including hydrogen, biogas, and diesel. Their idea is to have a fuel-agnostic platform where "Below the head gasket of each engine will have similar components and above the head gasket will have different components for different fuel types. Each engine version will operate using a different, single fuel."[108] This gives vessel owners the option of implementing an alternative fuel whilst knowing they can reasonably easily convert their engine to a more successful fuel type, including back to diesel.

[108] https://www.cummins.com/news/2022/02/14/cummins-new-low-carbon-fuel-agnostic-engine-platform-strategy

When it comes to propeller-shaft drivetrains most engine replacements consider continuing to use internal combustion engines of some form. However, it is possible to use an electric motor to drive the propeller, known in the industry as power take-in (PTI). This requires significant changes to the fuel system, engine, and drive train and is likely to be too costly and difficult to consider as an engine replacement.

Vessel Replacement

Because many of these are older vessels (42% of the fleet are more than 20 years old[109]), any effort beyond using renewable diesel is likely to prompt fishers to consider replacing their vessels with newer ones. This brings the widest range of possible options, but the ones most relevant for this analysis are those that require the purchase of a new vessel to be economically sound.

The three main alternatives are:

1. Hybrid propulsion engines.
2. Genset powered electric propulsion.
3. Fuel-cell powered electric propulsion.

Hybrid propulsion engines usually have a smaller diesel engine and a smaller electric motor that are both intended to drive the propeller shaft in parallel. In theory giving the emissions advantages of electric, whilst have a standard power pathway as a range extender and back-up in case of issues.

Moving towards electric only propulsion allows the electric motors to be optimised for the tasks required and then gives options as to how the electrons to power those motors will be supplied. Battery is an obvious solution, but the relatively low energy density of current battery technologies means the space and weight required are prohibitive for the purposes of this category of vessels. However, some use of batteries is advisable for any electric system as it gives backup capacity, smooths peak loads, and allows for some regenerative energy capture from other mechanical systems on the vessel.

One option is to use gensets to create the power for the electric motors. This has the benefit of allowing the vessel to start today with diesel generators, but transition to renewable diesel when that becomes available, or to replace the generators with other ones that are custom built for alternative fuels. An advantage of this in a new build is that fuel tanks can be sized for potential future fuels (many of which require more volume), whilst being setup for the current fuel use. The effect of net GHG emissions will vary depending on the fuel selected, but if a conservative option is selected for today then this potentially gives the easiest upgrade pathway to more aggressive GHG emissions reduction strategies.

Another option is to use fuel-cells to power the electric motors. In this case the technology for power generation moves away from internal combustion, which is inherently harder to control emissions from, to chemical reactions that involve lower temperatures, less vibration, less noise and much less emissions. Fuel options include hydrogen, methanol (sometimes needing a reformer to convert it to

[109] Blue Economy CRC webinar, Hydrogen as a Marine Fuel - opportunities and challenges, 16/08/2023.

hydrogen) and ammonia (sometimes needing a reformer to convert it to hydrogen[110]). Of the three possible fuel types, methanol is the friendliest to marine life (compared to ammonia), is liquid at room temperature and pressure, and has the smallest volume requirements (compared to liquid and gaseous hydrogen).

More About Propulsion Options

Traditionally, vessels with inboard engines have had a main engine driving the propeller shaft to propel the vessel through the water. Vessel auxiliary power has often been supplied either by taking power off the main engine (power take-out), or by dedicated generators.

When moving towards alternative fuels there are several ways this traditional system can be varied. For one, having a power take-in system on the propeller shaft can mean a shift from variable speed main engines to fixed speed gensets that can be more efficient across all speeds and torque ranges. Once the decision to generate electricity for propulsion is made, there are then also options to move away from propeller shafts to systems that give greater freedom at deciding how to design the interior of the vessel – allowing more optimal design for catch processing and freezers.

Hybrid Propulsion

Mechanical-electric systems have both internal combustion mechanical and electrical motors attached to the propeller shaft, with either both working at the same time, one or the other rotating the shaft, or even the mechanical drive working and the electrical system acting as a generator to power take-out to batteries or auxiliary loads.

These can be attractive when first looking at electrical propulsion as there is always a mechanical backup. Just like normal mechanical propulsion the main engine will have a design speed where it is most efficient, slower speeds are much less efficient, but the electric propulsion system can take over at that point. It is particularly efficient where the auxiliary load is a fraction of the propulsive power, for example with crab or lobster potting[111]. A disadvantage is that sophisticated electronic control systems need to be used to vary the load between the different propulsion types, and drive duplication can lead to a heavier and more complex solution.

Electric Shaft Propulsion (Power Take-In)

With electric shaft propulsion you have a generator, fuel cell or battery supplying electricity, and an electric motor on the propeller shaft is used to rotate it to create thrust. This allows a move away from ICE towards quieter and more efficient options. However, there is still the need for space to be allowed for the propeller shaft so that it exits the hull at the appropriate place for the propeller. Other options are to use a z-drive to reduce the need for engine/shaft alignment, however the principal is the same. Bury Design has publicly proposed new fishing vessel designs using an electric drivetrain (see Figure 28).

[110] https://news.northwestern.edu/stories/2020/11/ammonia-to-green-hydrogen/

[111] Gabrielii CH, Jafarzadeh S, 'Alternative fuels and propulsion systems for fishing vessels', Sintef Energy Research, 2020.

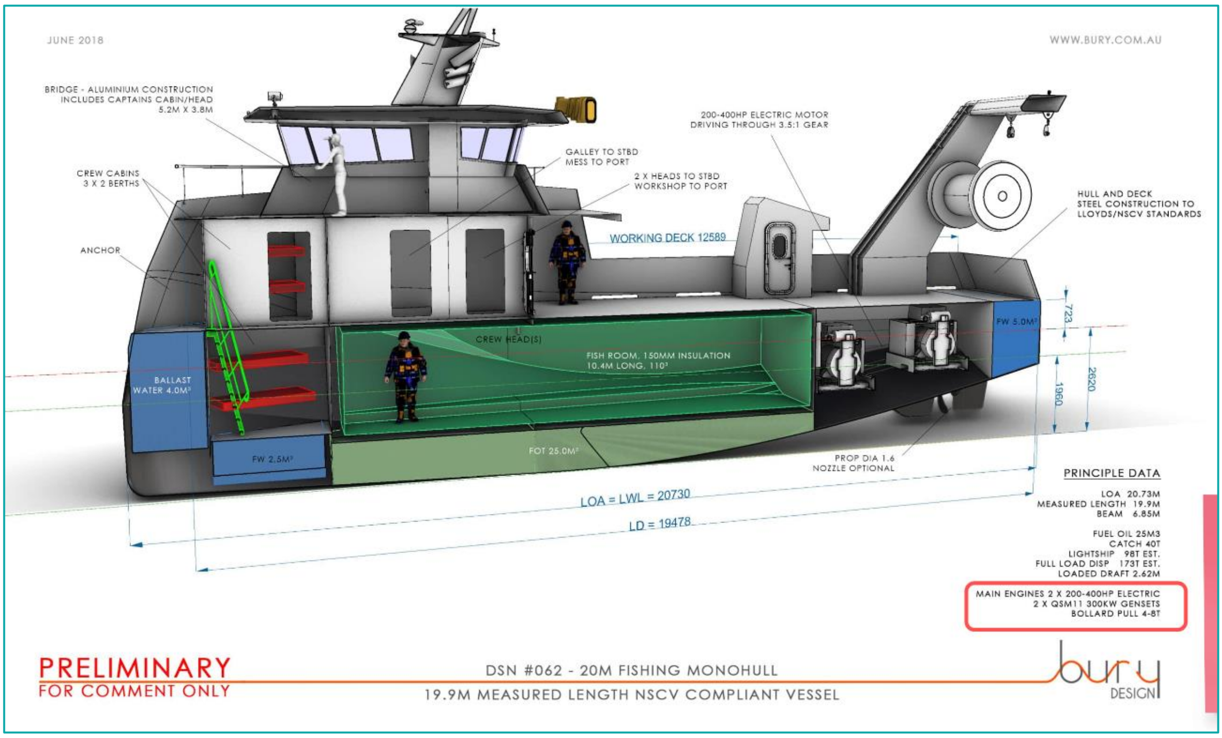

Figure 28: Proposed fishing vessel design with electric drivetrain. Source: Bury Design.

This can be especially efficient when auxiliary loads comprise a significant proportion of propulsive power required, for example prawn trawler freezers[112].

Using batteries to augment generators allows the generators to operate more efficiently, either charging the battery when operating below peak load, or being augmented by the battery to allow for short periods of above peak load. There is also the possibility of operating on battery only for low load periods.

Electric Pod Propulsion

Much like the electric shaft propulsion option, this is powered by generators, fuel cells or batteries. The difference is that rather than using an electric motor to rotate the propeller shaft the electric motors are co-located within a pod attached to each propeller with only an electrical wired connection the power generator. This allows for azimuth thruster pod drives which give greater manoeuvrability or fixed pod drives that are simpler to maintain. Using electric pod propulsion allows the vessel design to do without large propeller shafts running through the vessel. This can support more optimal designs of processing and freezer compartments. The disadvantage of pods, especially azimuth thruster ones, is the cost and complexity of maintaining them.

Volvo Penta claims their Inboard Performance System (IPS) typically offers 15-20% reduced fuel consumption, up to 30% in some use cases, and therefore reduced GHG emissions compared to inboard shaft installations[113]. Unusually it places the dual counter-rotating propellers in front of the propulsion unit that acts in place of a normal rudder. It has seen use on more and more commercial

[112] Gabrielii CH, Jafarzadeh S, 'Alternative fuels and propulsion systems for fishing vessels', Sintef Energy Research, 2020.
[113] https://www.volvopenta.com/about-us/news-page/2020/oct/volvo-penta-ips-a-win-for-customers-and-the-environment/

vessels in recent years, including a pair of hybrid diesel-electric crew transfer vessels in the North Sea (see Figure 29)[114].

Figure 29: Hybrid Electric Crew Transfer Vessel Using Volvo Penta IPS.

Emissions Capture

One developing technology area are mobile CO_2 capture and storage (CCS) systems that capture polluting emissions onboard at the point where they are created. Implied in these systems is the idea that the emissions will be sequestered, or buried, to simply remain in the ground.

This is already happening with closed loop emissions scrubbers on international shipping transports where they want to reduce their SOx emissions in line with IMO regulations, without switching to ultra-low sulphur fuels. The same principle is being used to remove carbon dioxide (and potentially methane) from ship's exhausts.

Many of these systems are very bulky and not applicable to small/medium vessels. They also rely on sequestration which ignores the need for carbon to produce many future fuels. Investments into climate solutions have started looking at decarbonising trucking and many of these systems are much more likely to be applicable with small to medium vessels using diesel inboards – and perhaps eventually petrol outboards. These systems are designed with the intention of finding a market for the carbon they capture.

This project proposes that the term *Exhaust Aftertreatment and CO_2 Re-use (EACR)* be used to differentiate these systems from mobile CCS which just serves to place the carbon underground. EACR creates a circular economy for carbon dioxide (CO_2) where the output from one process, in this case onboard use of e-fuels, becomes a valuable input for another process, the production of e-fuels

[114] https://www.volvopenta.com/about-us/news-page/2021/nov/new-hybrid-vessels-deliver-impressive-20-emission-savings/

(see Figure 30). An EACR system would also help clean up the emissions from using fossil fuels, although probably not capturing all the CO_2 emitted, but letting some go as fugitive emissions.

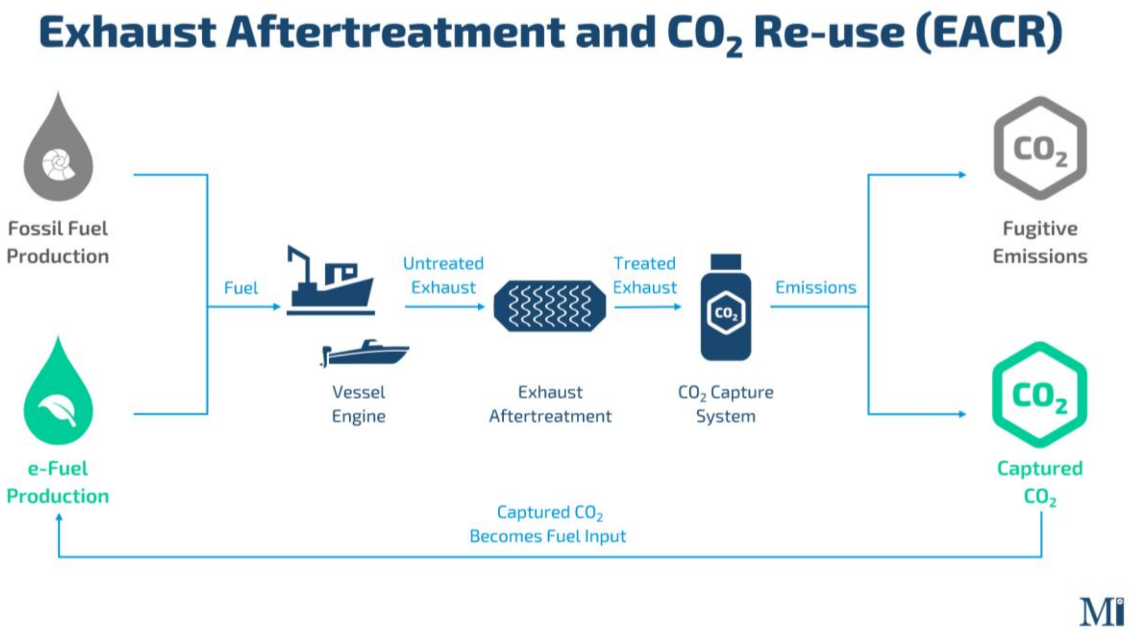

Figure 30: Exhaust Aftertreatment and CO_2 Re-use to Support e-Fuels

Some of the problems with this idea is that the fugitive CO_2 emissions created will still increase GHG emissions, and that as long as fossil fuels are used instead of sustainable fuels, then the CO_2 released in the process originally was from very long-term stored sources. There are also similar spent fuel issues similar to that of Metal Hydrides (Ambient) such as volume and weight of the CO_2 created and the equipment to compress and store it. However, as part of an overall solution it definitely has promise and may even help with some of the emissions downsides of SO Fuel Cells.

Some examples of companies specifically focusing on mobile diesel engines are Remora↗ (USA) and Qaptis↗ (Switzerland), Exhale Aerosystems↗ (Canada). Aramco has licensed their mobile CCS technology to Daphne Technology↗ (Switzerland) for maritime use. Seabound↗ (UK) also has plans to target international shipping. In Australia a startup that plans to target shipping with a similar solution is Kapture↗, although they don't expect to pilot anything in a maritime environment until 2024[115]. Research so far has not identified any systems with TRLs advanced enough for there to be an opportunity to trial something in a fishing vessel.

Detailed Analysis for Diesel Inboard Options

Sunshot Industries provided a viable technology holistic deep dive into the three most appropriate and realistic options for an Australian deep-sea trawl vessel.

These options were baselined against a petro-diesel internal combustion engine.

[115] Personal communication with CEO.

	Option 1 ICE + Green Methanol (Dual Fuel)	Option 2 ICE + Renewable Diesel	Option 3 Electric + Fuel Cell + Green Methanol
Technical Risk	Medium	Low	High
Regulatory Risk	Medium	Low	Medium
Commercial Risk	Medium	High	High
Environmental Impact	Low	Medium	Low
Infrastructure Risk	Medium	Low	Medium
Fuel & Feedstock Supply Chain Risk	Medium	High	Medium
Overall Risk	Medium	Medium	High

Table 4: Viable Technologies Compared

The full detailed assessment of viable technologies is attached in Appendix 4 – Technology Assessment and Recommendations.

Modelling the Costs of a Diesel Engine Replacement

Maritime Impulse Pty Ltd were commissioned to create a model in Microsoft Excel to allow the comparison of costs of different main engine replacements along with different fuel options for powering the example vessel from Austral Fisheries, the Comac Enterprise, a 23-meter-long demersal trap fishing vessel with an inboard diesel engine. The analysis extrapolated the costs per fishing trip (assuming 23 per year) and amortised the engine replacement costs across each trip in an assumed 10-year economic lifespan for the new main engine.

The Comac Enterprise (see Appendix 5 – Comac Enterprise Specifications) typically uses one fairly new auxiliary generator (100 kVA capacity) for the entire trip and the main engine is used to steam to the fishing grounds, and whilst fishing. Austral Fisheries already have in place practices that help minimise their fuel use, so one of the surprising elements of the analysis was that the auxiliary generator, whilst smaller than the main engine, used the bulk of the fuel.

This raised the question of whether we should analyse the main engine replacement alone, or even consider analysing the replacement of the auxiliary generator alone or replacing both. While all of these could be valid, we realised from our research that many other fishers would not be so strict with their main engine use and it would play a greater role for many (as well as being used differently for instance if trawling), so the model's analysis was limited to a main engine replacement – but the fuel use of the auxiliary generator was included as it forms a key part of the GHG emissions of the vessel.

Two main engine replacement scenarios were modelled:

1. **Replacing with a newer diesel engine.**
   This is simply using a newer like-for-like diesel engine. The model assumed a capitalised cost of $357,680 for the engine replacement, plus annual maintenance across ten years.

2. **Replacing with a dual-fuel methanol/diesel engine.**
   This also sources a newer diesel engine, but then retrofits it with Enmar Engine's dual-fuel methanol/diesel kit and replaces the existing fuel tanks with a new dual-fuel system. The model assumed a capitalised cost of $1,936,080 for the engine replacement, and new fuel system plus extra training costs, extra insurance cost and annual maintenance across ten years.

With each of those scenarios we looked at how the fuels on the Diesel Inboard Engine Roadmap would work in terms of cost and GHG emissions:

1. **Replacing with a newer diesel engine.**
   a. Diesel
   b. Renewable Diesel (RD100)
   c. Renewable Diesel Blend (RD50)

2. **Replacing with a dual-fuel methanol/diesel engine.**
   a. Grey Methanol (70%) and Diesel (30%)
   b. Green Methanol (70%) and Renewable Diesel (RD100) (30%)

A key observation is that given the assumptions we used in the model, the fuel cost for each trip far outweighed the amortised capital cost of the main engine replacement, no matter what engine replacement or fuel type was considered. This highlights the need for Government intervention to help the commercial wild catch fishing industry mitigate their impact on climate change.

The model is available as an Excel spreadsheet that can have the assumptions over-written so that stakeholders can look at how a different vessel, or different market situation might affect the results.

Where possible we derived the assumed values from either Austral Fisheries, EPA lifecycle costs for specific fuels, public information, or research done for the project. Discussions with renewable diesel supply chain participants and methanol supply chain participants helped form the basis of our costings for renewable diesel and green methanol – but these also assumed some degree of Government intervention to reduce prices to these levels. The renewable diesel prices have been influenced in part by the examples we see in California where use of it for commercial harbour craft has been mandated (since 1st January 2023) and supported by the State government. In order not to bias the results with these assumptions the Excel spreadsheet makes these explicit and allows interested parties to test their own assumptions instead.

It should be noted that the timeframe for an engine replacement or conversion is significant (at least 1-6 months) so the model makes allowance to include a number for the typical profit per trip for this vessel. As this is commercially sensitive Austral Fisheries did not provide this information – but the Excel spreadsheet contains a field to enter this value. Beyond about $100,000/trip this would alter the amortised capital cost enough that it would outweigh the fuel costs for some of the dual-fuel options.

Fuel prices are not static and so for each fuel type we modelled a minimum and maximum fuel price that shows how different prices for that same fuel type would affect the per trip costs. The modelling included a price on GHG emissions ("carbon price") that in Figure 31: Per Trip Amortised Engine Replacement and Fuel Costs is shown only on the maximum bar for each fuel type. Like our other assumptions this carbon price ($300/ton of CO_2-equivalent GHG emissions) is an assumption that can be modified in the Excel spreadsheet.

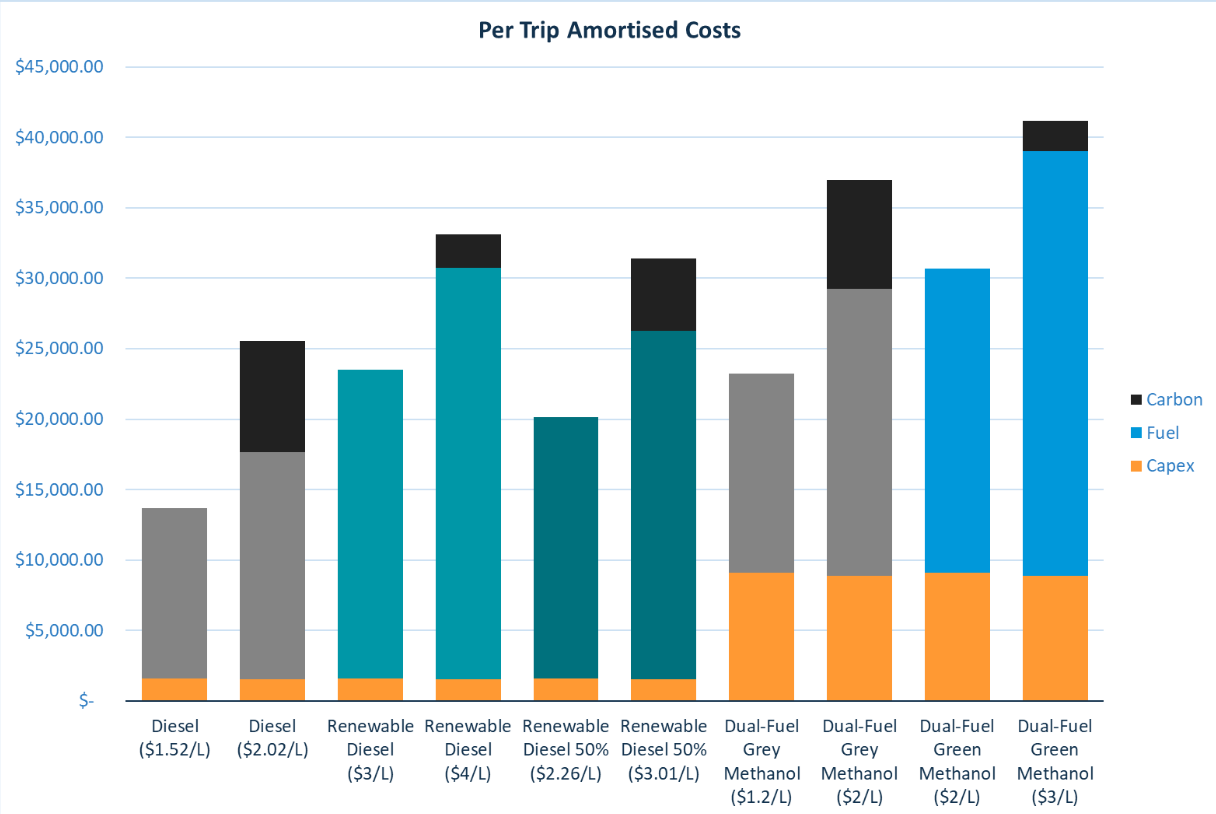

Figure 31: Per Trip Amortised Engine Replacement and Fuel Costs

With regards to the greenhouse gas (GHG) emissions for each fuel type Figure 31 shows that even with a reasonably conservative GHG emissions reduction for renewable diesel (70% reduction versus diesel) there is a significant reduction by using alternate fuels. With regards to the auxiliary generator, whilst it is not modified and so no capital cost is included for it, it is assumed to be using the same fuel type as the diesel portion of the main engine. This reflects in the costs in Figure 31 but also helps ensure the GHG emissions shown below are accurate for the whole vessel's fuel use.

The renewable diesel blend is shown in these charts as RD50, meaning a 50% volume blend of diesel and renewable diesel. That assumption is also something that can be modified in the Excel spreadsheet. By including these values, we can see that significant reductions in GHG emissions can be made by implementing some level of renewable diesel – even if it turns out that a pure RD100 blend is not financially viable to implement (see Figure 32).

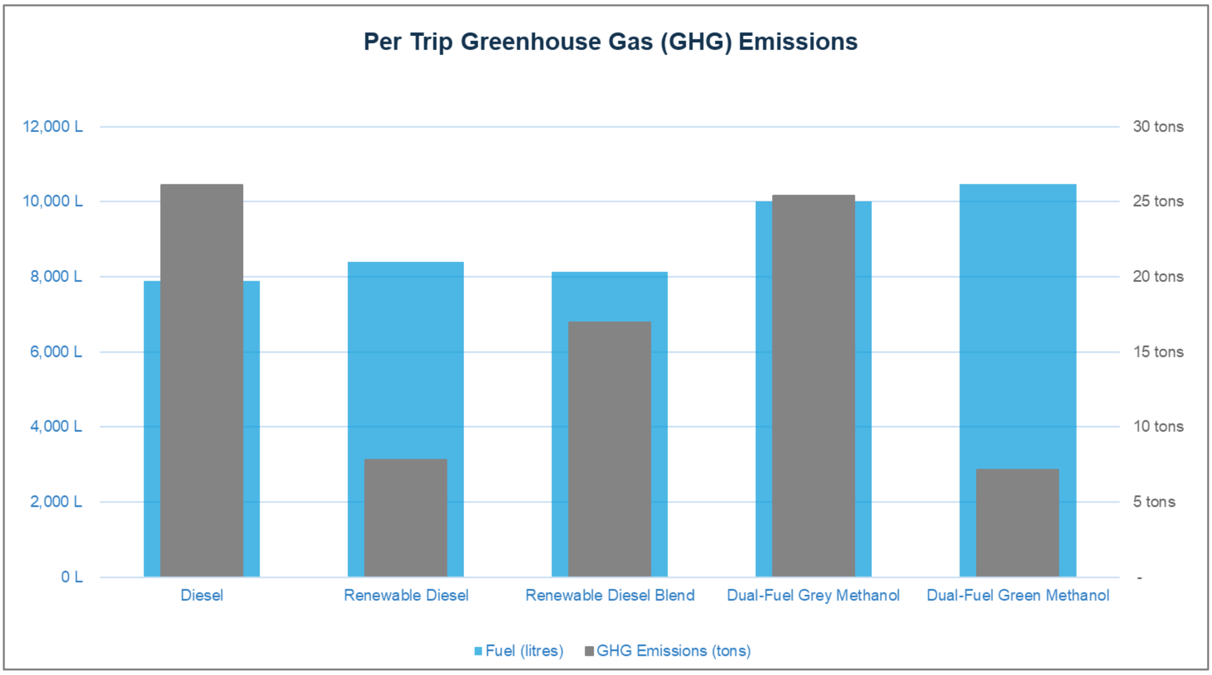

Figure 32: Per Trip Greenhouse Gas (GHG) Emissions Versus Fuel Used

The modelling does not make any assumptions about how the capital works are funded and so does not analyse the weighted average cost of capital or return on investment. Obviously, given the comments above about the typical profit per trip there is also an analysis that is needed to review whether the changes are in fact financially viable (e.g. if the per trip costs exceed the typical profit per trip). However, the commercial wild catch fishing industry may not be given a choice in reducing GHG emissions, so it is better to identify this as early as possible.

If a commercial wild catch fisher wanted to be more ambitious in reducing GHG emissions, then modifying the auxiliary generator(s) would be worth considering. In this case the importance of self-sufficiency might not be violated by a more radical change and so they could consider the use of an electron energy carrier such as fuel cells, matched perhaps with a pure methanol fuel. From a risk mitigation viewpoint, the dual-fuel methanol/diesel main engine would work even if only running on diesel, and so the self-sufficiency risk of using methanol and fuel cells would be limited.

Energy Transition Roadmaps

The Importance of Self-Sufficiency

While interviewing members of the commercial wild catch fishing industry it became apparent that there are issues that drive fishers to reject many technical options, which technologists might see as ideal solutions to challenges in commercial fishing.

The project team have identified that one of the unique requirements for fishers is self-sufficiency, the ability to deal with problems without help from other people. Especially the ability to be at sea and handle power, propulsion, or engine problems without the need to request help. There is an element here of economic independence (not wanting a catch to spoil, not needing to pay for others' help) mixed in with a focus on crew and personal safety.

The project hypothesises that this is a greater concern for single vessel inshore or deepwater fishers, but it can be seen in much of the resistance that new ideas around efficiency have sometimes had in the industry. As David Carter has said:

> "The legacy position was to buy any old piece of iron, develop a fishery and try and keep it going with bailing twine and fencing wire … metaphorically speaking. But when we look at the numbers, it's not the cheapest way to run boats, as the Europeans will tell you."[116]

Energy transition roadmaps must therefore take this into account and look to ensure that where possible ideas that better support self-sufficiency are prioritised.

Beyond Resilience, Achieving Antifragility

Nassim Nicholas Taleb, in his book *Antifragile: Things that Gain from Disorder* maps things on a spectrum of their ability to handle shocks (see Figure 33), or as he calls them, Black Swan events.

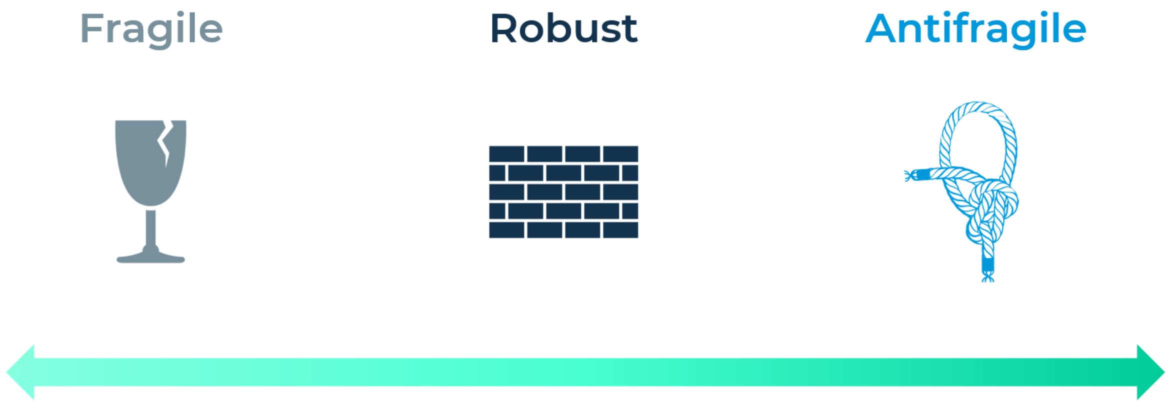

Figure 33: Mapping Ability to Handle Shocks. Source: Blue-X.

Things that are relatively more *fragile* are prone to experience negative consequences from disorder or volatility. *Robust* things are able to shrug off many disordering events, they resist positive changes as much as negative changes. Something is *antifragile* if disorder and volatility leads to positive outcomes.

In many ways the commercial wild catch fishing industry is fragile when it comes to the effects of climate change as it is likely to produce shocks that affect fish stocks[117]. Moving towards greater robustness, is therefore a positive step. However, if we can find opportunities in the energy transition that promote antifragility, then these should be aimed for.

One way that nature achieves robustness and is through redundancy, two kidneys give us double the chance of surviving a problem in one, the same with the rest of our body's symmetrical properties. An opportunity that gives deep enough redundancy without self-sufficiency might be acceptable,

[116] https://www.frdc.com.au/fish-vol-29-1/management-and-technology-deliver-fishery-confidence
[117] Fulton EA, Hobday AJ, Pethybridge H, Blanchard J, Bulman C, Butler I, Cheung W, Gorton B, Hutton T, Lozano-Montes H, Matear R, Pecl G, Villanueva C, Zhang X (2017) *Decadal scale projection of changes in Australian fisheries stocks under climate change*.

despite the previous point (hence the hypothesis that single vessel fishers are most in need of self-sufficiency).

Two examples of antifragility from the human body are brain neuroplasticity and the immune system. Both can recover from disorder, or shocks, in ways that improve function. For example, a person who becomes blind will often develop greater use of their other senses, especially hearing. In a similar way using millions of white blood cells to fight infection allows some to win and some to lose. Deliberately exposing humans to immune system shocks (e.g. dirt, other people, street vendor food on a backpacker holiday) can help them develop more robust immune systems[118].

A key to antifragility is optionality, allowing you more upside than downside to your decisions. By creating transition roadmaps that include optionality we can leave the door open to benefiting from changes we are not yet aware of. If we identify an option where the downside is too great, then we can de-prioritise that on our roadmap. On the other hand, if there is a better upside than downside, then we can include those in our roadmap and avoid limiting ourselves. Stephen Bungay describes this kind of strategic decision making in his book, Art of Action:

> "Conducting a campaign will involve continuous decision making, seeking not to take perfect decisions, any more than we should seek to create a perfect plan, but ones that are sensible given the circumstances. We need to make decisions which are "about right – now," take action to change the situation, and then move on to the next decision. The laws of probability dictate that if our decisions are reasonably good, we will avoid disaster and are likely to do quite well. We will certainly outperform someone who tries to take one big decision about how to do everything or someone who makes no decisions at all. We manipulate luck by making a series of small choices which open up further options."[119]

Hence, the roadmaps look to make small choices, but critical ones that can help open up options for the industry to benefit from adapting to climate change challenges.

Energy Transition Paradox

The paradox of the energy transition is that it is easy to be deadlocked between the view that the transition is impossible to accomplish, and yet at the same time the view that it will inevitably occur (see Figure 34). Like a surfer committing to a wave, the trick lies in committing earlier than appears sensible, but in a small enough way that the option of pulling out remains if the wave is not caught.

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[118] https://www.betterhealth.vic.gov.au/health/conditionsandtreatments/immune-system

[119] Bungay, Stephen. The Art of Action: How Leaders Close the Gaps between Plans, Actions and Results (p. 96). John Murray Press. Kindle Edition.

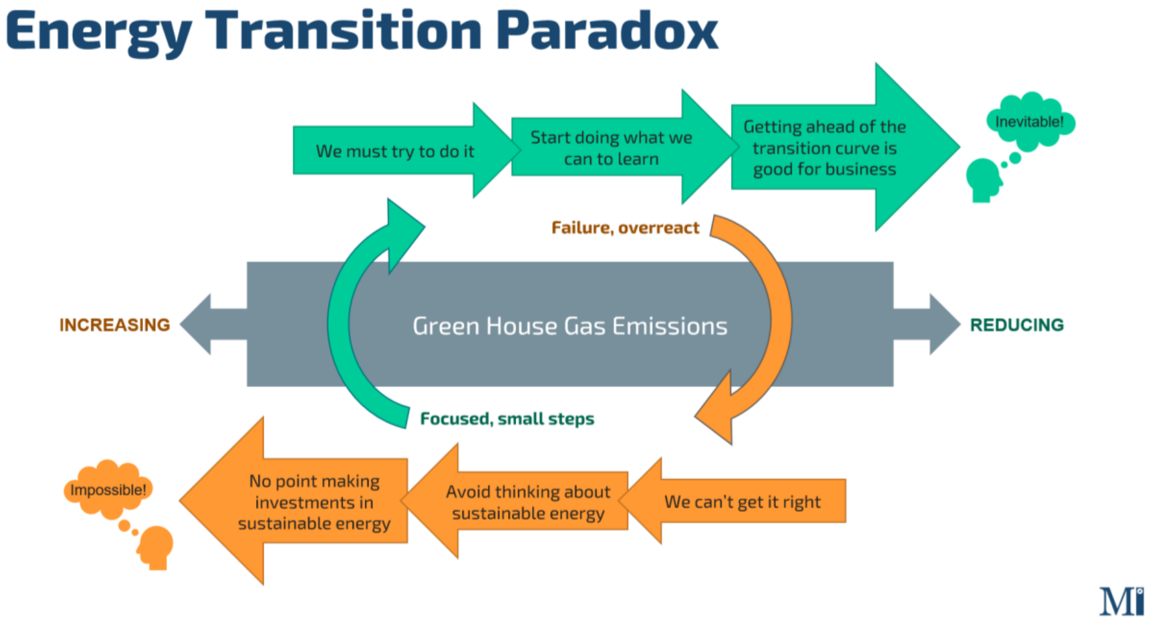

Figure 34: Energy Transition Paradox

The energy transition roadmaps must give enough priority to the industry's commitment to reducing GHG emissions that it gets us surfing, without requiring that any one wave breaks where we want it to, or that every part of the complex transition be executed flawlessly.

Industry-Wide Scenarios

A spreadsheet model was created to analyse how different assumptions would affect the potential reduction of greenhouse gas (GHG) emissions by the industry. This modelled how different types of interventions might spread, with a range of assumptions as to how effective the interventions might be through to how likely it would be that part of the industry would choose to do different interventions.

Most of the models assume some form of step-change, or breakthrough, either in technology or in commercial investment. They are not therefore intended to be seen as 'likely' or 'unlikely', they simply demonstrate what might happen with such a breakthrough in the near future.

Overall Assumptions

Some key assumptions were needed to be made to make such modelling possible:

1. **Overall Assumption 1:** There is currently no information about how many fishing vessels are using diesel inboards vs petrol outboards. Using AMSA's DCV fleet profile from 2020 we can assume that of the 24,000 DCVs they mention the fishing ones can be apportioned by length into either diesel inboard or petrol outboard[120]:

    a. 20.3% of DCVs are fishing vessels less than 7.5m long (assume petrol outboard)

[120] https://www.amsa.gov.au/domestic-commercial-vessels-fleet-profile

b. 5.3% of DCVs are fishing vessels between 7.5m and 12m long (assume half petrol outboard and half diesel inboard)
c. 7.2% of DCVs are fishing vessels between 12m and 24m long (assume diesel inboard)
d. 0.4% of DCVs are fishing vessels greater than 24m long (assume diesel)

This leads us to assume that the wild-catch commercial fishing fleet would have around 5,508 vessels using petrol outboards, and 2,460 vessels using diesel inboards. Separate AMSA data records the fuel type of class 3 (fishing) vessels and shows 2,001 use diesel, 3,231 use petrol, 35 use a range of other fuels (including 2 electric), and 2,074 are unknown[121]. This does not invalidate the length analysis, and given the large number of unknown values are vessels without a Certificate of Survey, it is reasonable to assume most of those are smaller vessels using petrol outboards.

Unfortunately, there is also no statistic that will indicate the amount of petrol or diesel fuel consumed by either group. The best indication of fuel consumption is the fuel excise subsidy data from the ATO, but that neither breaks out diesel vs petrol, nor records the number of litres of fuel[122].

It is likely that diesel inboard engines are consuming more than petrol outboard motors, despite the larger number of vessels being smaller. We have therefore assumed that the split of GHG emissions between diesel inboard engines and petrol outboard motors is even.

2. **Overall Assumption 2:** The current *National Greenhouse Gas Inventory Quarterly Update: December 2022*[123] shows that the Agriculture sector has reduced emissions by 6.2% from the 2005 base figures used by the National GHG Emissions targets. Wild-catch commercial fishing is not specifically called out, so we have assumed that a similar reduction (6%) has occurred up to the start of the 2023 base year for our scenarios. As per Overall Assumption #1 we have split the amount equally between outboards and inboards.

3. **Overall Assumption 3:** It is possible that with climate change impacts to fisheries and the increase in marine parks that there will be some decrease in the number of fishing concessions, and/or quota limits. These are likely to impact GHG emissions by reducing the fishing effort undertaken. We have chosen to assume that there will be no need for future changes in concessions, effort inputs, or quotas – but the spreadsheet model makes allowance for there to be some.

4. **Overall Assumption 4:** The scenarios focus on reductions to Scope 1 GHG emissions. We have assumed that the wild-catch commercial fishing industry needs to proportionally target emissions in Scopes 1, 2 and 3, with a previous FRDC project identifying that on average 49% of GHG emissions are Scope 1 (fuel use and fugitive refrigerant emissions) and then the bulk

[121] Project email communication with AMSA.
[122] Australian Taxation Office, Taxation statistics 2020–21 Excise and fuel schemes: Fuel tax credits scheme – claims paid, by industry, 2006–07 to 2021–22 financial years
[123] https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-update-december-2022

of the rest are Scope 3 (transport and processing)[124]. This study does not concern itself with reducing Scope 2 (electricity supply) or Scope 3 emissions, as these come from sectors which themselves will be aiming to meet the National GHG Emissions Targets (see Figure 2). Therefore the 2030 target for this modelling was assumed to be a 43% reduction on Scope 1 GHG emissions since 2005, with it being assumed that Scope 2 and 3 GHG emissions would also be reduced in line with that target. Not meeting the target with Scope 1 GHG emissions is less of an issue if the other scopes can exceed the targeted reductions, and likewise if Scope 1 emissions can be reduced below the target, then that can make up for shortfalls in the other scopes.

Each scenario we modelled also had specific assumptions relevant to it, these are discussed in the following sections.

Scenario 1 – BAU, Minimal Changes

The *BAU, Minimal Changes* scenario is the most basic one, assuming nothing drastically changes, that biofuels and e-fuels are minimally developed, no government regulation is introduced to mandate GHG reductions, and no government assistance is introduced to encourage the use of more sustainable energy sources. The industry is assumed to only take actions that economically make sense by reducing existing fuel consumption and saving money, with small pockets of the industry finding that customers push for them to become more sustainable (see Figure 35).

[124] FRDC Project No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April). CC BY 3.0

Cohort	2023	2030	2040	2050
Future Changes in Concessions/Effort/Quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Existing Outboard Fleet, Unchanged	3.00%*	4.81%	4.10%	3.23%
Existing Outboard Fleet Becoming More Efficient	0.18%	1.68%	3.69%	5.61%
New Outboard Diesel Motors	0.00%	0.73%	2.20%	3.68%
New Outboard Electric Motors	0.00%	1.71%	4.18%	6.38%
Newbuild Electric Outboard Vessels	0.00%	1.74%	4.22%	6.44%
Outboard GHG Reductions	*3.18%*	*10.68%*	*18.38%*	*25.32%*
Existing Inboard Fleet, Unchanged	3.00%*	6.60%	7.20%	6.00%
Existing Inboard Fleet Becoming More Efficient	0.21%	1.94%	4.30%	6.30%
Inboard Newbuilds Built More Sustainable	0.19%	1.12%	2.16%	2.91%
Existing Inboard Vessels Made Hybrid	0.26%	1.00%	1.98%	2.76%
Hybrid Inboard Newbuilds	0.00%	1.07%	2.80%	4.36%
All Electric Inboard Newbuilds	0.00%	0.72%	1.73%	2.63%
Inboard GHG Reductions	*3.66%*	*12.45%*	*20.16%*	*24.96%*
Scope 1 GHG Left	93.17%	76.87%	61.46%	49.72%
Total Reduction	**6.83%**	**23.13%**	**38.54%**	**50.28%**

Table 5: Scenario 1 – GHG reductions with BAU, Minimal Changes

In this scenario the greatest effect on GHG emissions would be efficiency gains that also improved the profitability of existing vessels. Both the 2030 target of 43% emissions reduction and the 2050 target of 100% emissions reduction will be missed.

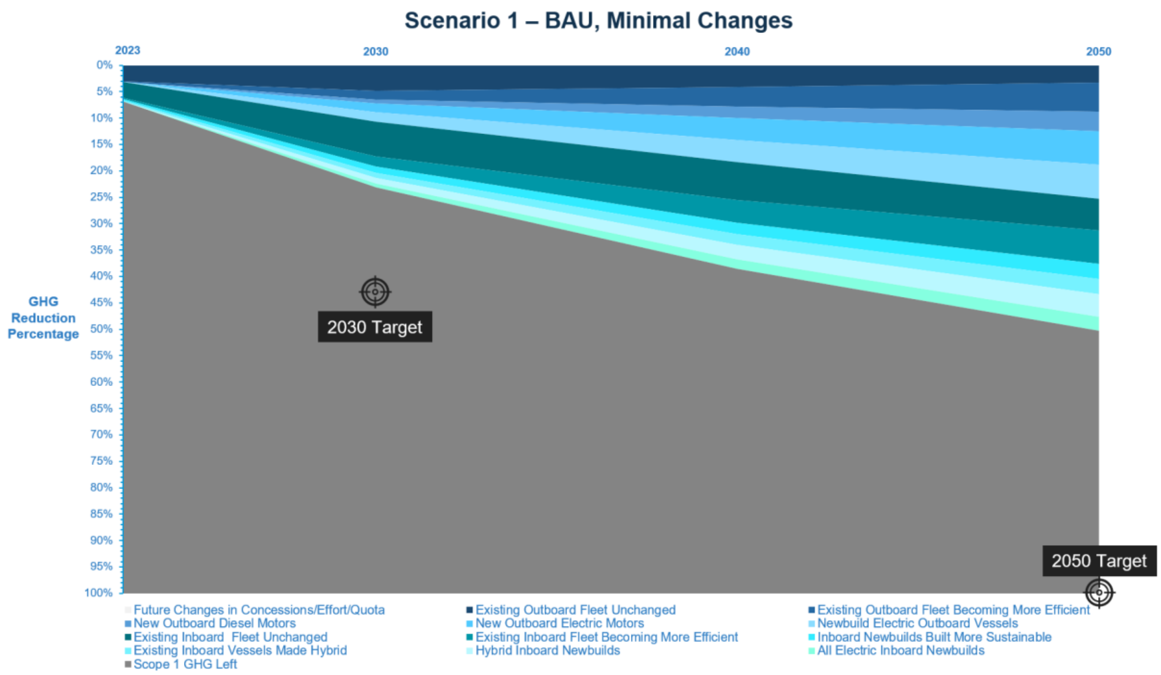

Figure 35: Scenario 1 – BAU, Minimal Changes

Assumptions

For the *BAU, Minimal Changes* scenario to occur as modelled, the following would have to be true:

1. Federal and State governments would have to not try to reduce the GHG emissions of the fishing sector.
2. Technologies to help reduce GHG emissions for the long-distance shipping sector would not create breakthroughs of use to fishing vessels.
3. Ports, harbours, and councils (with boat ramps) would make minimal changes to support shore charging of domestic commercial vessels.
4. Ports and harbours would make no change to support alternate fuels for domestic commercial vessels.
5. Seafood customers (wholesale and retail) would have to not want more sustainable energy use in the production of their seafood products, at least not if it drives up prices.
6. Any new carbon border taxes would have to ignore seafood products.

Scenario 2 – Plenty of Biofuels/e-Fuels

In the *Plenty of Biofuels/e-Fuels* scenario, we assume that there is plenty of sustainable biomass for biofuels, and/or plenty of sustainable carbon for e-fuels. The net effect of this will be to ensure that fuel blends like Bu16 to replace petrol and drop-in fuel blends like RD100 to replace diesel exist in the short-term, and green methanol is available in the longer term (see Figure 36). Note that we do not expect that drop-in e-fuels like e-gasoline or e-diesel will be available in sufficient quantity to be cost effective.

Cohort	2023	2030	2040	2050
Future Changes in Concessions/Effort/Quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Existing Outboard Fleet Unchanged	3.00%	10.98%	7.80%	3.90%
Existing Outboard Fleet Becoming More Efficient	0.18%	2.66%	5.01%	7.16%
New Outboard Diesel Motors	0.00%	0.53%	1.70%	3.00%
New Outboard Electric Motors	0.00%	1.71%	4.18%	6.38%
Newbuild Electric Outboard Vessels	0.00%	1.74%	4.22%	6.44%
Outboard GHG Reductions	*3.18%*	*17.62%*	*22.91%*	*26.88%*
Existing Inboard Fleet Unchanged	3.00%	15.00%	12.00%	4.20%
Existing Inboard Fleet Becoming More Efficient	0.21%	3.29%	6.79%	9.32%
Inboard Newbuilds Built More Sustainable	0.19%	1.75%	3.13%	4.02%
Existing Inboard Vessels Made Hybrid	0.26%	1.16%	2.23%	3.06%
Existing Inboard Vessels Made Dual-Fuel	0.00%	1.23%	2.10%	2.99%
Hybrid Inboard Newbuilds	0.00%	1.42%	3.48%	5.29%
Dual-Fuel Inboard Newbuilds	0.00%	1.29%	4.42%	6.22%
Alternate Fuel Inboard Newbuilds	0.00%	1.52%	4.98%	7.02%
All Electric Inboard Newbuilds	0.00%	0.72%	1.73%	2.63%
Inboard GHG Reductions	*3.66%*	*27.37%*	*40.86%*	*44.75%*
Scope 1 GHG Left	93.17%	55.01%	36.23%	28.37%
Total Reduction	**6.83%**	**44.99%**	**63.77%**	**71.63%**

Table 6: Scenario 2 – GHG emissions with Plenty of Biofuels/e-Fuels

In this scenario the greatest effect on GHG emissions would be efficiency gains that also improved the profitability of existing vessels, and electrification of the outboard fleet. However, in the short-term, the emissions reductions that RD100, Bu16 and sustainable methanol (green or bio) would offer will help boost the reduction beyond the 2030 target. This scenario makes the 2030 target, and will miss the 2050 target, but it comes close to reaching it.

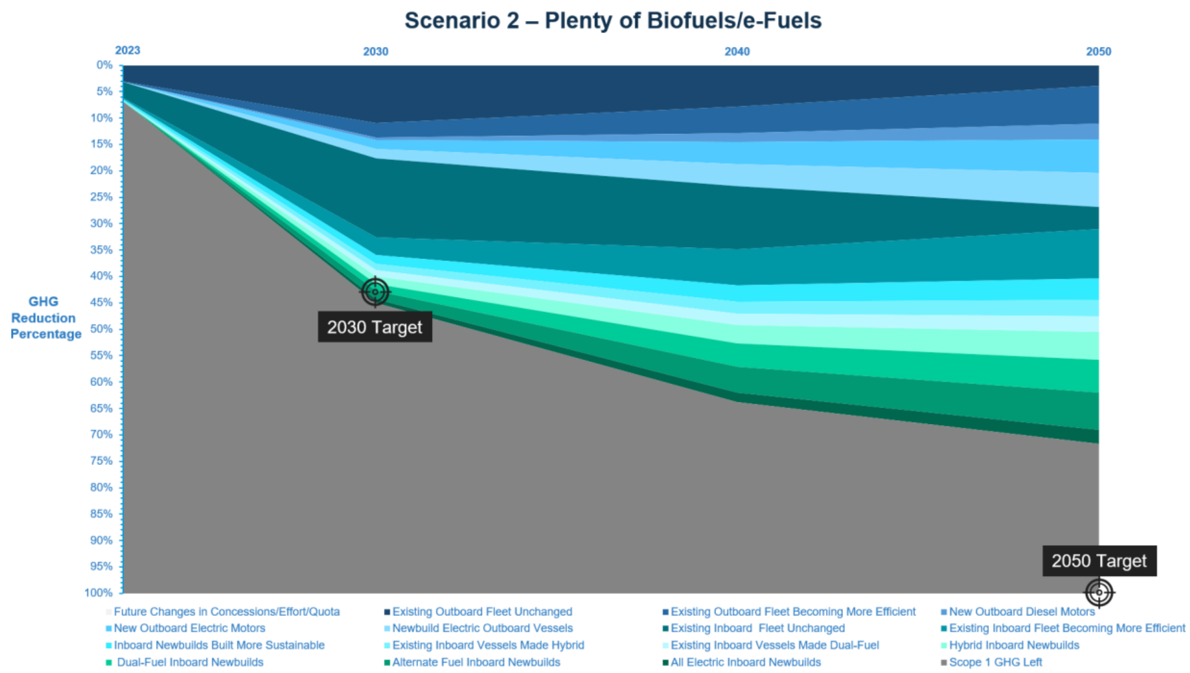

Figure 36: Scenario 2 – Plenty of Biofuels/e-Fuels

Assumptions

For the *Plenty of Biofuels/e-Fuels* scenario to occur as modelled, the following would have to be true:

1. Federal and State governments would have to try to prioritise reducing GHG emissions.
2. Either there would be plenty of sustainable biomass for biofuels (animal and agricultural residues[125]), and/or plenty of sustainable carbon for e-fuels (captured carbon waste streams[126]).
3. Clear demand signals to indicate to potential supply chain participants that it is worth investing in biofuels/e-fuels.
4. Clear supply signals to indicate to potential consumers that it is worth investing in equipment that utilises biofuels/e-fuels.
5. Ports and harbours would invest so they could fully support alternate fuels for domestic commercial vessels by 2030.
6. Consider second order effects of reducing GHG emissions in terms of competition with imported seafood and the economic consequences of increased food prices.
7. Seafood customers (wholesale and retail) would have to want more sustainable energy use in the production of their seafood products, even if it drives up prices.
8. Individual fisher companies feel they both need to and can, use more sustainable energy sources.

Scenario 3 – Battery Breakthrough

In the *Battery Breakthrough* scenario, we assume that within the next few years a major breakthrough in battery storage is achieved, whereby battery storage becomes economical for a wider range of maritime use cases that currently exist. This is assumed to lead to an increase in the

[125] 'Biomass to Energy Handbook', Kearney Energy Transition Institute, 2020
[126] 'Decarbonising society with Power-to-X', Ørsted, October 2020

amount of hybrid and fully electric engines aboard all sorts of vessels. At the same time, it would also likely lead to much less support for biofuels/e-fuels, so this scenario assumes limited support for renewable diesel or butanol fuel blends.

Cohort	2023	2030	2040	2050
Future Changes in Concessions/Effort/Quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Existing Outboard Fleet Unchanged	3.00%	4.44%	3.83%	3.08%
Existing Outboard Fleet Becoming More Efficient	0.18%	0.84%	2.46%	4.20%
New Outboard Diesel Motors	0.00%	0.29%	0.88%	1.47%
New Outboard Electric Motors	0.00%	6.56%	8.35%	10.20%
Newbuild Electric Outboard Vessels	0.00%	6.62%	8.45%	10.31%
Outboard GHG Reduction	*3.18%*	*18.75%*	*23.96%*	*29.26%*
Existing Inboard Fleet Unchanged	3.00%	6.10%	5.40%	3.15%
Existing Inboard Fleet Becoming More Efficient	0.21%	0.97%	2.87%	4.73%
Inboard Newbuilds Built More Sustainable	0.19%	0.75%	2.16%	3.49%
Existing Inboard Vessels Made Hybrid	0.26%	2.86%	6.59%	10.35%
Existing Inboard Vessels Made Dual-Fuel	0.00%	0.57%	0.65%	0.71%
Hybrid Inboard Newbuilds	0.00%	2.50%	4.34%	5.99%
Dual-Fuel Inboard Newbuilds	0.00%	0.30%	0.69%	1.11%
Alternate Fuel Inboard Newbuilds	0.00%	0.38%	0.83%	1.32%
All Electric Inboard Newbuilds	0.00%	2.52%	4.32%	6.14%
Inboard GHG Reduction	*3.66%*	*16.95%*	*27.85%*	*36.98%*
Scope 1 GHG Left	93.17%	64.31%	48.18%	33.77%
Total Reduction	**6.83%**	**35.69%**	**51.82%**	**66.23%**

Table 7: Scenario 3 – GHG emissions with Battery Breakthrough

In this scenario the greatest long-term effect on GHG emissions would come from electrifying. Both the 2030 and 2050 targets will be missed. The most surprising result is how even limited amounts of renewable diesel and green butanol can still contribute substantially to emissions reductions for the existing fleet (see Figure 37).

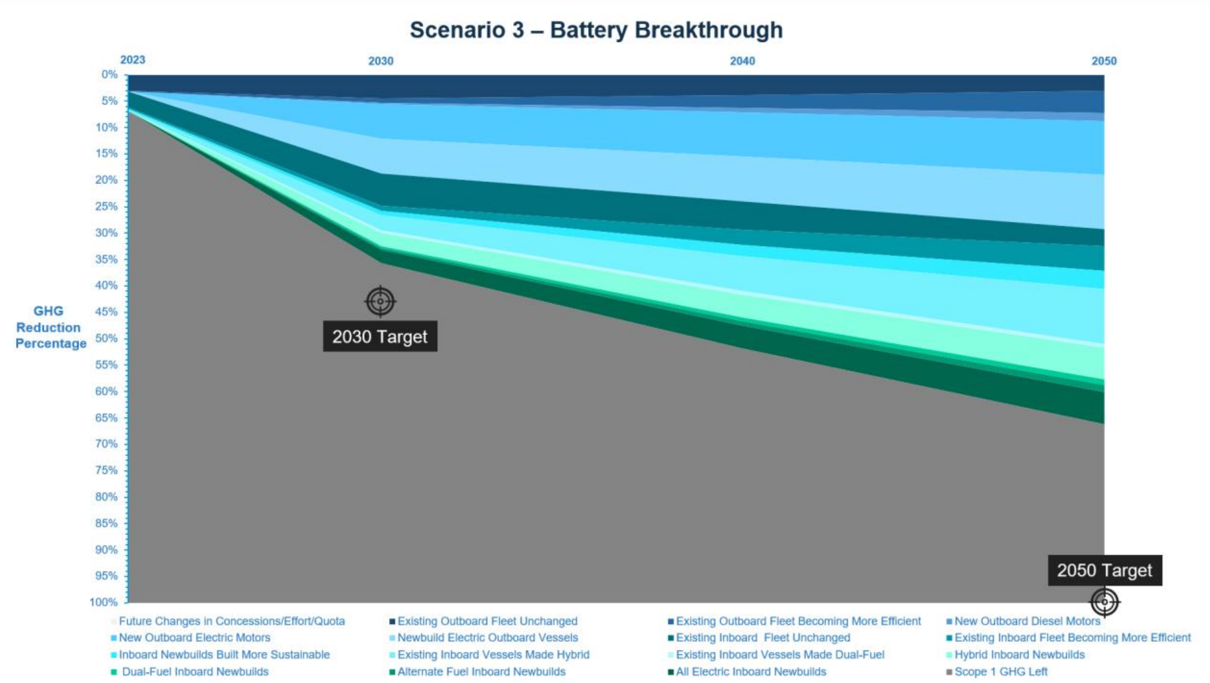

Figure 37: Scenario 3 – Battery Breakthrough

Assumptions

For the *Battery Breakthrough* scenario to occur as modelled, the following would have to be true:

1. Federal and State governments would have to try to prioritise reducing GHG emissions.
2. Battery storage breakthroughs lower the volume, weight, cost, and longevity of marine battery solutions enough that they become only slightly worse than diesel and petrol fuels. For example, instead of twenty times (20x) the storage volume, they only require (10x) the storage volume.
3. The wild-catch commercial fishing industry makes significant changes to optimise operations around the limitations of battery-electric and hybrid electric vessels. For example, offering offshore charging buoys, using more catamaran hull forms, and reducing the length of offshore fishing operations.
4. The breakthroughs in battery storage create less demand for biofuels/e-fuels, so the supply of these is limited, especially the more expensive drop-in fuels.
5. Ports, harbours, and councils (with boat ramps) would invest so they could fully support sustainable shore charging for domestic commercial vessels by 2030.
6. Consider second order effects of reducing GHG emissions in terms of competition with imported seafood and the economic consequences of increased food prices.
7. Seafood customers (wholesale and retail) would have to want more sustainable energy use in the production of their seafood products, even if it drives up prices.
8. Individual fisher companies feel they both need to and can, use more sustainable energy sources.

Scenario 4 – Hydrogen Breakthrough

In the *Hydrogen Breakthrough* scenario, we assume that a breakthrough in hydrogen storage (perhaps with Metal Hydrides (Ambient)) means it becomes economical for a wider range of maritime use cases that currently exist. This leads to a greater uptake of dual-fuel and fully alternate fuel engines, but a slightly lower uptake of electric or hybrid engines (see Figure 38). At the same time, it would also likely lead to much less support for biofuels/e-fuels, so this scenario assumes limited support for renewable diesel or butanol fuel blends.

Cohort	2023	2030	2040	2050
Future Changes in Concessions/Effort/Quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Existing Outboard Fleet Unchanged	3.00%	4.81%	4.10%	3.23%
Existing Outboard Fleet Becoming More Efficient	0.18%	1.68%	3.69%	5.61%
New Outboard Diesel Motors	0.00%	0.73%	2.20%	3.68%
New Outboard Electric Motors	0.00%	2.05%	4.18%	6.38%
Newbuild Electric Outboard Vessels	0.00%	2.07%	4.22%	6.44%
Outboard GHG Reduction	*3.18%*	*11.34%*	*18.38%*	*25.32%*
Existing Inboard Fleet Unchanged	3.00%	6.20%	5.40%	3.00%
Existing Inboard Fleet Becoming More Efficient	0.21%	0.65%	1.91%	3.15%
Inboard Newbuilds Built More Sustainable	0.19%	0.75%	2.16%	3.49%
Existing Inboard Vessels Made Hybrid	0.26%	1.14%	1.98%	2.76%
Existing Inboard Vessels Made Dual-Fuel	0.00%	2.07%	4.37%	6.78%
Hybrid Inboard Newbuilds	0.00%	1.25%	2.17%	3.00%
Dual-Fuel Inboard Newbuilds	0.00%	1.43%	3.04%	4.70%
Alternate Fuel Inboard Newbuilds	0.00%	1.84%	3.73%	5.63%
All Electric Inboard Newbuilds	0.00%	0.84%	1.73%	2.63%
Inboard GHG Reduction	*3.66%*	*16.17%*	*26.49%*	*35.13%*
Scope 1 GHG Left	93.17%	72.49%	55.13%	39.55%
Total Reduction	**6.83%**	**27.51%**	**44.87%**	**60.45%**

Table 8: Scenario 4 – GHG emissions with Hydrogen Breakthrough

In this scenario the greatest long-term effect on GHG emissions would be electrification of the outboard fleet and dual-fuel or alternate fuel vessels. Both the 2030 and 2050 targets would be missed. Once again, the most surprising result is how even limited amounts of renewable diesel and green butanol can still contribute substantially to emissions reductions for the existing fleet in the short-term. This is the second worst scenario in terms of climate outcomes.

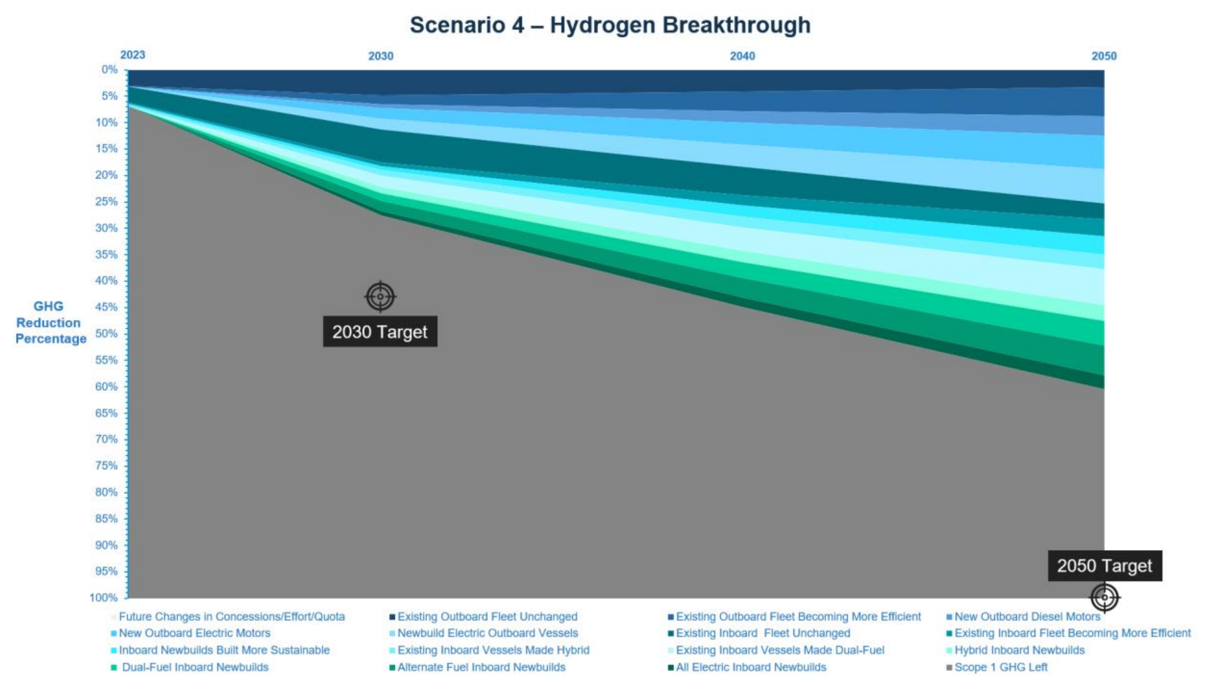

Figure 38: Scenario 4 – Hydrogen Breakthrough

Assumptions

For the *Hydrogen Breakthrough* scenario to occur as modelled, the following would have to be true:

1. Federal and State governments would have to try to prioritise reducing GHG emissions.
2. Hydrogen storage breakthroughs lower the volume, weight, and cost of marine hydrogen storage solutions enough that they become only slightly worse than diesel and petrol fuels. For example, instead of ten times (10x) the storage volume, they only require (5x) the storage volume. This is most likely a solution using Metal Hydrides (Ambient).
3. Maritime safety and design regulations for hydrogen fuel progress to the point where it is simply to classify a newbuild or retrofitted vessel using with hydrogen fuel.
4. No breakthroughs in battery storage occur, so electrification/hybridisation is only mildly affected by the need to reduce GHG emissions.
5. The breakthroughs in hydrogen storage create less demand for biofuels/e-fuels, so the supply of these is limited, especially the more expensive drop-in fuels.
6. Ports and harbours would invest so they could fully support hydrogen refuelling for domestic commercial vessels by 2030.
7. Consider second order effects of reducing GHG emissions in terms of competition with imported seafood and the economic consequences of increased food prices.
8. Seafood customers (wholesale and retail) would have to want more sustainable energy use in the production of their seafood products, even if it drives up prices.
9. Individual fisher companies feel they both need to and can, use more sustainable energy sources.

Scenario 5 – EACR Breakthrough

In the *EACR Breakthrough* scenario, we assume that a breakthrough has occurred with maritime exhaust aftertreatment and CO_2 re-use (EACR) technologies, such that the government feels comfortable regulating for much tougher emissions reduction action. This would create more demand for biofuels/e-fuels like renewable diesel and butanol fuel blends but would also rely on EACR to amplify the effect on GHG emissions reduction (see Figure 39). Uptake of more efficient engines by the existing fleet would also be more encouraged under this scenario than the others.

Cohort	2023	2030	2040	2050
Future Changes in Concessions/Effort/Quota	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Existing Outboard Fleet Unchanged	3.00%	20.03%	17.85%	6.71%
Existing Outboard Fleet Becoming More Efficient	0.62%	5.74%	8.89%	13.49%
New Outboard Diesel Motors	0.00%	0.63%	1.72%	2.62%
New Outboard Electric Motors	0.00%	1.71%	4.18%	6.38%
Newbuild Electric Outboard Vessels	0.00%	1.74%	4.22%	6.44%
Outboard GHG Reduction	*3.62%*	*29.85%*	*36.86%*	*35.64%*
Existing Inboard Fleet Unchanged	3.00%	20.37%	25.05%	18.75%
Existing Inboard Fleet Becoming More Efficient	0.65%	3.89%	7.82%	10.58%
Inboard Newbuilds Built More Sustainable	0.48%	2.02%	3.54%	4.48%
Existing Inboard Vessels Made Hybrid	0.37%	1.09%	1.98%	2.76%
Hybrid Inboard Newbuilds	0.00%	1.52%	3.70%	5.59%
All Electric Inboard Newbuilds	0.00%	0.72%	1.73%	2.63%
Inboard GHG Reduction	*4.50%*	*29.61%*	*43.82%*	*44.78%*
Scope 1 GHG Left	91.88%	40.53%	19.32%	19.58%
Total Reduction	**8.12%**	**59.47%**	**80.68%**	**80.42%**

Table 9: Scenario 5 – GHG emissions with EACR Breakthrough

In this scenario the greatest long-term effect on GHG emissions would be the contributions from the existing fleet, with both outboards and inboards relying on EACR retrofitting to make up for shortfalls in emissions reduction by other means. The 2030 target would be easily achieved, but benefits would level off at around 80% GHG emissions reduction and so the 2050 target would still be missed.

At the moment this scenario is highly speculative as no EACR solutions exist that are suitable for use on fishing vessels, especially ones using outboard motors – most mobile EACR developers are aiming to help international shipping and long-distance trucking (see Emissions Capture). There is also little indication as to the cost of such a system that delivers an appropriate amount of GHG emissions reduction.

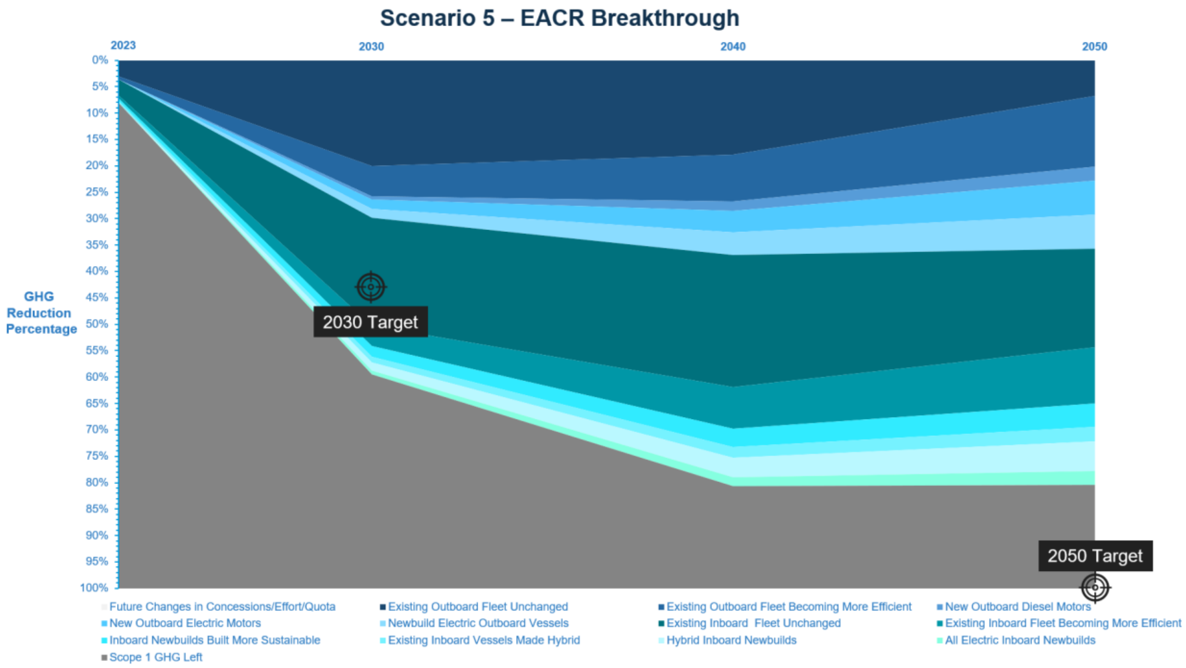

Figure 39: Scenario 5 – EACR Breakthrough

Assumptions

For the *EACR Breakthrough* scenario to occur as modelled, the following would have to be true:

1. Federal and State governments would have to try to prioritise reducing GHG emissions.
2. Breakthroughs in mobile exhaust aftertreatment and CO_2 re-use (EACR) systems produce affordable solutions for non-road mobile applications like petrol outboards and diesel inboards for fishing vessels. A significant amount of the GHG emissions reduction in this scenario's long-term (27.87%) is from EACR.
3. No breakthroughs in battery storage occur, so electrification/hybridisation is only mildly affected by the need to reduce GHG emissions.
4. No breakthroughs in hydrogen storage occur, so that does not change the uptake of alternate fuels.
5. There is more demand for drop-in biofuels to help decarbonise, so the supply of these is slightly increased.
6. There is not enough sustainable biomass or carbon to allow for as plentiful a supply of biofuels or e-fuels as in Scenario 2.
7. Ports and harbours would invest so they could support captured carbon offloading for domestic commercial vessels by 2030.
8. Consider second order effects of reducing GHG emissions in terms of competition with imported seafood and the economic consequences of increased food prices.
9. Seafood customers (wholesale and retail) would have to want more sustainable energy use in the production of their seafood products, even if it drives up prices.
10. Individual fisher companies feel they need to and can, reduce their GHG emissions.

Scenario Learnings

Reliance on Breakthroughs

The range of scenarios above show that step-changes, breakthroughs, in the technology around sustainable energy production, storage, and use are going to be important in driving a reduction of fishing's GHG emissions. However, they are unpredictable and many that we would like to occur may not happen in our lifetimes.

The low TRLs of some of the most useful sustainable energy solutions, and the fact that in many cases the technologies are not see as the most useful for maritime use, mean that there are few solutions worth relying on.

In the longer-term it is the technology breakthroughs that are most likely to influence the eventual direction of the energy transition. As was discussed in the Beyond Resilience, Achieving Antifragility section, the best concept to apply here is one of antifragility, where we look to maximise the positive benefits of surprises, whilst minimising the negative impacts of the same.

Important Note: None of the scenarios showed the industry meeting the 2050 National GHG Emissions target of 100% reduction.

The fact that all scenarios showed the industry missing the 2050 National GHG Emissions target is because we have assumed that none of the current solutions are likely to reduce 100% of an organisation's GHG emissions without more significant technological breakthroughs. Even renewably charged battery-electric solutions are still likely to create some small amount of GHG emissions in their use, for example resorting to generators when solar panels are offline for maintenance or repair. To meet the 100% reduction target then either the purchase of GHG offsets or a more substantial change in technology will be required.

Government Intervention

It is not economically rational for the fishing industry to transition from successful, affordable, and efficient energy sources like petrol and diesel to much more expensive, but sustainable, alternative fuels or engines. While small pockets of the industry may obtain a product premium or find customer demand for identifying how they have reduced GHG emissions, there is no indication that this will be enough of a driver that the wild-catch commercial fishing industry as a whole transition between energy sources in line with the National GHG Emissions targets.

Complicating matters is the fact that this energy transition does not involve the wild-catch commercial fishing industry alone. Figure 40 shows there are shared concerns across a range of industries, from sustainable energy production, to maritime, to heavy road transport, to the broader agriculture industry.

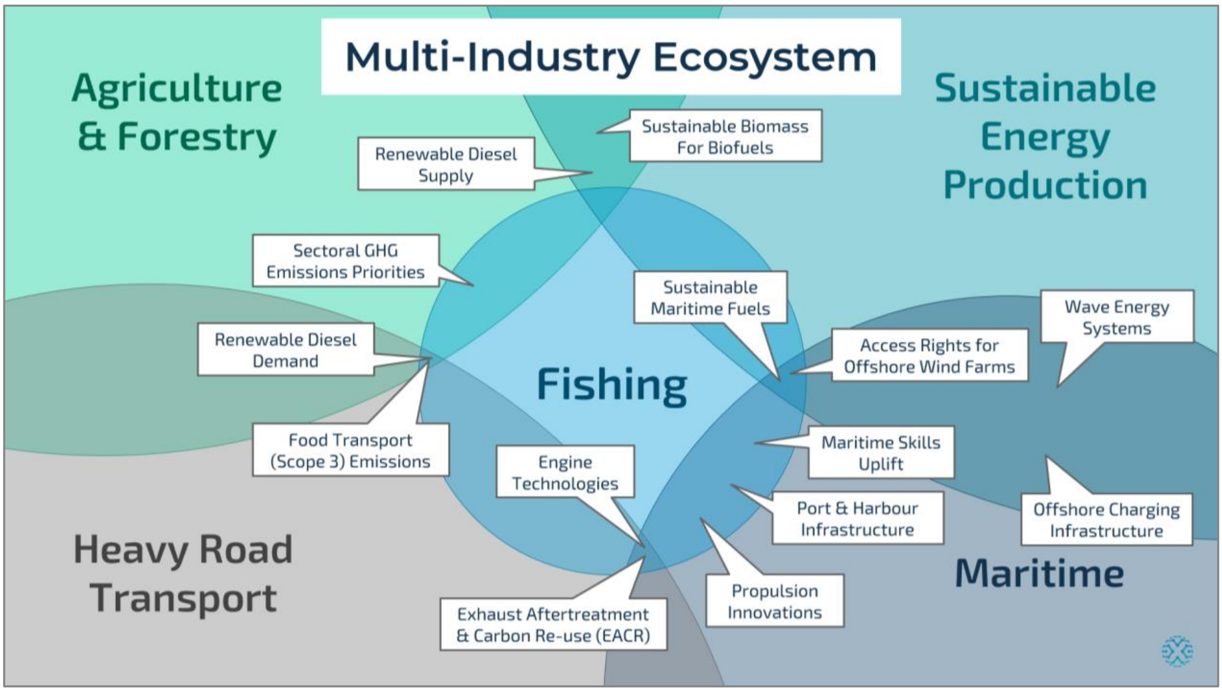

Figure 40: Industries involved in Fishing's energy transition journey.

For the Australian Government's National GHG Emission reduction targets to be met, there will need to be Government interventions that both enable and reward those who make the change, whilst discouraging those who delay making the change across multiple industries.

Clearly the Australian Government will need to be involved to help the Australian commercial wild catch fishing industry go through the energy transition, but if the industry is clear about what sorts of energy carriers are best used in the unique environment of commercial wild catch fishing, then that can help focus efforts appropriately.

From the scenario modelling and our energy carrier analysis, it is clear that Australian governments should be focused on maximising the optionality for three of the scenarios:

> Scenario 2 – Plenty of Biofuels/e-Fuels
> This scenario assumes sustainable biomass/carbon sources that allow for supply to expand of renewable diesel, biobutanol, biomethanol, and/or green methanol.
>
> Scenario 3 – Battery Breakthrough
> This scenario assumes that battery storage becomes smaller, lighter, and longer lasting so that it better supports long offshore trips.
>
> Scenario 5 – EACR Breakthrough
> This scenario assumes that exhaust aftertreatment and CO_2 re-use becomes affordable and available for small maritime vessels allowing the entire fleet to capture GHG emissions at the point they are created.

Under those three scenarios we would expect that the energy carrier share for the commercial wild-catch fishing industry as a whole would vary over time[127]:

		2023	2030		2050	
#	Energy Carrier	Baseline	Min	Max	Min	Max
1	Petrol	50%	24%	31%	9%	16%
2	Diesel	50%	15%	38%	0%	38%
3	Renewable Diesel	0%	11%	30%	8%	35%
4	Biobutanol	0%	2%	6%	1%	3%
5	Green/Bio Methanol	0%	0%	5%	0%	14%
6	Battery/Hybrid	0%	16%	31%	36%	56%

Table 10: Energy carrier share of commercial fishing fleet over time across the 3 best scenarios.

In 2020 the Kearney Energy Transition Institute (Kearney) examined how regulation and legislation could impact the demand for biofuels (see Figure 41), and while their work is specific to biofuels, it gives a good overview of the way that governments can both influence drivers of adoption, and enablers that remove blockers to that adoption[128].

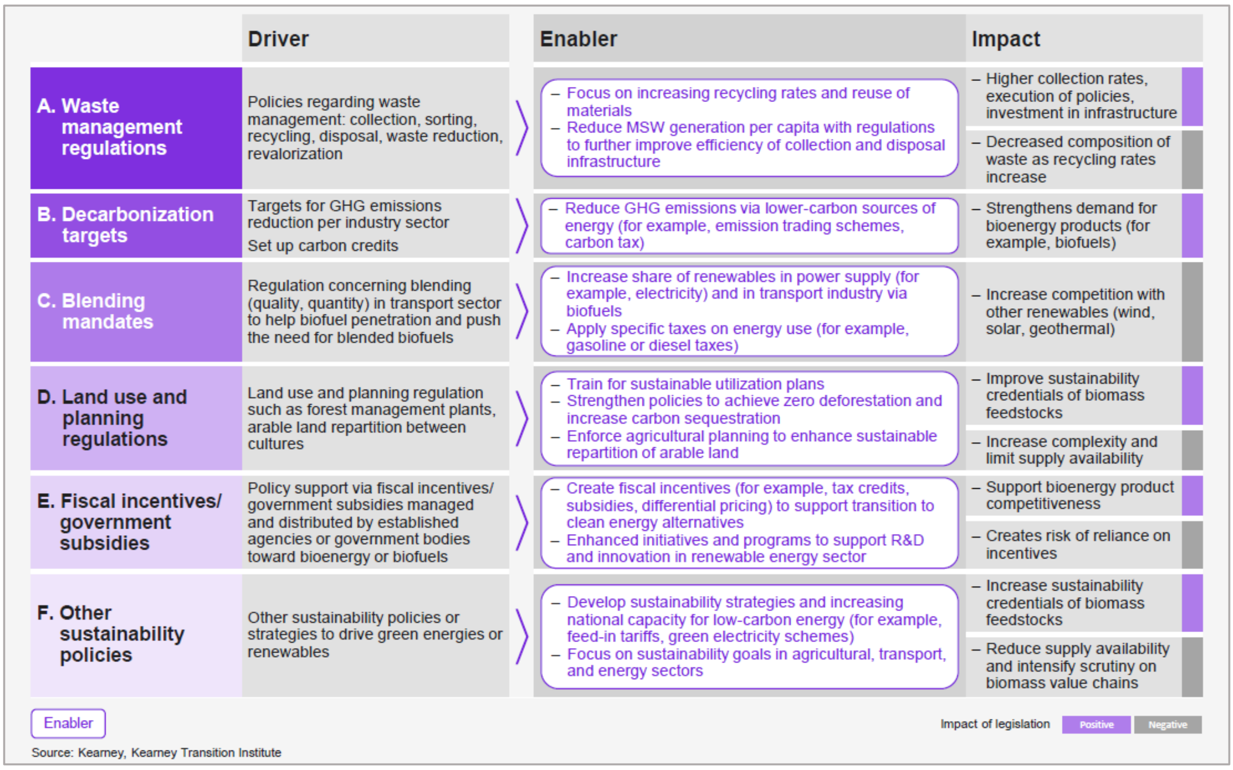

Figure 41: Regulation and legislation impact on supply and demand for biofuels. Source: Kearney.

[127] Percentage shares derived from scenario data and assumptions.

[128] 'Biomass to Energy Handbook', Kearney Energy Transition Institute, 2020

Reviewing the assumptions for the preferred scenarios and bearing in mind the Kearney research around drivers and enablers, six areas were identified that governments could help with:

1. **Assumption: Federal and State governments would have to try to prioritise reducing GHG emissions.**
   At the moment Australia has National GHG Emissions targets but very little clarity around the regulatory changes that will be made to achieve them. This makes it difficult for the private sector to respond with the appropriate investments into sustainable energy use. Foundational steps the government could take are:

   a. Provide clarity as to the priority of meeting GHG emissions targets.

   b. Mandate reporting of current GHG emissions by all participants in the seafood supply chain. This would both inform future government actions and the seafood industry of the scale of the GHG emissions problem.

   c. Offer subsidies/grants to help provide training and recording systems for fishers to learn about and begin to record energy use, and GHG emissions data.

2. **Assumption: Clear demand signals to indicate to potential supply chain participants that it is worth investing in biofuels/e-fuels.**
   - and -
   Assumption: Clear supply signals to indicate to potential consumers that it is worth investing in equipment that utilises biofuels/e-fuels.
   Renewable diesel and biobutanol definitely have a part to play in helping the industry decarbonise – green/bio methanol may also, given that methanol is likely to be available as a maritime fuel because of shipping needs. The government can further signal future demand for sustainable fuels by:

   a. Mandate blending percentages for drop-in fuels like renewable diesel and biobutanol.

   b. Mandate specific GHG emissions reduction targets from fuel use to encourage future fuels.

   c. Offer subsidies/grants/low-interest loans to help reduce the capital cost of changing equipment to allow the use of more sustainable energy carriers.

   d. Offer subsidies/tax breaks to mitigate the operating cost increases of using sustainable biofuels/e-fuels.

3. **Assumption: Ports and harbours would invest so they could fully support alternate fuels for domestic commercial vessels by 2030.**
   Private sector participants may respond to the clear demand/supply signals around sustainable fuels, but safety regulators and government-owned entities need to also focus on the use cases most applicable to the fishing and maritime industries. For drop-in fuels there is little that is needed, other than supporting a different fuel blend than the current diesel/petrol offerings, but for methanol there is a much greater set of changes required.

4. **Assumption: Ports, harbours, and councils (with boat ramps) would invest so they could fully support sustainable shore charging for domestic commercial vessels by 2030.**
   Battery electric or hybrid vessels will be a significant number of the vessels in use, therefore support for shore charging is vital. To encourage private sector support for shore charging, and indeed cold ironing, the government could:

   a. Mandate when cold ironing must be used by domestic commercial vessels.

   b. Mandate the percentage of electricity that must be sustainably sourced when used to provide shore power.

   c. Offer subsidies/grants/low-interest loans to help reduce the capital cost for ports, harbours, and councils of providing sustainable shore power.

   d. Offer subsidies/grants to help reduce the operating cost for ports, harbours, and councils of providing sustainable shore charging.

5. **Assumption: Consider second order effects of reducing GHG emissions in terms of competition with imported seafood and the economic consequences of increased food prices.**
   Imposing economic burden on the Australian seafood industry by requiring GHG emissions reduction will harm its export and domestic competitiveness and lead to consumers replacing more sustainable local seafood with less sustainable imported seafood, or other protein sources.

   The government must consider how to help the industry's competitiveness and what the impact will be on Australian consumers, and Australia's inflation, if food prices are simply allowed to increase. The government is already conducting a feasibility assessment for an Australian carbon border adjustment mechanism (CBAM)[129] in order to deal with carbon leakage from less sustainable imports. Any requirement on the fishing and aquaculture industries to reduce GHG emissions must also be considered in a CBAM feasibility assessment.

6. **Assumption: Ensure that Australia encourages the breakthroughs required and has the opportunity to be a supplier of solutions, not just a consumer of them.**
   Each of the selected scenarios depends on some sort of breakthrough, in biofuel/e-fuel supply, in battery storage, and in exhaust aftertreatment and CO_2 re-use (EACR). There are opportunities for Australian research institutions to develop these breakthroughs and for Australian companies to become key suppliers of solutions based on these breakthroughs. However, prosecuting these opportunities may require that the government directs public and private funds towards these efforts over ones less critical to these roadmaps. Also, multiple potential pathways should be funded and explored for each type of breakthrough, as any one pathway may end up failing.

[129] https://www.innovationaus.com/govt-to-consider-import-tariffs-for-high-carbon-goods/

Given the part that biofuels and e-fuels are likely to play in energy carrier futures, the emphasis for the commercial wild catch fishing industry must be on supporting the efforts by the wider agriculture sector to promote access to renewable diesel, whilst pushing for consideration of promotion of the biobutanol blend (Bu16) to reduce emissions for petrol outboards.

Battery storage breakthroughs would benefit a huge range of industries, and so it is an area that needs less focus from the commercial wild catch fishing as the broader maritime industry is already focused on solving the issues that remain.

Breakthroughs in EACR systems would have a far more powerful impact on reductions in GHG emissions than other breakthroughs. While the TRLs of solutions in this area are still low, the issues are less about the fundamental science questions and more about solving engineering problems. Supporting the development of this should be more of a focus for FRDC and other industry players than the other areas.

The actions suggested by these assumptions have been included in the project's Recommendations.

Vessel Safety

When considering alternative fuels and propulsion systems the commercial wild catch fishing industry will need to consult with the Australian Maritime Safety Authority (AMSA) to develop standards and regulations to enable the industry to adopt them. The transition roadmaps offer an opportunity to help focus discussions with AMSA on the most appropriate priorities to use when driving that work.

Currently, it is apparent that the most future-leaning alternate fuel and propulsion systems will be dealt with under the AMSA Novel vessel exemption.[130] However, some promising future fuels like methanol can be handled under AMSA's rules for low flashpoint (<60°C) fuels, although if used in an inboard engine they will require the vessel is surveyed and provide a survey modifier[131].

When considering the regulatory status for handling low flashpoint fuels like methanol the IMO points to the GreenVoyage2050 website for regulatory mapping (as of March 2023)[132].

[130] https://www.amsa.gov.au/news-community/news-and-media-releases/new-policy-novel-vessels-available
[131] https://www.amsa.gov.au/vessels-operators/domestic-commercial-vessels/survey-modifiers
[132] https://www.imo.org/en/MediaCentre/Pages/WhatsNew-1841.aspx

Marine standards in progress	High regulatory readiness level	Low regulatory readiness level
Marine standards in progress **ISO/AWI 6583** "Specification of methanol as a fuel for marine applications" is under development. Currently, IMPCA[1] Methanol reference specification and ASTM[2] D1152 standard are used when specifying methanol quality.	SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through ● SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively ● SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover methanol as fuel but **MSC.1/Circ.1621** *Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel* has been developed.	Methanol is assigned category Y as per the IBC Code, meaning it presents a hazard to either marine resources or human health. MARPOL Annex II requirements do not apply for spill and discharges of methanol as fuel. **High regulatory readiness level** MARPOL Annex VI regulates emissions of CO_2 and NO_x

Figure 42: Regulatory mapping for methanol as a marine fuel. Source (GreenVoyage2050)[133].

Workforce Training

The Australian commercial wild catch fishing and associated sectors will need to work to understand what level of workforce retraining needs to occur to enable safe and effective adoption of more sustainable energy sources.

Key areas where there needs to be more training are:

1. Energy and GHG emissions tracking.
2. Operating vessels more efficiently.
3. Hybrid and fully electric powertrains.
4. Future fuel (i.e. methanol) powertrains.
5. Digitalisation and digital tools.
6. Low flashpoint fuel (i.e. methanol) handling.
7. Marine electrical systems.

This includes the following segments of industry:

- Refuelling staff (fuel providers, tankers, and motherships).
- Fleet managers (with respect to refuelling frequency, maintaining new technologies and GHG emissions tracking).
- Crew (safety and maintenance training).
- Diesel mechanics (in new fuel and drive systems).
- Marine electricians (in new systems and electric motors)
- Marine systems integrators (understanding impacts on equipment and design choices).
- Naval architects (understanding the design implications).

The report's recommendations include actions that will help progress knowledge in this area.

Energy Intelligence

Any change by fishers to reduce GHG emissions must begin by understanding the current areas where energy is used in their business. The Australian/New Zealand Energy Audit Standard (AUS/NZ

[133] https://greenvoyage2050.imo.org/alternative-marine-fuels-regulatory-mapping/

Standard 3598:2000) specifies how to do an energy audit to properly document where energy is being used. But with regards to energy audits, FRDC project 2006-229 identified that:

> "most fishing companies are not properly prepared for undertaking energy audits, simply because the 24 months of historical data required to complete the simplest energy audit (i.e. level 1) is either not being kept, or is kept in an inappropriate form that compromises its analytical worth."[134]

A lack of data will hamper efforts to reduce GHG emissions and is likely to cause fishers to over-estimate the size of the sustainable energy systems needed – magnifying the capital expense and perhaps creating unnecessary long-term operational expenses. Government grants and subsidies should focus on helping create real change, so baseline operational data will be a necessity for that too.

Industry-led research and innovation are needed to create *Energy Intelligence*, developing processes and systems that can help reduce the need for two years of operational data, simplify the process of capturing operational data, and start fishers on the road to capturing and understanding their energy usage in order to create more resilient businesses (see Figure 43). At the same time the emissions can be reported to fisheries managers who should be tracking how GHG emissions relate to the aquatic resources they manage in order to identify the climate impact of using those resources available to promote economic development.

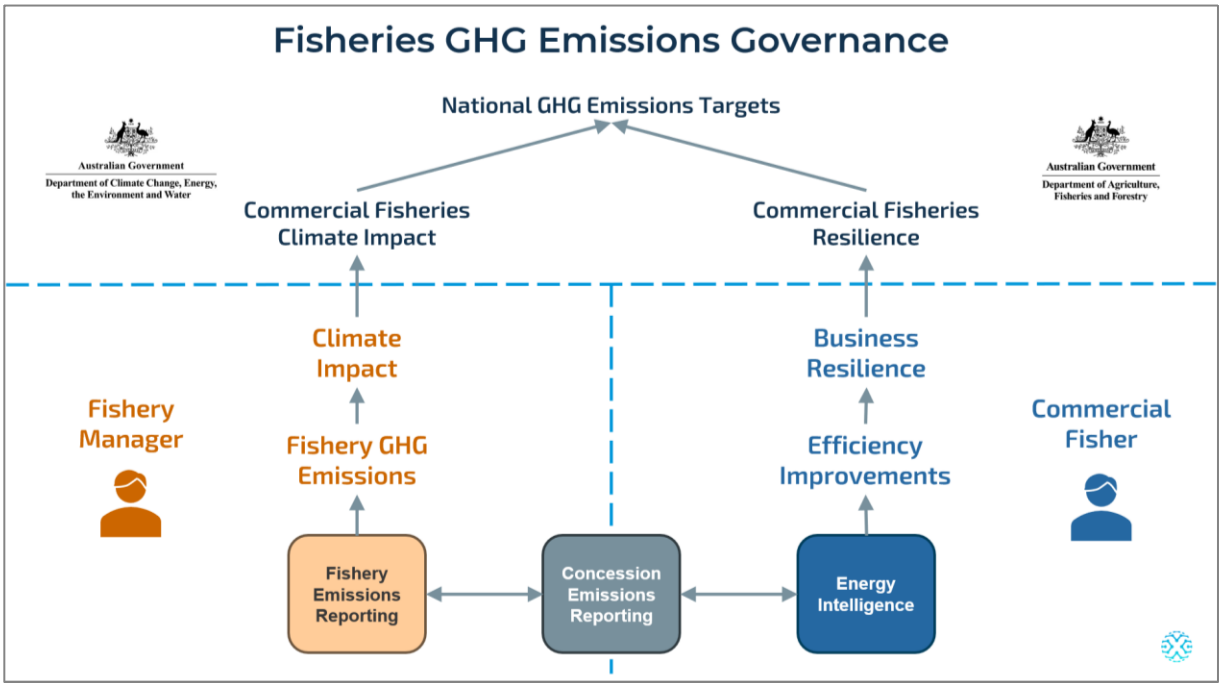

Figure 43: Fisheries GHG Emissions Governance

[134] FRDC Project No 2006/229. Wakeford, Dr J., University of Tasmania 2010, *Development and Implementation of an Energy Audit Process for Australian Fishing Vessels*, Hobart, Australia.

Outboard Motor Roadmaps

These roadmaps offer fishers who currently use petrol outboards a way forward to decarbonise existing or newbuild vessels.

Decarbonising an Existing Vessel

There are five steps to the roadmap for decarbonising an existing vessel using a petrol outboard (see Figure 44):

1. Perform an energy assessment.
2. Improve fuel efficiency.
3. Upgrade to newer petrol engine.
4. Decide on how to become more sustainable.
5. Continue to optimise operations.

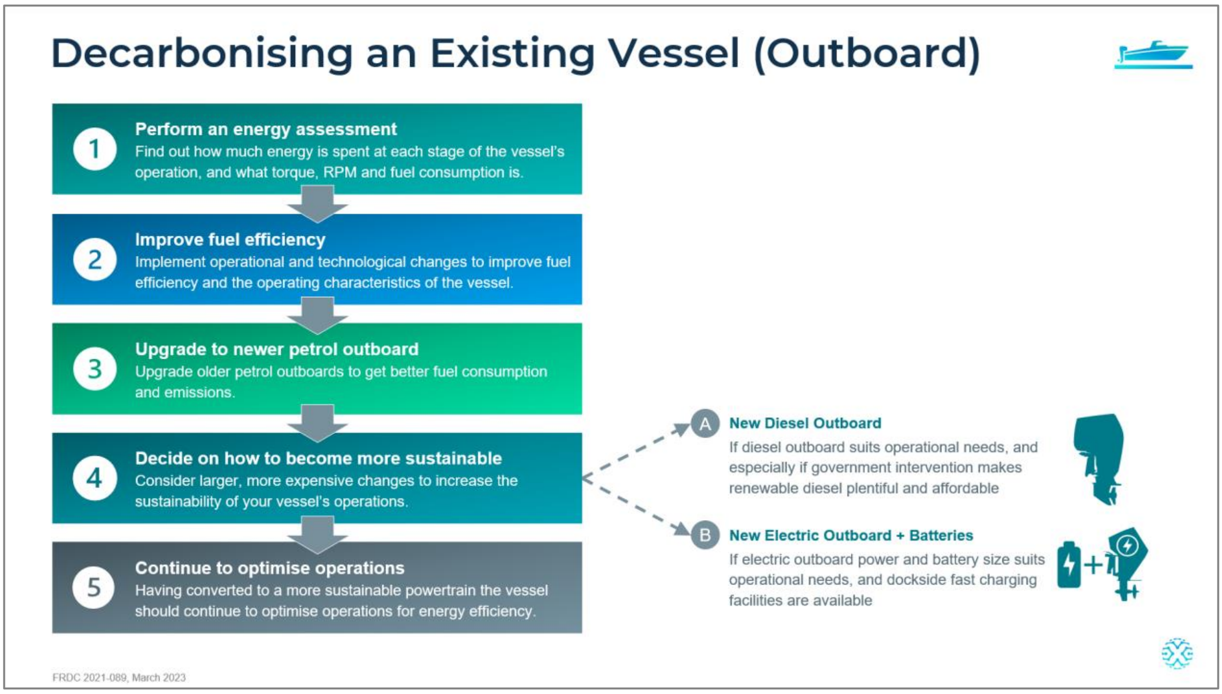

Figure 44: Roadmap for Decarbonising an Existing Vessel (Outboard)

1. Perform an energy assessment

Find out how much energy is spent at each stage of the vessel's operation, and what torque, RPM and fuel consumption is.

This step is all about creating a baseline of performance data that allows the fisher to establish which operations are the more energy intensive, and what sort of actions or situations use more or less energy.

2. Improve fuel efficiency

Implement operational and technological changes to improve fuel efficiency and the operating characteristics of the vessel.

Actions at this step can run the gamut of all the possible Fuel Reduction Interventions (Both Categories) that make sense for this vessel and the fisheries it operates in. The earlier energy assessment is critical to ensuring that the efficiency gains are both real, and at the most relevant parts of the vessel's operations.

Another reason that accurate energy tracking is important is the need to ensure that operational efficiency does lead to fuel efficiency, and most importantly, to reductions in GHG emissions.

3. Upgrade to newer petrol outboard

Upgrade older petrol outboards to get better fuel consumption and emissions.

If the vessel has an older outboard motor, then a straightforward means of reducing GHG emissions is to consider doing a replacement of the petrol outboard motor with a newer one better tuned to the operational needs of the fisher.

4. Decide on how to become more sustainable

Consider larger, more expensive changes to increase the sustainability of your vessel's operations. These options are ranked from least GHG reducing to most.

A. New Diesel Outboard

If diesel outboard suits operational needs, and especially if government intervention makes renewable diesel plentiful and affordable.

Diesel outboard motors are a fairly new development, with some notable advantages over petrol outboard motors – most notably lower RPMs, higher torque, lower needs for maintenance and greater fuel economy[135]. For commercial use where they will be used nearly every day they can make a lot of sense – although they are still an expensive option.

As well as the generally better fuel economy, if renewable diesel has been made plentiful and affordable, then there is an additional GHG reduction available. In addition, Oxe Marine is introducing a hybrid diesel-electric outboard motor that promises to offer "the energy efficiency of diesel operation with the electric motor's steep torque curve and the possibility of a completely emission-free operation"[136].

B. New Electric Outboard + Batteries

If electric outboard power and battery size suits operational needs, and dockside fast charging facilities are available.

For many fishers using smaller petrol outboards there are already many good options for implementing electric outboard motors with battery packs. Most electric outboards come with digital readouts to show you plenty of extra information, such as estimated remaining range and can show you how fast you are using the battery too. Smaller electric outboards tend to have replaceable internal battery packs, whilst larger ones can have external battery packs. In both cases multiple

135 https://boattest.com/cox-cxo300
136 https://www.oxemarine.com/oxe-hybrid-450/

battery packs can be carried to improve the range. There is also a much larger reduction in power use when idling, compared to a petrol motor.

The source and quality of the electricity used to recharge the batteries will affect how much GHG emissions reduction is actually achieved. For example, coal-powered electricity is not as sustainable as electricity sourced from solar, wind, or wave power.

The ability to fast charge at a dock may be important if more than a few hours of power is needed. Options like solar panels or shore charging can mean that the batteries can be recharged whilst the boat is stationary, which can help extend range. Spare batteries can also be kept on land and replaced as needed during the day if multiple trips to shore are possible.

5. Continue to optimise operations

Having converted to a more sustainable powertrain the vessel should continue to optimise operations for energy efficiency.

Continually assessing the energy needs of different fishing operations is the only way to ensure that GHG reductions are maximised. Given that energy use is only likely to increase in terms of percentage of input costs for fishers, this also makes good economic sense.

The same steps for promoting more efficient operations are applicable after improving the sustainability of the powertrain.

Decarbonising a Newbuild

There are four steps to the roadmap for decarbonising a new vessel using an outboard motor (see Figure 45):

1. Perform an energy assessment.
2. Pick a sustainable design.
3. Select a sustainable power source.
4. Operate newbuild efficiently.

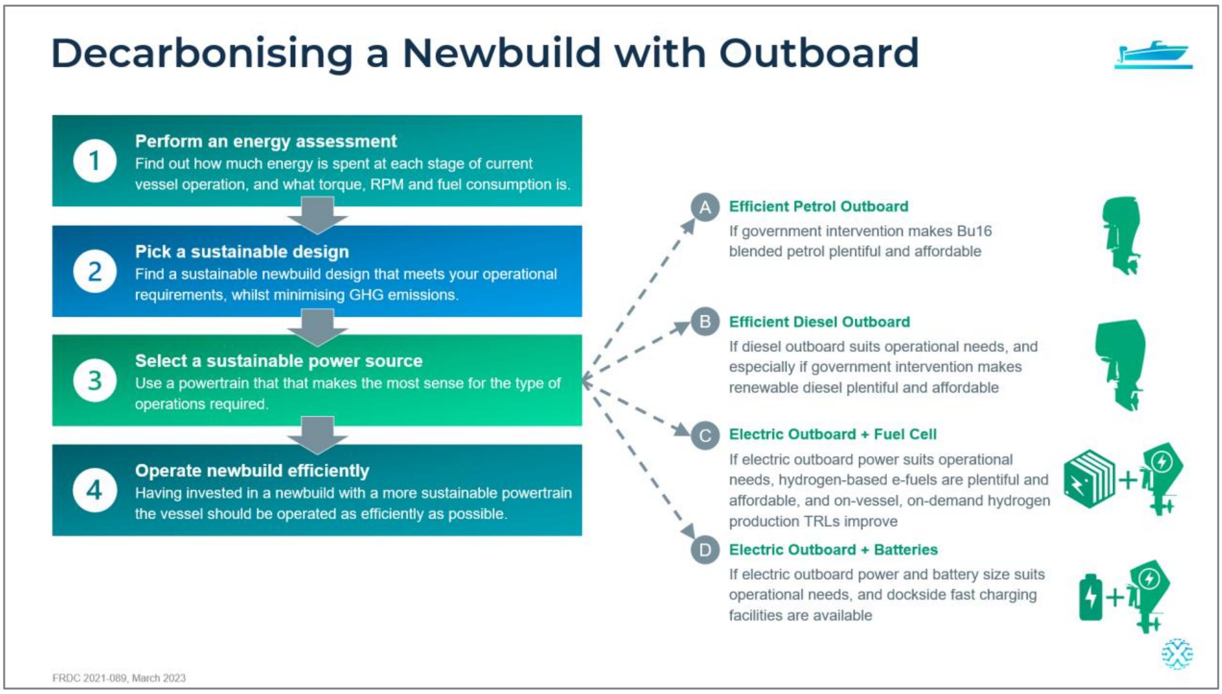

Figure 45: Roadmap for Decarbonising a Newbuild with Outboard

1. Perform an energy assessment.

Find out how much energy is spent at each stage of current vessel operation, and what torque, RPM and fuel consumption is.

This step is all about creating a baseline of performance data that allows the fisher to establish which operations are the more energy intensive, and what sort of actions or situations use more or less energy.

2. Pick a sustainable design.

Find a sustainable newbuild design that meets your operational requirements, whilst minimising GHG emissions.

This step is very closely related to the next one, and in reality, it is likely that the design process will iterate between the two. The point is to challenge pre-conceptions in two ways:

1. **What makes this fishing operation commercially successful?**
   The length of fishing trip, the distances travelled, the amount of catch that needs to be stored whilst at sea, the species fished, and the conditions of the fishing boat license all need to be considered. Could two smaller boats using alternative fuel be a good investment? Should the fisher consider moving towards a more passive fishing approach (e.g. traps) versus a more active one (e.g. trawling)? Can multiple shorter trips replace one longer one?

2. **What sort of vessel is the best suited to the operations needed?**
   Given what is needed to be commercially successful, what sort of vessel could best conduct those operations if we want to minimise GHG emissions? Fuel efficiency is a good proxy measure for GHG emissions, but it is not the only one. Would moving towards a centre console, or a carbon fibre hull be useful?

Importantly, the embodied GHG emissions in the newbuild should also be considered as Scope 3 emissions for the fisher, so selecting a boat builder that is able to offer a more sustainable build process will also help reduce GHG emissions.

3. Select a sustainable power source.

Use a powertrain that that makes the most sense for the type of operations required.
These options are ranked least reducing to most.

A. Efficient Petrol Outboard

If government intervention makes Bu16 blended petrol plentiful and affordable.

Given that petrol blended with 16% biobutanol (Bu16) can offer a 30% reduction in GHG emissions, there are good reasons to consider staying with a modern petrol outboard if Bu16 is readily available and affordable.

B. Efficient Diesel Outboard

If diesel outboard suits operational needs, and especially if government intervention makes renewable diesel plentiful and affordable.

Diesel outboard motors are a fairly new development, with some notable advantages over petrol outboard motors – most notably lower RPMs, higher torque, lower needs for maintenance and greater fuel economy[137]. For commercial use where they will be used nearly every day they can make a lot of sense – although they are still an expensive option.

As well as the generally better fuel economy, if renewable diesel has been made plentiful and affordable, then there is an additional GHG reduction available. In addition, Oxe Marine is introducing a hybrid diesel-electric outboard motor that promises to offer "the energy efficiency of diesel operation with the electric motor's steep torque curve and the possibility of a completely emission-free operation"[138].

C. Electric Outboard + Fuel Cell

If electric outboard power suits operational needs, hydrogen-based e-fuels are plentiful and affordable, and on-vessel, on-demand hydrogen production TRLs improve.

For many fishers using smaller petrol outboards there are already many good options for implementing electric outboard motors with battery packs. Most electric outboards come with digital readouts to show you plenty of extra information, such as estimated remaining range and can show you how fast you are using the battery too. Smaller electric outboards tend to have replaceable internal battery packs, whilst larger ones can have external battery packs. In both cases multiple battery packs can be carried to improve the range. There is also a much larger reduction in power use when idling, compared to a petrol motor.

This option would solve the range issues of battery packs by using a hydrogen-based e-fuel such as green methanol (or biomethanol) with some form of fuel cell for the power source. The EFOY fuel cell

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[137] https://boattest.com/cox-cxo300
[138] https://www.oxemarine.com/oxe-hybrid-450/

pilot project with ePropulsion was testing exactly this scenario with a direct methanol fuel cell, although the lack of a final report on that project does not perhaps bode well[139]. There have been several yachts that have implemented EFOY fuel cells with good results but with perhaps smaller power requirements[140]. Nevertheless, if TRLs for creating hydrogen on-vessel, on-demand improve via direct methanol fuel cells, solid oxide fuel cells, or pairing an onboard methanol reformer with a fuel cell, then it may be feasible to replace batteries.

The plentiful and affordable availability of a hydrogen-derivative fuel like green methanol (or biomethanol) would be needed to ensure that such a system reduced GHG emissions.

D. Electric Outboard + Batteries

If electric outboard power and battery size suits operational needs, and dockside fast charging facilities are available.

For many fishers using smaller petrol outboards there are already many good options for implementing electric outboard motors with battery packs. Most electric outboards come with digital readouts to show you plenty of extra information, such as estimated remaining range and can show you how fast you are using the battery too. Smaller electric outboards tend to have replaceable internal battery packs, whilst larger ones can have external battery packs. In both cases multiple battery packs can be carried to improve the range. There is also a much larger reduction in power use when idling, compared to a petrol motor.

The source and quality of the electricity used to recharge the batteries will affect how much GHG emissions reduction is actually achieved. For example, coal-powered electricity is not as sustainable as electricity sourced from solar, wind, or wave power.

The ability to fast charge at a dock may be important if more than a few hours of power is needed. Options like solar panels or shore charging can mean that the batteries can be recharged whilst the boat is stationary, which can help extend range. Spare batteries can also be kept on land and replaced as needed during the day if multiple trips to shore are possible.

4. Operate newbuild efficiently.

Having invested in a newbuild with a more sustainable powertrain the vessel should be operated as efficiently as possible.

Continually assessing the energy needs of different fishing operations is the only way to ensure that GHG reductions are maximised. Given that energy use is only likely to increase in terms of percentage of input costs for fishers, this also makes good economic sense.

The same steps for promoting more efficient operations are available to newbuilds as for existing vessels, even if they use a novel powertrain.

[139] https://www.sfc.com/en/sfc-energy-cooperates-with-epropulsion-in-the-field-of-electric-boat-drives/
[140] https://www.my-efoy.com/en/story/volker-andreae-silent-power-for-regatta-and-long-distance-yachts/

Inboard Engine Roadmaps

These roadmaps offer fishers who currently use diesel inboards a way forward to decarbonise existing or newbuild vessels.

Decarbonising an Existing Vessel

There are five steps to the roadmap for decarbonising an existing vessel using a petrol outboard (see Figure 46):

1. Perform an energy assessment.
2. Improve fuel efficiency.
3. Upgrade to newer diesel engine.
4. Decide on how to become more sustainable.
5. Continue to optimise operations.

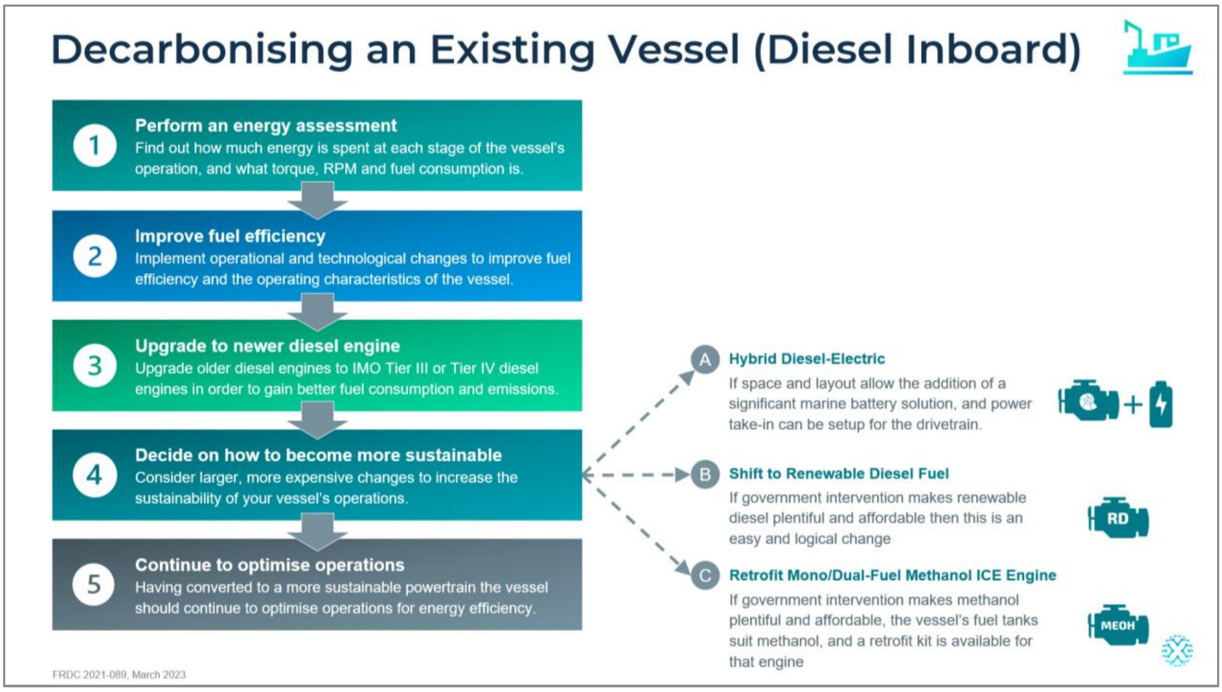

Figure 46: Decarbonising an Existing Vessel (Diesel Inboard)

1. Perform an energy assessment

Find out how much energy is spent at each stage of the vessel's operation, and what torque, RPM and fuel consumption is.

This step is all about creating a baseline of performance data that allows the fisher to establish which operations are the more energy intensive, and what sort of actions or situations use more or less energy.

2. Improve fuel efficiency

Implement operational and technological changes to improve fuel efficiency and the operating characteristics of the vessel.

Actions at this step can run the gamut of all the possible Fuel Reduction Interventions (Both Categories) that make sense for this vessel and the fisheries it operates in. The earlier energy assessment is critical to ensuring that the efficiency gains are both real, and at the most relevant parts of the vessel's operations.

Another reason that accurate energy tracking is important is the need to ensure that operational efficiency does lead to fuel efficiency, and most importantly, to reductions in GHG emissions.

3. Upgrade to newer diesel engine

Upgrade older diesel engines to Tier 4 diesel engines in order to gain better fuel consumption and emissions.

If the vessel has an older engine, then a straightforward means of reducing GHG emissions is to consider doing an in-situ replacement of the diesel engine with one better tuned to the operational needs of the fisher. In some cases, this is about making a trade-off between reliability (having an older mechanical fuel injection diesel engine that is run outside its most efficient RPMs) and efficiency (having a newer electronic fuel injection engine with low emissions technology that is dialled in for the RPMs it will typically be run at).

It is important to note that the USA EPA Tier 4 standards don't directly target GHG emissions, but minimising SOx, NOx and particulate matter which is important in improving human health outcomes. In addition, engine manufacturers have been making their Tier 4 engines more efficient and claim they use more than 5-20% less fuel[141].

4. Decide on how to become more sustainable

Consider larger, more expensive changes to increase the sustainability of your vessel's operations. These options are ranked from least GHG reducing to most.

A. Hybrid Diesel-Electric

If space and layout allow the addition of a significant marine battery solution, and power take-in can be setup for the drivetrain.

The intention is to have a marine battery solution that can allow one or more of the vessel's key systems, particularly propulsion, to operate without running the engine or an auxiliary generator. This will give the ability to use shore charging to access renewable energy whilst docked, and creates the opportunity for other ways of harvesting energy (e.g. solar, wind, mechanical energy harvesting, etc.) to be used to top up the battery whilst at sea.

B. Shift to Renewable Diesel Fuel

If government intervention makes renewable diesel plentiful and affordable then this is an easy and logical change.

Depending on the renewable diesel blends available (RD20, RD50, RD100) this could contribute a significant reduction to the GHG emissions from engine and generator use. The effectiveness of it as a solution depends on how easy it is to get those blends, and the price for them. No engine

[141] NSW EPA, *Reducing Emissions from Non-road Diesel Engines*, August 2014.

retrofitting or changes to fuel systems are required, and there is always a backup option of using petro-diesel if renewable diesel is not available (e.g. if forced into refuelling at a harbour that can't supply renewable diesel.).

Because renewable diesel will likely remain more expensive than petro-diesel, it is important to implement steps 1-3 before just using renewable diesel.

C. Retrofit Mono/Dual-Fuel Methanol ICE Engine

If government intervention makes methanol plentiful and affordable, the vessel's fuel tanks suit methanol, and a retrofit kit is available for that engine.

With methanol's popularity surging as a marine fuel for shipping (over 200 newbuild or retrofit ships ordered, and numbers of orders now surging past LNG[142]) it is worth looking at the option to retrofit an existing vessel as we can expect sustainable versions of the fuel will become more plentifully available and cheaper.

However, in our analysis, we saw that the main issues for this are the retrofitting of fuel systems, particularly fuel tanks for use with a low flashpoint fuel, such as methanol. Most fishing vessels will not be able to easily retrofit existing diesel fuel tanks for use with methanol (see Fuel System Replacement) and for these vessels this is a poor option.

Lastly, if retrofitting an existing engine, then the availability of a retrofit kit that is approved by that engine's manufacturer is also an important consideration as it can reduce the cost and risk of the retrofit. Especially useful is knowing what the retrofit kit's impact is on the warranty for the underlying diesel engine.

5. Continue to optimise operations

Having converted to a more sustainable powertrain the vessel should continue to optimise operations for energy efficiency.

Continually assessing the energy needs of different fishing operations is the only way to ensure that GHG reductions are maximised. Given that energy use is only likely to increase in terms of percentage of input costs for fishers, this also makes good economic sense.

The same steps for promoting more efficient operations are applicable after improving the sustainability of the powertrain.

Decarbonising a Newbuild

There are four steps to the roadmap for decarbonising an existing vessel using a petrol outboard (see Figure 47):

1. Perform an energy assessment.
2. Pick a sustainable design.
3. Select a sustainable power source.

[142] https://safety4sea.com/will-methanol-remain-an-alternative-maritime-fuel/

4. Operate newbuild efficiently.

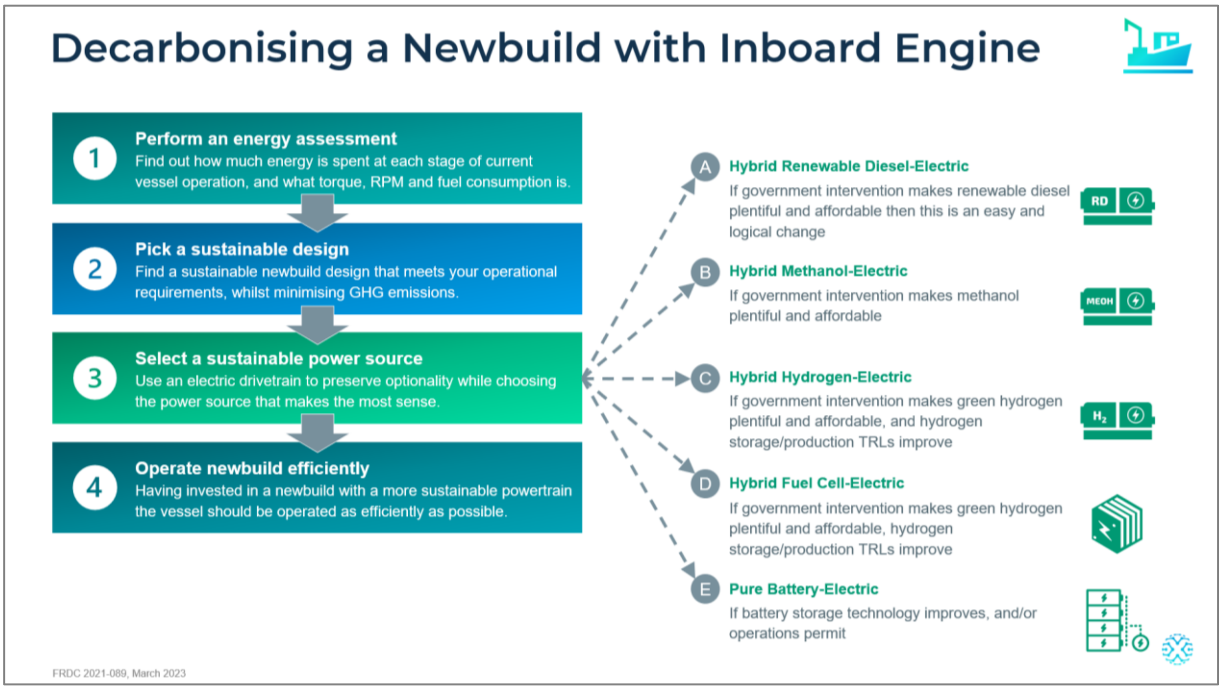

Figure 47: Decarbonising a Newbuild with Inboard Engine

1. Perform an energy assessment

Find out how much energy is spent at each stage of current vessel operation, and what torque, RPM and fuel consumption is.

This step is all about creating a baseline of performance data that allows the fisher to establish which operations are the more energy intensive, and what sort of actions or situations use more or less energy.

2. Pick a sustainable design

Find a sustainable newbuild design that meets your operational requirements, whilst minimising GHG emissions.

This step is very closely related to the next one, and in reality, it is likely that the design process will iterate between the two. The point is to challenge pre-conceptions in two ways:

1. **What makes this fishing operation commercially successful?**
   The length of fishing trip, the distances travelled, the amount of catch that needs to be stored whilst at sea, the species fished, and the conditions of the fishing boat license all need to be considered. Could two smaller boats using alternative fuel be a good investment? Should the fisher consider moving towards a more passive fishing approach (e.g. traps) versus a more active one (e.g. trawling)? Can multiple shorter trips replace one longer one?

2. **What sort of vessel is the best suited to the operations needed?**
   Given what is needed to be commercially successful, what sort of vessel could best conduct those operations if we want to minimise GHG emissions? Fuel efficiency is a good proxy

measure for GHG emissions, but it is not the only one. Would moving towards a catamaran, or a planing hull be useful?

Importantly, the embodied GHG emissions in the newbuild should also be considered as Scope 3 emissions for the fisher, so selecting a boat builder that is able to offer a more sustainable build process will also help reduce GHG emissions.

3. Select a sustainable power source

Use an electric drivetrain to preserve optionality while choosing the power source that makes the most sense. These options are ranked least reducing to most.

By electrifying the vessel's drivetrain, the issue of how to propel the vessel is separated from the issue of how to generate power. This means that an interim power generating solution can be selected, whilst leaving the option for it to be easily replaced in the future by a more appropriate one without making major changes to the vessel's propulsion system.

Batteries should be as large as possible, with the intention that they can bear as much of the load, for as long as possible, and allow cruising under battery. The system should be setup to use shore charging to access renewable energy whilst docked, and opportunities for other ways of harvesting energy (e.g. solar, wind, mechanical energy harvesting, etc.) should be looked for so the battery can be passively topped up whilst at sea.

A. Hybrid Renewable Diesel-Electric

If government intervention makes renewable diesel plentiful and affordable then this is an easy and logical change.

Because renewable diesel is a drop-in fuel, it can be used to run a normal marine genset, with some GHG emissions reduction thrown in.

If pursuing this step, it is advisable to consider consulting the rules around low flashpoint fuels, especially methanol, in order to ensure that fuel tanks are setup in such a way that they can be easily retrofitted for methanol in the future. This will maintain continuity best.

As this fuel still creates GHG emissions at the exhaust, it is best matched with an exhaust aftertreatment and CO_2 re-use (EACR) system to capture CO_2, NOx, and particulate matter emissions (see Emissions Capture).

B. Hybrid Methanol-Electric

If government intervention makes methanol plentiful and affordable.

In this case there could be a number of dual-fuel methanol ICE generators available, or a single fuel methanol ICE generator, or even just dual-fuel retrofit kits for existing diesel generators. The one most appropriate and affordable can be selected.

As this fuel still creates GHG emissions at the exhaust, it is best matched with an exhaust aftertreatment and CO_2 re-use (EACR) system to capture CO_2, and NOx emissions (see Emissions Capture).

C. Hybrid Hydrogen-Electric

If government intervention makes green hydrogen plentiful and affordable, and hydrogen storage/production TRLs improve.

Green hydrogen must be plentiful and affordable for this option. But hydrogen internal combustion engines (ICE) will only be useful in most cases if there is a breakthrough in either hydrogen storage that reduces volume and mass requirements (e.g. a Metal Hydrides (Ambient) solution), or if there is a breakthrough in on-vessel, on-demand hydrogen production from a denser hydrogen derivative fuel like green methanol.

As burning hydrogen in internal combustion engines still creates NOx emissions a closed loop scrubber of some sort should be used to reduce NOx emissions.

D. Hybrid Fuel Cell-Electric

If government intervention makes green hydrogen plentiful and affordable, and hydrogen storage/production TRLs improve.

Green hydrogen must be plentiful and affordable for this option. But hydrogen fuel cells will only be useful in most cases if there is a breakthrough in either hydrogen storage that reduces volume and mass requirements (e.g. an Metal Hydrides (Ambient) solution), or if there is a breakthrough in highly pure, on-vessel, on-demand hydrogen production from a denser hydrogen derivative fuel like green methanol, or a breakthrough in the development of solid-oxide fuel cells.

On-vessel, on-demand hydrogen production can still create NOx emissions, in which case a closed loop scrubber of some sort should be used to reduce NOx emissions.

E. Pure Battery-Electric

If battery storage technology improves, and/or operations permit.

Unlike a retrofit, a newbuild that aims to run on a pure battery-electric powertrain can be built to optimise the vessel to minimise inefficiencies and maximise the benefits of the pure electric system. Much like the way battery-electric cars have started to place the heavy batteries along the floor of the car or using carbon fibre more regularly to save weight elsewhere, there should be consideration with pure battery-electric vessels of both the restrictions and freedoms that a battery-electric powertrain gives.

If there have been significant breakthroughs in battery storage size and longevity, then this makes this a more attractive option for more fishing vessels.

4. Operate newbuild efficiently

Having invested in a newbuild with a more sustainable powertrain the vessel should be operated as efficiently as possible.

Continually assessing the energy needs of different fishing operations is the only way to ensure that GHG reductions are maximised. Given that energy use is only likely to increase in terms of percentage of input costs for fishers, this also makes good economic sense.

The same steps for promoting more efficient operations are available to newbuilds as for existing vessels, even if they use a novel powertrain.

Objective 4: Progress Made

Objective 4: To demonstrate rapid and practical progress towards climate resilience and elements of SIA's 'Our Pledge'.

Climate resilience is the ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate. Improving climate resilience involves assessing how climate change will create new, or alter current, climate-related risks, and taking steps to better cope with these risks.[143]

The project has identified the need for co-ordinated fisher climate advocacy via a range of suggested key activities:

- Strengthening networks and identifying shared values among fishing industry members in diverse regions;
- Enhancing the capacity of individuals, businesses, and associations to evaluate climate solutions and participate in climate and energy planning processes;
- Offering policy, technical, and communications expertise to support active and informed engagement by fishing industry members in shaping policy outcomes;
- Development of a digital platform and embedded tools, so that:
    - Fishers can submit letters and issue statements calling on policy makers at multiple levels of government to support wild-catch-fisheries-friendly climate action.
    - Fishers can begin the process of assessing the existing carbon footprint of their businesses, using appropriate online tools.
    - All industry stakeholders can keep up with the changing landscape of climate policy.
    - Information campaigns can be published and catalogued, such as: policy explainers, podcasts, online learning exchanges, and a variety of live and pre-recorded webinars.
- Initiatives designed to help commercial fishers, fishery associations, and fishery businesses such as markets, and retailers understand the implications of different policy approaches for the climate and fisheries, to support advocacy for the most fishery-friendliest mix of strategies possible as Australia and the world undertakes the enormous yet critical task of transitioning to the lowest possible carbon setting, as rapidly as possible.

The project has identified the need to prioritise Australian-fisher-centric decarbonisation solutions which simultaneously **reduce, or avoid greenhouse gas emissions while** also:

- Avoiding collateral impacts on ocean, coastal, and estuarine environments (e.g. From potential Ammonia fuel spills);
- Avoiding food security issues, due to interference with the harvest and provision of wild seafood;

[143] https://www.c2es.org/content/climate-resilience-overview/

- Avoiding job losses and wider community impacts from diminished commercial viability of continued fishing operations, especially in regional Australia;
- Avoiding loss of biodiversity, due to land clearing to plant fuel crops;
- Contributing conservation co-benefits that enhance the resilience of these ecosystems to climate change and other stressors; and
- Facilitating the voluntary adoption of cost-effective, locally appropriate technologies and practices to reduce fuel use and greenhouse gas emissions by fishing vessels and shoreside businesses.

This project contributes to progress in several elements of SIA's 'Our Pledge':

The Australian seafood industry is committed to putting the best Australian seafood on tables now and for generations to come.

The Australian seafood industry promises to:

- Actively care for Australia's oceans and environment and work with others to do the same;

By reducing the carbon footprint of the industry and its reliance on fossil fuels, the industry demonstrates a commitment to reducing their contribution to the speed and impact of global warming. Like land-based food production, Australia's oceans and marine environment will benefit from removing carbon from the atmosphere. Alternate fuels that burn cleaner, or utilising propulsion systems that don't burn at all is a tangible and rapid way to progress this objective.

- Value our people, look after them and keep them safe;

With new technology it is possible to not only reduce fuel and maintenance costs but also positively address occupational health and safety fatigue management.[144] Alternate propulsion systems, electric drives in particular, run much more quietly than diesel ICEs. Over the course of a fishing trip, engine noise can damage the hearing of the crew as well as contribute to increased fatigue.

- Continually improve our practices.

This project is driven and led by industry and intended to put it ahead of the curve. Industry is placing the onus on itself to improve its environmental impact. Whilst there may be market or price benefits from doing so in the future, the industry has a desire to reduce its carbon footprint now as evidence by the engagement throughout this project.

Key Technology Vendor Developments

MAN Energy Solutions / MAN Truck and Bus

Two stroke / Low Speed marine engine developments:

[144] 'Old Men: Older Boats Electric Drive, Power Storage and Power Generation in Commercial Fishing Vessels', Dennis Holder 2016 Nuffield Scholar, March 2018, Nuffield Australia Project No 1603.

MAN Energy Solutions developed the ME-LGIM dual-fuel engine for operation on methanol, as well as conventional fuel. The engine is based on the company's proven ME-series. When operating on green methanol, the engine offers carbon-neutral transportation of large merchant-marine vessels.

MAN developed the ME-LGI engine in response to interest from the shipping world in operating on alternatives to fuel oil in order to reach decarbonisation targets. Methanol carriers owned by Waterfront Shipping Company Ltd. (WFS), Marinvest, Westfal-Larsen Management (WL), and Mitsui O.S.K. Lines, Ltd. (MOL) have been operating at sea since 2016 using the engine, and, as such, the ME-LGIM has a proven track record offering great reliability, high fuel-efficiency, and reductions in GHG emissions.

<u>Four stroke marine engine developments:</u>

"In 2022, we will offer engines that are designed for later conversion – if required – to methanol operation. From 2024, we will make solutions for the use of methanol in four-stroke engines available." said Marita Krems, Head of the Four-Stroke Marine Engines Division at MAN Energy Solutions.

Insights:

- The MAN Energy Solutions (ES) and MAN Truck and Bus divisions are entirely separate entities.
- MAN ES are focused on low and medium speed engines for large ocean going vessels such as container and tanker ships.
- MAN Truck and Bus are focused on high speed engines for land and marine based applications.
- Whilst the MAN ES division is the market leader in Dual Fuel Diesel/Methanol engine development and sales, the MAN Truck and Bus division lacks the same decarbonisation vision, focus and product development roadmap.
- The Truck and Bus division has partnered with CMB.TECH (Belgium) to develop a fully integrated Dual Fuel (Diesel/Hydrogen) system which is assembled in the MAN factory and carries a comprehensive warranty.
- The MAN dual fuel (Diesel/Hydrogen) engine is the V12 D2862, is not commonly found in the engine room of the Australian fishing fleet, due to a variety of considerations such as power, weight, dimensions and cost.
- We have learned that MAN Truck and Bus are prioritising the development of a Dual Fuel (Diesel/Hydrogen) kit for their In-line 6 engine, the D2676
- A co-ordinated effort is required, to try and influence MAN Truck and Bus to include Dual Fuel Diesel/Methanol marine engines as a joint priority alongside their Diesel/Hydrogen developments. The release of a Dual Fuel Methanol i6 D2676 would cater to the technical needs of a portion of the Australian fishing fleet.

Caterpillar

Caterpillar Marine has publicly announced that Cat® 3500E-series marine engines can be modified to run as dual fuel methanol in the future.

> "Today's energy transition represents a significant opportunity to support customers with solutions that advance sustainable operations," said Brad Johnson, Caterpillar Marine vice president.[145]

Caterpillar, Pon Power and Damen Shipyards signed an agreement (28 November 2022) for the joint development of a series of dual-fuel methanol and diesel-powered vessels.

Under this arrangement, Pon Power will deliver to Damen a methanol-ready CAT 3500E series dual-fuel engines for marine propulsion in 2024, when the process of integration and testing will begin. The companies anticipate that this process will lead to series production of vessels with these methanol/diesel, dual-fuel engines on board in 2026. The process will involve integrating the pilot engines with all aspects of the ship's control, monitoring, ventilation and other systems. This will be undertaken in close co-operation with classification societies.[146]

Caterpillar Marine announced (December 2014) that they had successfully completed the commercial marine industry's first dual fuel engine retrofit conversion in hull. Performed in under six weeks, Caterpillar Marine along with Cat® dealer Bolier, completed an in hull retrofit onboard the *Coral Anthelia*, an LNG carrier vessel. The existing diesel engine was retrofitted to a dual fuel platform. As a result of performing the retrofit within the hull, no modifications had to be done to the ship's structure and no docking was required.

Caterpillar continues its research and development program and plans to expand its methanol engine portfolio.

> "Caterpillar Marine will share more information as development continues, with the understanding that an expanded methanol portfolio is required for success."[147]

Insights:

- The engine displacement, dimensions, weight and power of the 3500 E Series is not well suited to the Australian fishing fleet.
- The 3500 E Series engine is not commonly found in our offshore fishing vessels, however it is common within inland container barges in Europe, for example.
- Unlike Cummins, Caterpillar has already made several public announcements pertaining to their intended future product releases & R&D investments in Dual Fuel Diesel/Methanol marine engines.
- A co-ordinated effort is required, to try and influence Caterpillar to prioritise its product development and releases of Dual Fuel Diesel/Methanol engines, towards engine displacement and power ranges which fit the profile of the Australian fishing fleet, for example the CAT C18.
- Our estimate for the product release of the Dual Fuel Diesel/Methanol – Caterpillar C18 is 2026-2027.

[145] https://www.rivieramm.com/news-content-hub/news-content-hub/damen-and-caterpillar-sign-methanol-engine-mou-74072
[146] https://www.rivieramm.com/news-content-hub/news-content-hub/damen-and-caterpillar-sign-methanol-engine-mou-74072
[147] https://www.cat.com/en_US/news/engine-press-releases/caterpillar-marine-to-support-select-cat-3500-E-series-engines-with-dual-fuel-methanol.html

Cummins

Cummins currently sells a Dual Fuel engine in the QSK50 model range. The base QSK50 is made available with an optional Dual Fuel package that has been designed, developed, assembled, and tested by Cummins, and allows customers to power their operations with 100 percent diesel or a mixture of diesel and natural gas whilst still meeting US EPA Tier 2 and Tier 4 emissions.

Insights:

- The engine displacement (50 litres) dimensions, weight and power of the QSK50 is much too large for the Australian fishing fleet.
- The Cummins KTA/QSK19 (19 Litres) is commonly found in our offshore fishing vessels.
- Marinised versions of the QSK50 engine are not yet available.
- Although Cummins has not yet made any public announcements, during this project we've learned that their R&D lab within their corporate headquarters in Columbus, Indiana is putting Dual Fuel Diesel/Methanol through its paces, with the marine market in mind.
- A co-ordinated effort is required, to try and influence Cummins to prioritise its product development and releases of Dual Fuel Diesel/Methanol engines, towards engine displacement and power ranges which fit the profile of the Australian fishing fleet.
- Our estimate for the product release of the Dual Fuel Diesel/Methanol - KTA19/QSK19 is 2026-2027.

Overview of Cummins Dual Fuel adoption pathways for the QSK50:

- Customers who currently have Tier 2 engines can choose to purchase a Tier 2 Dual Fuel kit, which requires only minor changes to the base engine.
- Customers can convert their Tier 2 spec engine to Tier 4 spec.
- Customers can choose to purchase a Tier 4 Dual Fuel kit (available after a T2-T4 conversion), which retrofits your Tier 4 engine with few equipment integration requirements.

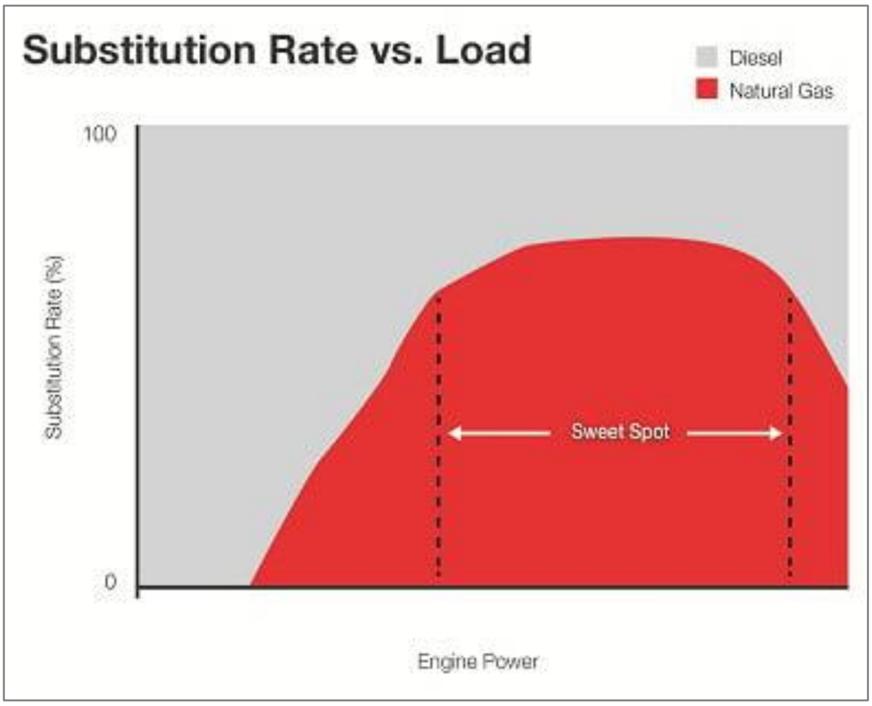

Figure 48: An illustrative example of Cummins Dual Fuel engine fuel substitution Rate vs Load: Source: Cummins.com

Mercury

In January 2023 Mercury unveiled their new Avator electric outboard range↗ at the Consumer Electronics Show (CES) in Las Vegas. The launch model is the 7.5e electric outboard motor with 750W rated power (3.5 hp) and an integrated 1kWh lithium-ion battery, which comes in a modular case and can easily be swapped with a fresh battery while out on the water.

At the same time Mercury announced the Avator 20e and 35e outboard concepts which would produce roughly 9 hp and 15 hp respectively. While these are still fairly low power outboard motors, they represent a definite acknowledgement by one of the leading outboard OEMs that battery powered electric outboards are here to stay.

Maritime Industry investments in Decarbonisation

Maersk

In 2022, Maersk continuously signed new-build contracts for the supply of 19 methanol dual-fuel containerships, with an estimated build cost in excess of $200m per vessel. The first of the confirmed vessels are due to enter service in the first quarter of 2024. The vessels will be powered by MAN Energy Solutions ME-LGIM (dual fuel) engines which can burn bio-methanol as well as e-methanol.

In addition to ordering new vessels, Maersk has been signing green methanol off-take agreements with the growing global network of producers, and Maersk's strategic investment vehicle Maersk Growth has been investing in startups who are developing cutting edge solutions to enable efficient scaling of production of low carbon alternative fuels.

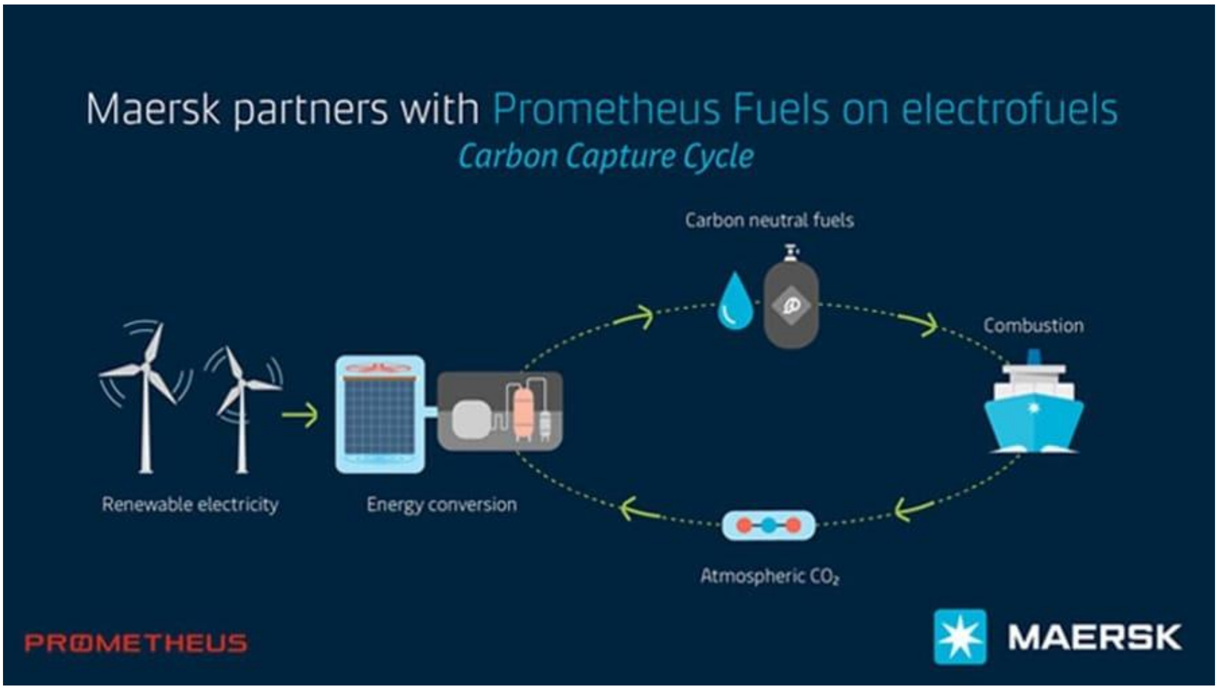

Figure 49: Maersk invests in Prometheus Fuels startup. Source: maersk.com

Disney Cruise Line

U.S.-based cruise shipping company Disney Cruise Line has acquired cruise ship Global Dream, currently under construction at German shipyard Meyer Werft, which will be one of the first in the cruise industry to be powered by green methanol.

Objective 5: Partnerships & Relationships

Objective 5: To build partnerships and relationships with global leaders to enable advancement of prioritised solutions that will enable improved climate resilience.

The project's technical lead has contacted and built relationships with the following entities throughout FRDC 2021-089.

Maritime Decarbonisation Associations

Organisation	Role	Future Actions
Zero Emissions Ship Technology Association (ZESTAs)	Based in London, UK. Focused on international shipping decarbonisation. Membership includes a large number of innovators.	Their members may be worth reaching out to for involvement in the Fishing Gear Forum or for the newbuild concept designs.
Global Centre for Maritime Decarbonisation (GCMD)	Based in Singapore. Focused on exploring specific pathways for international shipping decarbonisation, notably ammonia, although they have started looking at methanol too. Small number of founding/strategic partners, including BHP and BP.	Worth working with to establish standard methanol processes and training needs.

Blue Sky Maritime Coalition	Based in Houston, Texas, USA. The coalition is aimed at developing and executing a road map to a commercially viable net-zero emission logistics value chain across the commercial maritime industry in North America.	Whilst they operate in a different context, their value chain focus is a useful one to incorporate into work with the broader maritime industry around fuel supply chains and port/harbour infrastructure.
Green Marine, Green Marine Europe	Based in Quebec, Canada and Biarritz, France. Voluntary certification for maritime companies in USA and Europe wishing to demonstrate and reduce their environmental footprint.	They already have a single Australian participant, Spirit of Tasmania[148]. An Australian outreach of the model might help bring greater awareness of steps required to help make ports and harbours, and other maritime organisations into alignment around decarbonisation steps.

Naval Architects

Organisation	Relationship summary	Future Actions
ScandiNAOS	Direct contact made at the SMM Hamburg event, Site visit in Gothenburg Sweden. From a Naval Architecture perspective, ScandiNAOS have the reputation as being the foremost authority on the application of Methanol within the maritime sector, they have been actively involved in the vast majority of commercial applications, collaborative research projects and demonstrator vessels, dating back to 2012. Including adaptation of existing vessels to dual fuel methanol engines and the design and commissioning of the required safety systems.	It may be advisable for the Australian Seafood industry to commission ScandiNAOS to create a "Dual Fuel Methanol Vessel Blueprint" and open source it to members of the Australian industry. This approach should in theory enable significant cost and complexity avoidance, from industry stakeholders being otherwise forced to engage Classification societites who are both lacking in real world experience and potentially taking an overly conservative approach to the matter of alternative fuels. (especially given that the Stena Germanica has been operating on Dual Fuel Methanol since 2015)
Bury Design	Direct contact made with Paul Bury, founder of Bury Design, to discuss an innovative fishing vessel design they had published a few years ago. Designs have progressed into a range of sizes and configurations, but none have yet been built. They are also developing Hydrogen fuelled electric drive system ideas for fishing vessels.	They could be engaged to modify their hydrogen ideas to methanol.

[148] https://green-marine.org/members/participants/spirit-of-tasmania

The Whiskey Project Group	Through their Naiad and Yamba Welding & Engineering arms they create new patrol vessels for many state and federal government departments and create pro punts for the aquaculture industry. Contacted Ryan Carmichael, COO, and discussed directions the Whiskey Project Group has considered with regards to creating sustainably powered patrol craft up to 12m in size. They have found it hard to justify more sustainable builds as it greatly increases the price of the vessel. Several government tenders for sustainable patrol vessels have closed without finding a solution due to this limitation.	If government vessel operators could agree to promote renewable diesel as the next step in decarbonisation of the local marine industry that would be a big help.

Table 11: Naval Architects Contacted

Engine Manufacturers

Organisation	Relationship summary	Future Actions
Enmar Engines	Enmar Engines is a spin-out company of ScandiNAOS (referenced above within Naval Architecture) The company was born out of the need for High Speed Marine Engines capable of running Methanol. Enmar currently utilise donor engines from Scania and Volvo Penta , which they've already developed Dual Fuel Methanol kits for. In addition to the existing product offering, Enmar also offer a bespoke engineering service, whereby customers can commission the development of Dual Fuel Methanol kits for engines such as the CAT C18, Cummins K19 series, or Cummins X15, to name but a few.	Keep in contact to see what changes and the successes they have in creating retrofit kits for relevant engines.
Caterpillar	@SMM Hamburg event – During discussions with the global lead for CAT's fishing business, and CAT engineers from North America and Europe, it was communicated that whilst CAT is in fact publicising the developing of a Dual Fuel Diesel/Methanol marine engine (3500 E Series), the company line being shared in sales meetings is highly conservative, the overriding impression was that there is a fear of creating a scenario whereby customers are holding off repowering their	Track formal public announcements of Dual Fuel Diesel/Methanol engine product releases. (~Year: 2026 onwards)

	vessels with products from their existing diesel product range, whilst awaiting new product releases enabling lower carbon fuel usage such as Methanol. There seems to be a reluctance towards the prospect of collaborating with developers of third party dual fuel kits. Estimates place the formal product release of the CAT 3500 E Series Dual Fuel Methanol engine at 2026, with the optimal lever to place pressure on that timeline is strong market signals/demand.	
Cummins	Direct contact made – The contact at Cummins Australia has been attentive / supportive of our enquiries and push to see the development and release high speed marine engines catering the decarbonisation challenges of the Australian fishing industry. There is a refreshing openness towards the prospect of collaborating with developers of third-party dual fuel kits. With the prospect of sharing of relatively detailed technical design information under strict NDA, to help third party kit developers produce optimal equipment. (*Naturally, Engine OEM factory warranties do not cover third party bolt on components of any kind) Contacts at the Methanol Institute from Washington DC advise us that there is a current dual fuel diesel/methanol development program underway at Cummins HQ, however there is no clarity as yet as to estimated product release timeframes.	Track formal public announcements of Dual Fuel Diesel/Methanol engine product releases. (~Year: 2026 onwards)
MTU Rolls Royce	@SMM Hamburg – Major Product announcements have been made, publicly stating MTU Rolls Royce's intention to become the #1 market leader in Dual Fuel Diesel/Methanol marine engines. MTU engines currently fit within a size/power range which lacks relevance to the vast majority of Australian fishing vessels, however they seemed bullish on leveraging the changing landscape (triggered by the maritime industry wide focus on decarbonisation) to enter new	Track formal public announcements of Dual Fuel Diesel/Methanol engine product releases. (~Year: 2026 onwards)

	market segments in the not too distant future.	
MAN Truck and Bus	Referred contact made - MAN Truck and Bus has appointed SeaPower to represent their Marine engine business in Australia. Our contact is keen to work with Australian industry to influence / encourage MAN HQ in Germany to prioritise the development of a dual fuel MAN i6 engine to cater to size/power needs of the Australian fishing fleet. (Their current Dual Fuel engine offering is a V12 which can run Diesel/Hydrogen)	Track formal public announcements of Dual Fuel Diesel/Methanol and/or Diesel/Hydrogen engine product releases.
MAN ES (Energy Solutions) – Marine Division	Direct contact made – Recommendation and introduction received to pursue MAN Truck and Bus division, as the size/power ranges of their marinized engine portfolio are more relevant to the Australian fishing fleet. Our contact has maintained touch and is willing to help influence (where possible) the MAN Truck and Bus division to follow the lead of their sister division in riding the delivering Dual Fuel Methanol engines to industry.	Despite their engines being much too large for application within the vessels of the Australian fishing fleet, it might be advantageous to maintain contact nonetheless, with a view to convincing MAN ES to gently influence their sister company MAN Truck and Bus to prioritise the development of Dual Fuel Diesel/Methanol engines, such as the D2676 (i6).
Wartsila	@ MIAL Decarbonisation event – Whilst Wartsila publicly states on their website that they are proud of being the first to have developed a complete Methanol fuel delivery system for large marine engines, their senior Australian rep was 100% focused on pushing LNG engines during the recent MIAL Decarbonisation Summit in Sydney Q4 2022.	Their solutions are for much larger vessels, however the technological advancements developed for adjacent markets almost always filters through, and so it would be wise to keep watch of how those fuel delivery and safety systems might positively impact the Australian fishing fleet during scoping and upon implementation.
Volvo Penta	Volvo Penta have begun entering into collaborations with third party engineering firms (such as CMB.TECH who are experts in the field of developing dual fuel engine kits, evidenced by their recent announcement of a Dual Fuel D4 (Diesel/Hydrogen) engine.	Volvo Penta seem to have adopted a less “closed wall” strategy, by selectively partnering with highly reputable/leading class engineering firms, such as CMB.TECH Belgium in order to co-develop dual fuel engines conversion kits, which should result in engine customers having a broad selection of fuel transition optionality, and so it would be wise to keep track of joint press/product releases in the months and years ahead.

Weichei/Geely/Deutz Group	Despite countless attempts, Weichai China have proven impossible to contact. The Australian operation is simply a franchise-style sales office, with just 3 models of construction engines on offer – the representative had zero interest in exploring anything related to marine / alternative fuels.	Although China has many millions of vehicles operating on methanol, they seem to be quite reluctant to export any of that technology overseas for some unknown reason. This line of enquiry has not been overly fruitful, and so continued investment in future may or may not have much merit.

Table 12: Engine Manufacturers Contacted

Equipment Suppliers

Organisation	Relationship summary	Future Actions
Heinzmann	@ SMM Hamburg event – Heinzmann have developed a range of Stainless Steel Methanol injectors which are being used in a wide variety of the Methanol demonstrator projects and commercial vessels across Europe.	Heinzmann have an office in Australia, however most of their engineering works take place in their EU Headquarters. If an industry member chooses to engage in the custom development of a conversion kit for their engine/s, then Heinzmann would most likely be a component supplier to the kit developer.
Clear Flame (conversions of diesel ICEs into methanol engines.)	Clear Flame have developed an IP portfolio which is centred around the conversion of the existing global network of Compression Ignition Diesel engines, to run Methanol or Ethanol. The technology essentially re-routes the heat from exhaust gases to the intake manifold, to create the conditions required for effective combustion of low cetane rated fuels such as Ethanol & Methanol, without the need for a high cetane pilot fuel with rating, such as diesel. The key point to make is that whilst this solution is simpler due to being mono-fuel, the optionality of this solution is lower due to the loss of backwards compatibility with diesel.	For those in industry who are not concerned with mono-fuel conversions, then Clear Flame technology is likely to be a highly sought after solution within the next few years, their technology will be simply embedded within certain models of engines from the likes of John Deere etc, and so procurement will lack complexity. As with many of the other engine OEM's listed above, this technology presents a "wait, watch and observe" proposition for industry.

Table 11: Equipment Suppliers Contacted

Alternate Propulsion System Manufacturers

Organisation	Relationship summary	Future Actions
RIX Industries	RIX Industries manufacture Methanol to Hydrogen Reformer solutions, which are designed for on-demand, on-vessel	Within the roadmaps, these technologies are placed in the "Future" section, as they are low

	conversion of liquid Methanol & Water into Gaseous Hydrogen, which is then purified and then pumped into Hydrogen Fuel Cells.	TRL, high cost, and present some unknowns from a reliability and longevity perspective. The methanol reformer to Hydrogen pathway is enticing, and therefore one to keep an eye on, as things mature.
E1Marine	E1Marine produce Methanol to Hydrogen Reformer solutions, which are designed for the on-board, on-demand conversion of Methanol into a Hydrogen gas, for use within Hydrogen Fuel Cells.	Due to the shared IP portfolio between RIX and e1Marine, our recommendations are identical.

Table 13: Alternate Propulsion System Manufacturers Contacted

Renewable Diesel Supply Chain Participants

Organisation	Relationship summary	Future Actions
Refuelling Solutions (RFS)	The team at RFS currently specialise in transporting fuel to remote, regional sites anywhere in Australia, and whilst the majority of their business in focused on regular diesel, they have emerged as a key partner for organisations looking to decarbonise through the transition to lower carbon fuels.	Continue dialogue with RFS, as they are working to lobby for the enabling factors to enable the rapid growth of low carbon fuels market. Their success will be our success, as the supply chain and industry users must keep aligned in order to jointly navigate the complex road ahead.

Table 14: Renewable Diesel Supply Chain Participants Contacted

Methanol Supply Chain Participants

Organisation	Overview
OEG Offshore (storage)	One of Australia's largest methanol bunkering operations, they have the volumes consistently housed within their bunded storage tanks to mitigate short term risks, associated production shortages, and they are open to supplying new markets.
Chem-Trans (transport & last mile)	The Chem-Trans network is extensive, they have all of the infrastructure, training, and systems to cater to the unique last mile delivery needs of clients dotted along the Australian coastline.
Methanex Taranaki NZ (grey methanol producer)	Currently the largest methanol producer globally. Their methanol operation in New Zealand could easily cater to the future needs of the Australian fishing industry. Their sales office is based in Singapore.
Abel Energy Tasmania (green methanol producer)	Abel Energy are currently the most advanced with regards to breaking ground on their new Green/Bio methanol plant in Tasmania. They have secured a $1.7bn investment from Spanish energy giant Iberdrola and are now pushing full steam ahead.
MGC Queensland (green methanol producer)	Both Mitsubishi Gas Chemical Company (MGC) and Cement Australia (CA) have partnered with the Qld govt & the Port of Gladstone to create a Methanol production facility to service the projected growing demand for Methanol as a marine fuel.

VAST Solar South Australia (green methanol producer)	Vast utilises an ingenious Concentrated Solar Power technology, which allows for energy to be generated almost around the clock. They have consistently announced one groundbreaking deal after another during 2023. • They recently agreed to a $US586million merger with Nabors SPAC, which will see it be listed on the New York Stock Exchange, enabling them to access capital from a much broader group of investors than what the private market and ASX could offer. • They received $19.48m co-investment from the Australian and German government HyGATE collaboration program. • They have also secured $65m from ARENA (Fed Govt) for the establishment of a Port Augusta plant which will produce what they refer to as "Solar Methanol". Vast Solar is an Australian developer of concentrating solar thermal power technology. Its innovative modular tower solar array combines the best elements of molten salt towers and parabolic trough systems to deliver the world's lowest cost dispatchable, renewable energy for hot, dry climates. In October 2019, the Company was awarded the International Energy Agency's prestigious SolarPACES Technical Innovation Award for the world's most innovative concentrated solar thermal power technology, and it was shortlisted in 2022 as one of Bloomberg New Energy Finance's Pioneers. Vast Solar is currently developing two CSP projects in Australia: the 30MW/ 288MWh VS1 in Port Augusta, South Australia; and the 50MW VS2 baseload solar hybrid in Mount Isa, Queensland.

Table 15: Methanol Supply Chain Participants Contacted

Recommendations

The project's recommendations are broadly divided into ones specific to the Australian commercial wild catch fishing industry, and ones that require cross-industry efforts to obtain results.

Fishing Industry Specific

These recommendations are specific to changes for the commercial wild catch fishing industry. Figure shows which parts of the fisher profit tree these recommendations apply to (the actions left dark).

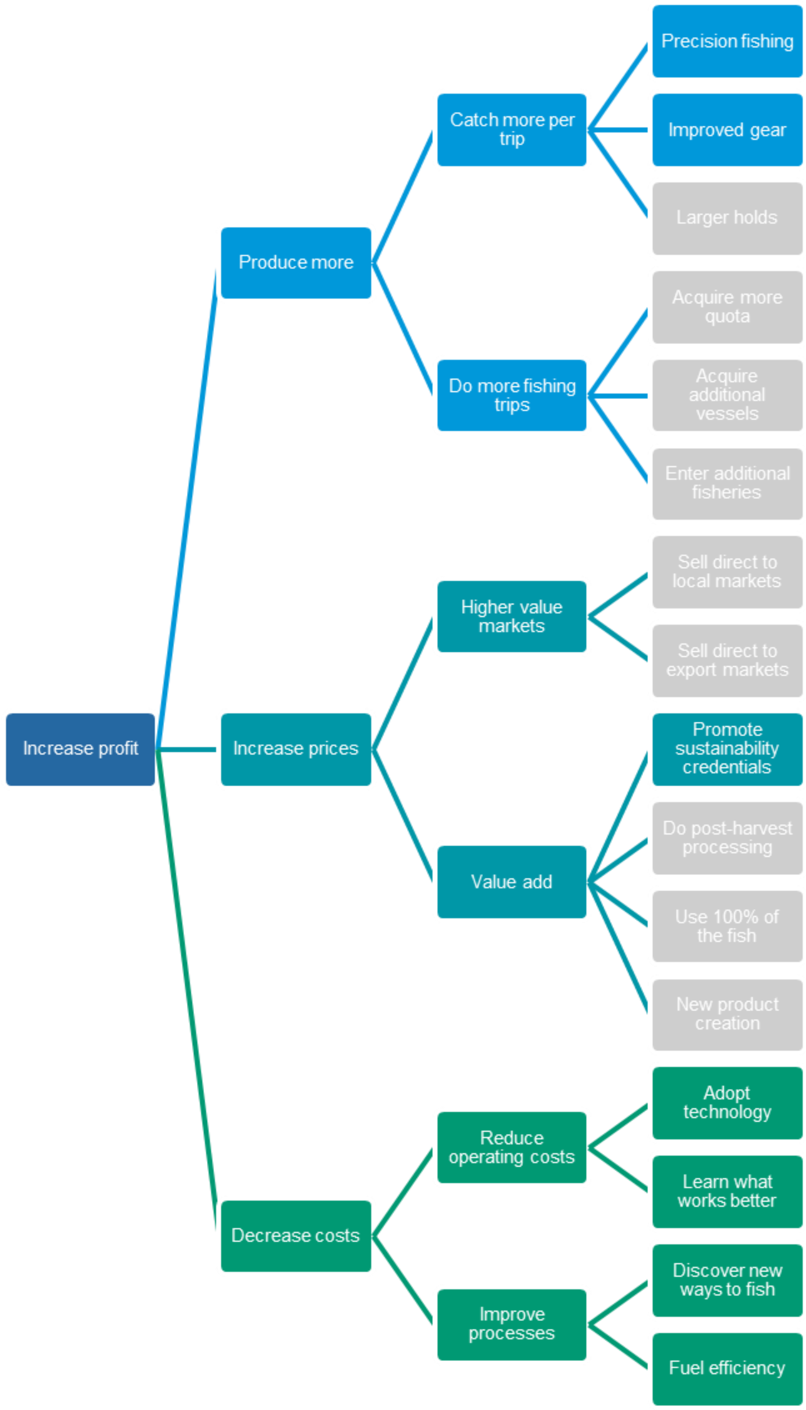

Figure 50: Profit tree mapped to recommendations.

Precision Fishing

This project has not considered the benefits of precision fishing, but the focus in this action is to minimise bycatch and maximise the effectiveness of efforts to catch targeted species – which can lead to reducing GHG emissions. CSIRO has previously called this out in one of their Foresight articles[149]. This is likely to create benefits for both the targeted challenges:

1. Reducing GHG emissions by reducing energy use.
2. Improving fisher profitability by eliminating wasted effort.

In the AgTech space there has been a huge leap in recent years of innovative solutions that build on digital technologies, especially artificial intelligence (AI), to create opportunities for farmers to reduce costs, more precisely use fertiliser, soil treatments, and even harvest their crops.

Recommendation F1

As part of its digitalisation and climate resilience promotion strategies, FRDC should promote and, where necessary, fund the development of digital innovations that can help fishers practice **precision fishing**. These efforts should be coordinated with the recommendations to create a Gear Forum and the Future of Fishing.

Improved Gear

Fishing Gear Database

During the project we found the Seafish Gear Database↗ a very useful source of information on more efficient fishing gear, and a much easier way of accessing relevant research than the simple search tag on the FRDC project database.

FRDC already has a Knowledge Hub article on "Energy Efficiency and Renewables"[150] and already has many projects looking at gear innovations, this should be expanded upon with the specific aim to develop an Australian-context gear library to help fishers easily browse for information and identify both the benefits of new gear and specific startups that might have innovations worth acquiring.

Recommendation F2

FRDC should create and maintain an up-to-date and online **fishing gear database** for Australian commercial wild catch fishers to learn from. Innovators and suppliers to the industry should be encouraged to nominate outstanding gear innovations to be included.

Gear Forum

The UK's Seafish organisation has focused on how gear changes can help reduce GHG emissions[151], and in order to encourage innovations in this area they have created the UK Gear Forum↗ which

149 https://research.csiro.au/oceanfutures/foresighting/foresight-8/
150 https://www.frdc.com.au/energy-efficiency-and-renewables
151 https://www.seafish.org/responsible-sourcing/climate-change-and-the-seafood-industry/how-fishing-gear-design-can-help-reduce-carbon-emissions/

"aims to facilitate discussion, develop and deliver initiatives to advance sustainability through the lens of selective gear innovations".

Membership of the UK Gear Forum includes:

- Fishing associations
- Producers' organisations
- Gear technologists
- Research community
- UK-wide governments

Learnings from a gear forum like this could be captured in the proposed Fishing Gear Database.

➔ Recommendation F3

FRDC should create an **Australian Gear Forum** that works in a similar way to the UK one, and seek to connect with Seafish↗ in order to share learnings and knowledge across the UK and Australian commercial fishing contexts. The forum could be promoted to members of the Australian International Marine Export Group (AIMEX)↗, the Advanced Manufacturing Growth Centre (AMGC)↗, and the Blue Economy CRC↗.

Promote Sustainability Credentials

At the moment there are a small number of Australian commercial wild catch fishers that promote their sustainability credentials beyond being MSC certified. The FRDC project Know & Show your Carbon Footprint is already looking at how this can be spread across the industry, and this project indicates this could help improve climate change resilience.

The global fishing industry has made sustainable fisheries management the main sustainability message, but largely ignored the climate change impacts of how it is harvested. Professor Ray Hilborn at Seafood Directions 2022 pointed out that "Comparing wild catch fisheries to conventional land-based farming, he said protein from fish didn't come with the same environmental costs, such as water pollution, pesticide and antibiotics residues, soil erosion and loss of biodiversity."[152]

➔ Recommendation F4

Early adopters that reduce GHG emissions will find there is an economic cost to this pursuit, even whilst they help clarify the potential roadmaps for the rest of the industry. The FRDC should both help encourage GHG emissions reduction, and early adopters, by promoting ways that more sustainably run fishing businesses can increase the market value of their catch. One possible avenue that should be explored is whether mandatory and consistent **sustainability labelling** on locally sold seafood could help consumers choose to shift from unsustainably harvested imported seafood to more sustainably harvested Australian wild caught seafood.

[152] https://www.frdc.com.au/good-news-sustainability

Adopt Technology

Celebrate Gear Innovations

Whilst the recommendations for creating Improved Gear will help promote innovation around commercial fishing gear, to promote adoption of the best ideas they will need to be identified, assessed, and promoted to the commercial wild catch fishing industry.

Recommendation F5

The biannual Seafood Directions conference should have a **Sustainable Gear Innovation Award** to celebrate innovations in commercial fishing gear that promote more sustainable fishing and operational practices. FRDC and Seafood Industry Australia (SIA) could put together prize money and recognition packages (promotion and press releases about the winning innovations) for the winners.

Newbuild Concept Designs

The roadmaps for outboard newbuilds and inboard newbuilds both assume that it is easy for a fisher to consider more sustainable vessel designs. However, whilst individual naval architects may have experience in sustainable newbuilds for ferries and offshore support vessels (OSV) there are few working on new fishing vessel designs.

In the UK, Fisheries Innovation & Sustainability commissioned a report on Net Zero Vessels Concept Design from MacDuff Ship Design which created six different vessel designs for methanol, LNG and battery-electric powertrains. Apart from creating viable 'off the shelf' concept designs, the learnings from the design process can inform future work in the area. One of the key learnings they had was financial:

> The key financial issue is that all the modified vessels incur a greatly increased capital cost for the same fishing capability. In addition, uncertainties on fuel prices and availability for methanol and LNG make it hard to analyse through life costs. For the battery electric vessels charged from shore power, these should make a significant saving in operational expenditure but, given the additional capital cost, a significant period of time may need to fall before this can be offset.[153]

Fishing vessel designs in the UK environment may not be a good match for Australian context, one key difference being the local experience with aluminium hulls, nevertheless a similar design process here could be very informative.

Recommendation F6

FRDC should commission a set of **sustainable vessel design** projects to a) identify the vessel designs of most interest to the Australian commercial wild catch fishing industry, and b) to create a set of concept designs around the use of hybrid diesel-electric, mono/dual-fuel methanol, and battery-electric powertrains.

[153] Macduff Ship Design Ltd. (2023) *Net Zero Fishing Vessels Concept Design Project, Stage 2*. A study commissioned by Fisheries Innovation & Sustainability (FIS) https://fisorg.uk.

Because these projects will require local boatbuilding experience, it is recommended that they be promoted in conjunction with the Australian International Marine Export Group (AIMEX)↗, Australian Commercial Marine Group (ACMG)↗, the Australian Division of the Royal Institution of Naval Architects (RINA)↗, Blue Economy CRC↗, and the Advanced Manufacturing Growth Centre (AMGC)↗.

Learn What Works Better

FRDC is already attempting to ensure that good ideas are disseminated within the Australian commercial wild catch fishing industry. The recommendation under Improved Gear of a fishing gear database would also help with this. However, it is important that the understanding already achieved by this project is built upon and spread more widely across the industry.

➔ Recommendation F7

FRDC's Capability, Capacity and Culture Change enabling strategy is key to helping drive the **culture change** needed across the Australian commercial wild catch fishing industry.[154] Promotion of Energy Intelligence and encouragement of travel bursaries to relevant maritime and fishing technology conferences and exhibitions should be promoted, and the learnings shared widely with the industry as a whole.

Discover New Ways to Fish

Adaptation

This project has found that adaptability will help fishers deal with the issues that climate change and other disruptions will create. To that end fishers that can handle the following changes well, will do better than ones who cannot adapt in these ways:

- Change their vessel,
- Change their fishing method, and/or
- Change where they fish/their fishery.

SIA and FRDC can play a role in helping the Australian commercial wild catch fishing industry prepare fishers for these sorts of changes.

➔ Recommendation F8

SIA and FRDC's Capability, Capacity and Culture Change program should collaborate on creating a **climate adaptation program** to help fishers become more adaptable in terms of the fishing vessels and fishing methods they use, and the fishing grounds/fisheries they target.

Fishers using active fishing vessels or methods that are known to be energy inefficient, should be identified and helped to a) understand their energy use, b) analyse how changes to what they do might impact their profitability and business resilience, and c) access financing and grants to help them make those changes.

[154] https://www.frdc.com.au/capability-capacity-and-culture-change

Fishers operating in areas or fisheries that might be at risk, from climate changes or fishing restrictions, should be identified and helped to a) understand what the nature of the risks are, b) review how they might change the ways their business operates, and c) access financing and grants to help them make those changes.

Future of Fishing

FRDC's innovation strategy (see Figure 50) is explicitly looking for disruptive Horizon 3 innovations that will help define the future of fishing[155].

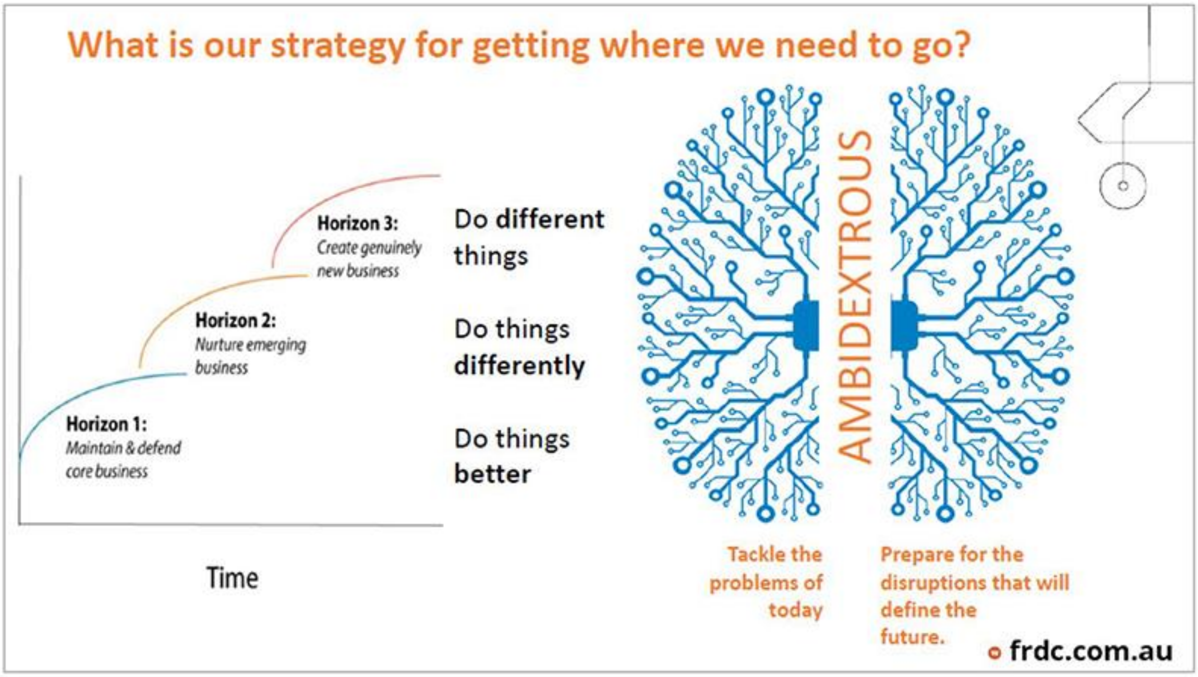

Figure 50: FRDC Innovation Strategy. Source: FRDC.

At Seafood Directions 2022 Professor Ray Hilborn pointed out that the fishing's problems require we have "many divergent groups working together"[156]. Indeed, the range of issues that need to be addressed requires that an innovation ecosystem be established to reach and inspire innovators from outside the Australian commercial wild catch fishing industry's normal orbit to help create innovations to handle the "disruptions that will define the future"[157].

Some of the key technological disruptions that this project has seen will define the future are:

- **Automation**
  The impact automation will have on fishing operations, with some overseas fishers already testing automated fish finding drones[158].

[155] https://www.frdc.com.au/innovating-solve-shared-problems-fishing-and-aquaculture
[156] https://www.frdc.com.au/good-news-sustainability
[157] https://www.frdc.com.au/innovating-solve-shared-problems-fishing-and-aquaculture
[158] https://www.kongsberg.com/maritime/about-us/news-and-media/news-archive/2022/tasa-delivery/

- **Electrification**
  The way that electrifying drivetrains can change the way vessels are designed to work better, the opportunities with having 'power stations' at sea[159] that enable recharging[160].

- **Jobs-To-Be-Done**
  Instead of having a single general-purpose vessel, breaking fishing operations up into multiple steps that might be most energy efficiently fulfilled with a multi-vessel approach that minimises the reliance on displacement hulls.

- **Commercial Innovation**
  Re-thinking what makes commercial sense in terms of the distance of fishing grounds from vessel home ports, the desirable size of harvest, and whether fishers should seek to diversify, or vertically integrate to create more resilient businesses.

- **Digitalisation**
  The most public success of Artificial Intelligence (AI) in 2023 was in the field of generative AI, which opens the field of possible applications for AI from data modelling to human assistance, especially with simple chat and verbal systems. Without innovators who understand the technology working on fishing solutions the commercial wild catch fishing industry won't experience the benefits of this change.

FRDC needs to create an innovation ecosystem that explicitly tries to bring startups, scaleups, industry players, venture studios, accelerators, cross-sector scaleups, investors, and FRDC together. Figure 51 shows the definition of innovation ecosystem that highlights important qualities of the idea[161].

Innovation Ecosystem: An innovation ecosystem is a community of interdependent but diverse actors coordinated through an alignment structure who collectively deliver an ecosystem-level outcome(s).

[159] https://oceanpowertechnologies.com/
[160] https://stillstrom.com/
[161] Modified from Thomas, L. D. W., and E. Autio (forthcoming), "Innovation ecosystems", Oxford Research Encyclopaedia of Business and Management. Aldag, R. (Editor). UK: Oxford University Press.

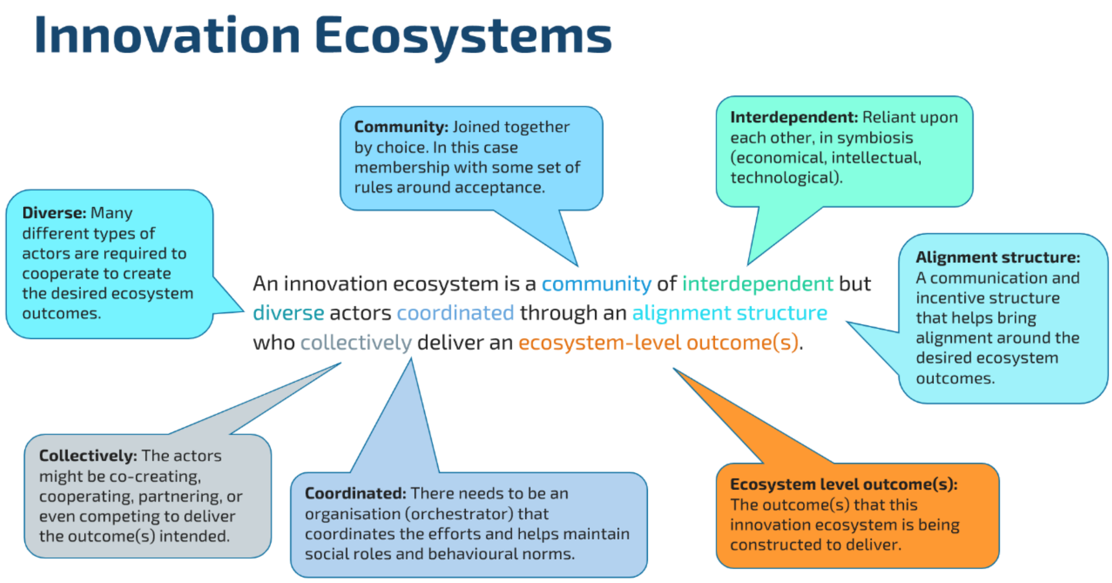

Figure 51: Definition of Innovation Ecosystems. Source: Blue-X.

Applying the principles of antifragility to the innovation ecosystem definition and leveraging research around indicators of innovation ecosystem health[162] and leveraging complexity[163] we can also identify key qualities which lead to a healthy innovation ecosystem (see Figure 52).

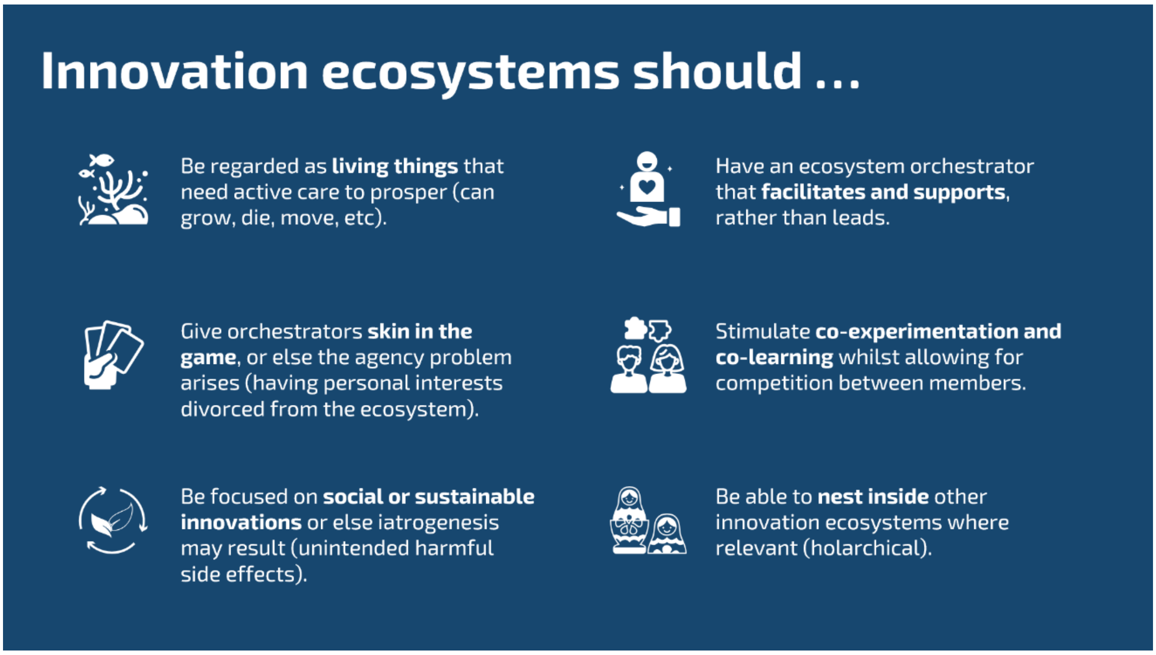

Figure 523: Qualities of healthy innovation ecosystems. Source: Blue-X.

It should be noted that the current modes of innovation creation that FRDC is involved should be thought of as mode 1 (linear), or mode 2 (networked) and an innovation ecosystem represents a

[162] Cobben , D., Ooms, W., Roijakkers, N., Indicators for innovation ecosystem health: A Delphi study, March 2023.
[163] Russell, M., Smorodinskaya, N., Leveraging complexity for ecosystemic innovation, February 2018, CC BY-NC-ND 4.0.

mode 3 innovation model (see Figure 534). This sort of ecosystem model is described by Russell and Smorodinskaya in this way:

> "And since the turn of the century, the most advanced countries are cultivating an even more complex innovation, seen as a continual, or systemic process ('mode 3'), which results from and simultaneously predefines further proliferation of ecosystems, or an increasing organizational complexity of the economy." [164]

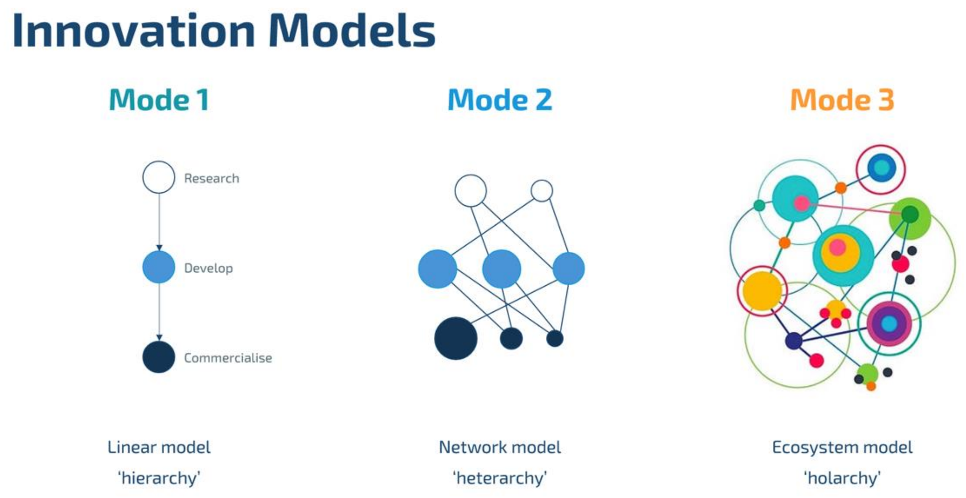

Figure 534: Innovation Models. Source: Blue-X.

FRDC has tried something like this before, with the Fish-X program. Figure 545 describes the journey that FRDC went on with Fish-X, Fish 2.0 and TekFish, with the circular arrows demonstrating the innovation momentum that existed during those programs, and how that has since declined.

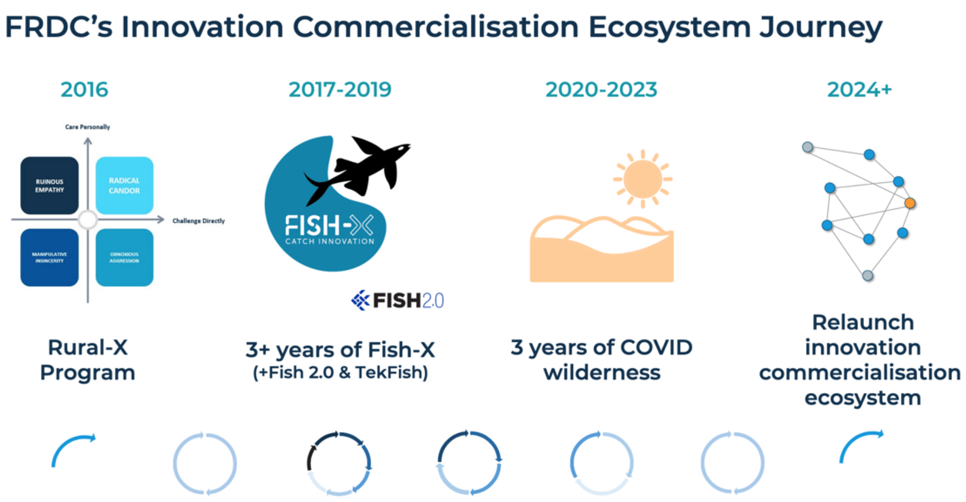

Figure 545: FRDC's Innovation Commercialisation Ecosystem Journey

[164] Ibid.

One important point is that the initiators of the innovation ecosystem, including the orchestrator, need to be bound by a shared vision and commitment to its goals (see Figure 55). The key role is that of the orchestrator who must both be committed to facilitating and supporting (not leading), and yet have enough skin in the game that their interests are aligned with those of the innovation ecosystem.

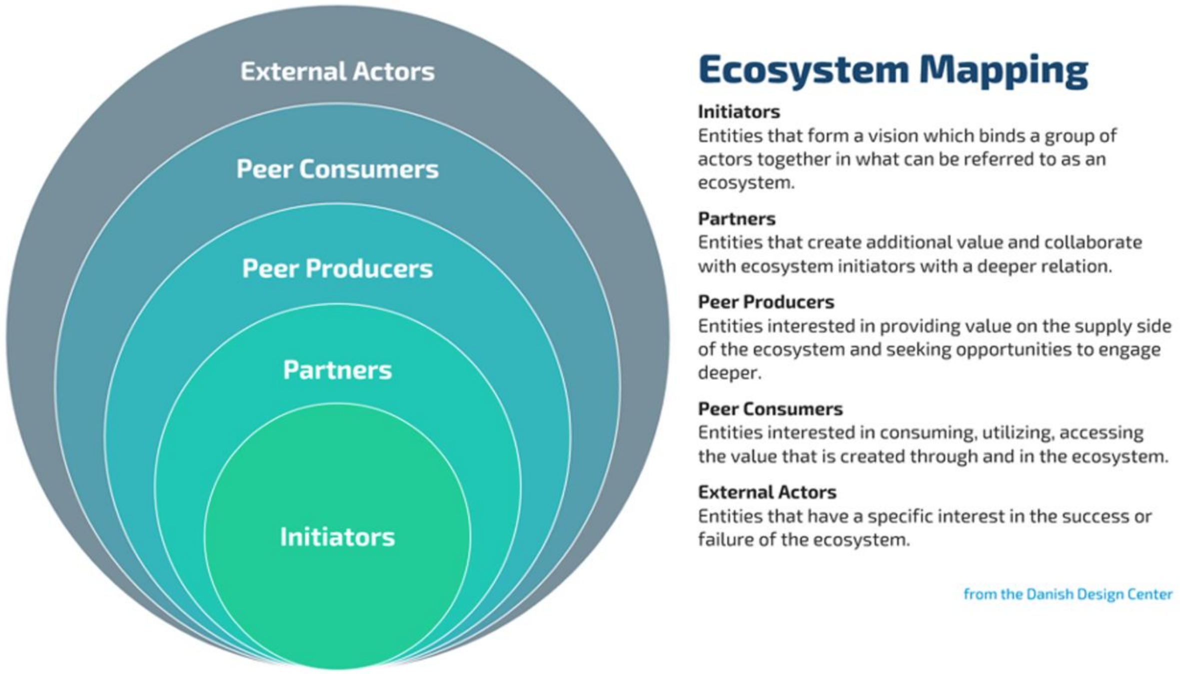

Figure 556: Ecosystem Mapping. Source: Blue-X.

Recommendation F9

The FRDC should seek initiators to help launch an innovation commercialisation ecosystem that can address the climate, technological, social, and economic disruptions facing the commercial wild catch fishing and aquaculture industries. Initiators can fill roles such as orchestrator, sources of funding, and sources of knowledge.

It is suggested that the vision of the innovation ecosystem be explicitly bound to social or sustainability goals rather than GVP or economic return. This can both help address FRDC's key strategic risks of biosecurity, cybersecurity, sustainability, climate change, and ocean planning; and reduce the chance of entrepreneurial iatrogenesis[165] (harmful side-effects).

Most importantly, the orchestrator organisation should be one that can help recruit innovators in the partner, peer consumer, and peer producer roles – implying they have a broad network across the fishing, aquaculture, seafood, venture capital, private capital, AgTech, ClimateTech, SpaceTech and DeepTech industries.

Fuel Efficiency

Energy Tracking

The starting point for the most basic level of achieving energy efficiency is to understand how much energy is being used at a given point in time. If the current engine for the vessel does not provide fuel

[165] Montiel, O., Entrepreneurial Iatrogenesis: An Explorative View, SWAM, March 2021.

flow monitoring, then third-party fuel flow meters are available. If a physical fuel flow meter is thought to be too likely to create a blockage, then a virtual one can be acquired. Electrical current data loggers can measure electrical usage. This has the benefit of allowing immediate feedback as to how much energy a given operation uses and can help moderate the sorts of operations that use most of the energy.

Recommendation F10

FRDC should seek Australian Government support for running an **energy tracking campaign** across the Australian commercial wild catch fishing industry to ensure that every engine or generator on every vessel which can have a fuel flow monitor does so, that every vessel with a large battery have an electrical current data logger, and that training is organised to show fishers how to use the monitors and loggers to help them manage operational use of their vessels to reduce fuel consumption, with the added benefit of reducing GHG emissions.

Energy Intelligence

Whilst tracking energy use is a good start, the Australian commercial wild catch fishing industry needs to go much further to successfully navigate the energy transition to more sustainable energy sources.

Processes and digital systems need to be developed that help reduce the need for two years of operational data, simplify the process of capturing operational data, and start fishers on the road to capturing and understanding their energy usage in order to create more resilient businesses.

The energy use of a fishing business needs to go from being something like a black box, with quarterly fuel use tallied and measured, to more like a digital map that shows exactly where and when energy is used – and matches that use to the business operations in question. Only then can fishers navigate the energy transition in a way that will help reduce GHG emissions without economically penalising fishers, or their customers.

Globally there is a rising level of interest in improving the fuel efficiency of fishing and the FRDC should make sure that optimisations and learnings from overseas organisations and fisheries are made available for Australian fishers. Fishers from across the USA[166] to Canada and Norway[167] are looking at fuel efficiency. In Italy an energy efficiency audit for fishers has been suggested[168], and in Alaska the Alaska Fisheries Development Foundation (AFDF) has funded the development of a Fishing Vessel Energy Analysis Tool and identified a set of energy conservation measures for fishers to consider.[169]

[166] https://fishermensnews.com/article/an-energy-revolution-in-the-commercial-fishing-fleet/
[167] https://www.globalseafood.org/advocate/net-zero-heroes-hybrid-and-electric-commercial-fishing-vessels-set-out-to-cut-the-industrys-carbon-emissions/
[168] https://www.nature.com/articles/s41597-022-01478-0
[169] https://afdf.org/research-and-development/vessel-energy-solutions

➔ Recommendation F11

As part of its digitalisation and climate resilience promotion strategies, FRDC should fund an **Energy Intelligence** program that develops processes and digital systems to simplify and where possible automate the process of capturing operational energy use data.

FRDC's Capability, Capacity and Culture Change program should develop energy assessment training to help fishers learn how to do a basic energy assessment that can help them understand better how to apply the relevant outboard motor or inboard engine roadmaps.

Cross-Industry Efforts

We can see from Figure 56 that many of the issues that must be addressed lie in the area of influence of multiple industries. This report recommends that the commercial wild-catch fishing (Fishing) industry must identify where they are a key player and should help lead efforts, and where there is existing work from other industries that should be supported. Four of the issues that are in common with the Agriculture & Forestry industry and 5 of the issues that are in common with the Maritime industry are recommended to be addressed.

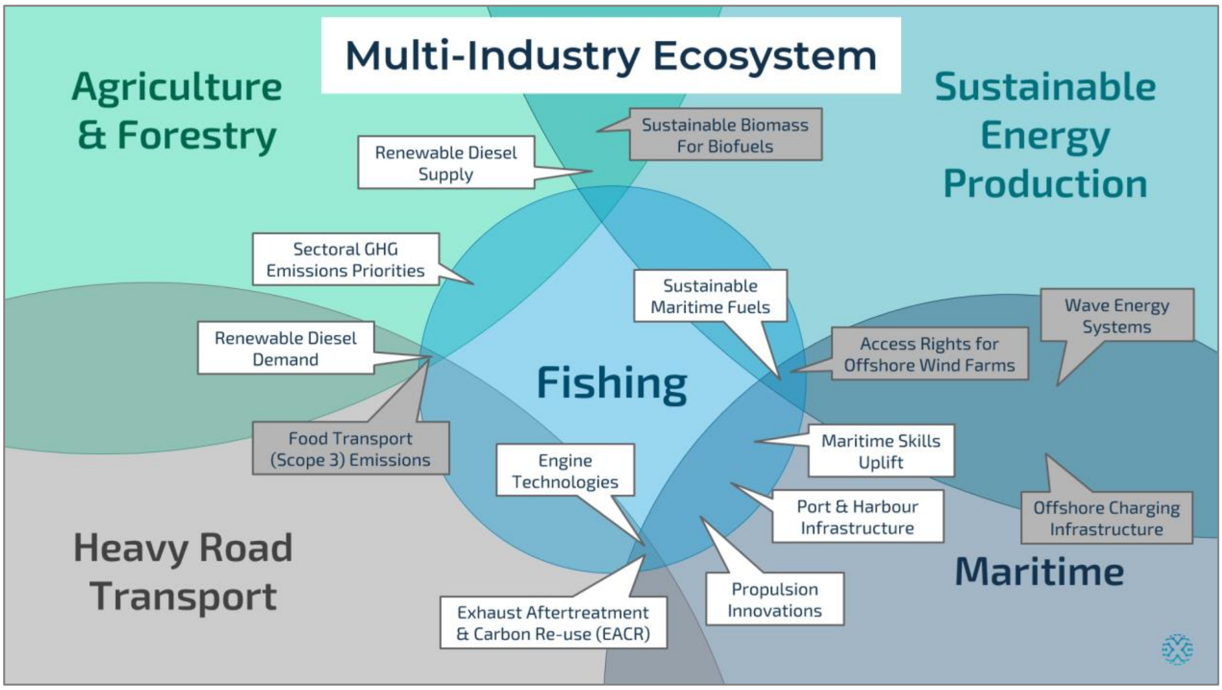

Figure 56: Report recommendations focus on the highlighted cross-industry issues.

Agriculture Industry Related

Sectoral GHG Emissions Priorities

Getting greater clarity from the Australian Government on the priority to be given to the National GHG Emissions targets is something that Agriculture & Forestry also would like to see, and in this area the report recommends that the Fishing industry should support the broader Agriculture, Forestry & Fishing sector in asking for greater clarity as to future requirements.

There is a project under way by Agricultural Innovation Australia (AIA) to develop an "environmental accounting platform for Australian agriculture, fisheries and forestry, with the first stage underway to deliver a cross-sectoral carbon footprinting solution."[170] Given that the GHG emissions footprint of different protein sources is a subject of topical debate amongst the media[171], NGOs[172], governments[173], and even the FRDC[174] it would be helpful for the Fishing industry to protect the relatively good status of wild caught fish versus other protein sources by ensuring carbon footprints are accurate and defensible.

The Treasury, advised by the Australian Accounting Standards Board, are developing mandatory climate-related financial disclosure reporting requirements for Australian businesses, initially just targeting ones that have more than $50m revenue, or more than $25m in assets, or more than 100 employees. Some of the largest commercial wild catch fishers will be affected by these. Voluntary reporting under the standards is encouraged for other businesses and a phased approach targeting smaller businesses is indicated[175]. The reporting is risk focused, meaning it seeks to establish what risk climate change poses to the business, and requires public disclosure of the transition plan and climate-related targets.

➔ Recommendation A1

FRDC should support the development of new, and/or integration of existing, digital tools for fishers that can help them record their **carbon footprint** with the AIA's environmental accounting platform, the digital tools should also enable the easy creation of reports to help larger fishers meet their mandatory climate-related financial reporting requirements.

Renewable Diesel Supply/Demand

Renewable diesel's supply depends on the availability of suitably sustainable biomass from the Agriculture & Fishing industry, in this area Fishing should take a supporting role. AgriFutures Australia has identified the *Pongamia pinnata* tree as a potential crop for renewable diesel and an emerging industry[176].

Demand for renewable diesel has been identified for several hard to abate industries, such as Agriculture & Forestry[177], Heavy Road Transport[178], Construction[179], and now Fishing. Very recently a consortium of industry associations and major companies, including Austral Fisheries and Maritime

[170] https://www.aginnovationaustralia.com.au/initiatives/
[171] https://www.bbc.com/future/article/20221214-what-is-the-lowest-carbon-protein
[172] https://www.fairplanet.org/story/sustainable-food-protein-carbon-emissions/
[173] https://envcomm.act.gov.au/wp-content/uploads/2021/11/Scope-3-Greenhouse-Gas-Emissions-in-the-ACT-FINAL-Report-A30648089.pdf
[174] https://www.frdc.com.au/fish-vol-30-2/calculating-seafoods-carbon-footprint
[175] https://treasury.gov.au/consultation/c2023-402245
[176] P. Wylie, P. Gresshoff, G. Muirhead, S. Fritsch, R. Binks and K. Bowman, *A technical and economic appraisal of* Pongamia pinnata *in northern Australia*, AgriFutures Australia, February 2023.
[177] Gjerek M, Morgan A, Gore-Brown N, Womersley G. (2021). Diesel Use in NSW Agriculture and Opportunities to Support Net Zero Emissions. Sydney: Australian Alliance for Energy Productivity for NSW Department of Primary Industries.
[178] https://bigrigs.com.au/2023/08/24/consortium-calls-for-establishment-of-a-local-renewable-diesel-industry/
[179] https://www.lendlease.com/au/insights/stepping-up-the-pace-fossil-fuel-free-construction/

Industry Australia Ltd (MIAL), presented a letter to the Minister for Climate Change and Energy, the Hon Chris Bowen MP, requesting that the Australian government "facilitate the establishment of a local renewable diesel refining industry in Australia."[180]

Recommendation A2

Seafood Industry Australia will coordinate with Maritime Industry Australia Ltd (MIAL)↗ to advocate for Australian government action to progress local production of **renewable diesel** and make sure the needs of the Australian commercial wild catch fishing industry are recognised.

Maritime Industry Related

Sustainable Maritime Fuels

The sustainable maritime future fuels that fishers may need to rely upon, such as green methanol, biomethanol or biobutanol are also in demand in the broader maritime industry, whether it be for offshore support vessels, pilot boats, ferries, or other domestic commercial vessels (DCVs).

However, the maritime industry is most focused on the needs of international shipping to comply with IMO targets. The Australian commercial wild catch fishing industry should inform and cooperate with activities in the broader maritime industry to ensure that the need of fishers for regional and smaller scale solutions are also catered for.

Recommendation M1

FRDC should establish connections with efforts by Maritime Industry Australia Ltd (MIAL)↗, the Australian Renewable Energy Agency (ARENA)↗, Blue Economy CRC↗, and iMove CRC↗ to create credible **sustainable future fuel options** for the maritime industry, especially domestic commercial vessels (DCVs).

These efforts should target Methanol Hubs created in response to the Port & Harbour Infrastructure recommendations.

Maritime Skills Uplift

The Workforce Training implications section identified the key areas where training and capability needs to be developed, and some of the industry groups most likely to be affected. A deeper review of what will be needed is beyond the scope of this project, but many of these issues run across the broader maritime industry as well.

Recommendation M2

FRDC's Capability, Capacity and Culture Change program should work with the Australian Maritime College (AMC)↗, Australian Maritime and Fisheries Academy↗, Batavia Coast Maritime Institute↗, Great Barrier Reef International Marine College↗, and other industry capability and training groups to ensure that the future educational needs of maritime workers to remain **energy transition relevant** can be satisfied.

180 https://hvia.asn.au/hvia-joins-call-to-establish-local-renewable-diesel-industry/

Port & Harbour Infrastructure

Regional ports and harbours are important to many parts of the maritime industry, and the fishing industry should work with the commercial and recreational boating sectors to ensure that the shore infrastructure is available to help the industry move forward. There are already DC fast charging options appearing for ports, harbours and marinas with offerings from Aqua SuperPower↗ (UK), Plug↗ (Norway), and Heliox Energy↗ (Netherlands) – but as yet no Australian products.

Recommendation M3

Sustainable energy shore infrastructure and sustainable vessels need to be matched together so that supply and demand ensures investment on either end is not wasted. To that end it is recommended that FRDC works with Ports Australia↗, Maritime Industry Australia Ltd (MIAL)↗, Blue Economy CRC↗, Boating Industry of Australia (BIA)↗, Australian International Marine Export Group (AIMEX)↗, and Australian Commercial Marine Group (ACMG)↗ to create **regional maritime sustainability hubs** where stakeholders across the maritime ecosystem, from harbour managers, to fuel suppliers, DCV operators, unions, equipment manufacturers and government authorities can focus efforts on progressing the effort to improve maritime sustainability.

From this report, two initial focus areas for different hubs would be:

1. Electrification Hub
Exploring shore charging, battery-electric outboards and inboards, hybrid diesel-electric vessels. Fishing vessels, smaller ferries, pilot boats, and offshore support vessels could all be involved.

2. Methanol Hub
Exploring methanol fuels handling procedures, methanol bunkering, grey/green methanol 'last mile' supply issues, AMSA-compliant vessel design, new engine/fuel-cell technologies and economics. Fishing vessels, coastal transport, larger ferries, and offshore support vessels could all be involved.

Propulsion Innovations

The project's investigation into fuel reduction interventions showed that a number of propulsion innovations have already been suggested for fishing vessels, and that many more exist now that the broader maritime industry is more focused on sustainability. In particular ones around using wind to boost propulsive effort, lowering drag across the wet and dry surfaces of the boat, and hull changes that could be made to improve fuel efficiency. Australian innovations in aluminium catamaran hulls[181] and carbon fibre hulls[182] and components[183].

Recommendation M4

FRDC should work with Seafood Industry Australia (SIA)↗, Maritime Industry Australia Ltd (MIAL)↗, Boating Industry of Australia (BIA)↗, Blue Economy CRC↗, Australian International Marine Export Group (AIMEX)↗, and Australian Commercial Marine Group (ACMG)↗ to promote the uptake of **Australian propulsion innovations** across the Australian commercial wild catch fishing industry.

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[181] https://blacklab.design/aus-design-spotlight-catamaran/
[182] https://www.thewhiskeyproject.com.au/
[183] https://www.carbongametowersinternational.com/

Emissions Aftertreatment and CO_2 Re-use (EACR)

Scenario planning revealed how impactful emissions aftertreatment and CO_2 re-use (EACR)could be, supporting both circularity and reducing GHG emissions. The benefits of a mobile version of EACR would be felt across the broader maritime industry and the heavy road transport industry. Given the low to medium TRLs of solutions in this area, there is a need to promote research, development, and commercialisation of solutions. Importantly, the creation of a CO_2 capture industry could help make the production of e-fuels more cost effective.

Recommendation M5

FRDC should work with the Australian Renewable Energy Agency (ARENA)↗, Blue Economy CRC↗, iMove CRC↗, and CO2CRC↗ to identify and promote areas where research, development and commercialisation are needed to create **Emissions Aftertreatment and CO_2 Capture (EACR)** breakthroughs, solutions and products, and also to promote circular economy thinking in the development of sustainable maritime fuels.

Engine Technologies

This report points out that internal combustion engine original equipment manufacturers (OEMs) are already working on creating new engine technologies and more sustainable options for their customers. However, they are focused on the largest and most advanced markets in terms of sustainability – which has meant mostly focussing on the European market and international shipping (due to IMO regulations). The domestic commercial vessel (DCV) market in Australia should be exploring these new technologies and making engine OEMs aware that Australian small to medium vessels need solutions other than battery-electric or diesel-electric ones.

Recommendation M6

FRDC should work with the Australian Renewable Energy Agency (ARENA)↗, Blue Economy CRC↗ and iMove CRC↗ to **identify and fund pilot projects** for dual-fuel diesel/methanol retrofit kits, mono-fuel methanol engines, and methanol fuel cells. These projects should consider the full range of operational requirements of offshore maritime operations such as deepsea fishing, offshore supply vessels, coastal transport, and long-distance ferries.

These pilot projects should be connected to Methanol Hubs created in response to the Port & Harbour Infrastructure recommendations.

Extension and Adoption

Communication Objectives

SIA's extension and adoption strategy has been to position itself as the go-to thought leader and expert within the Australian seafood sector among industry, stakeholders, government, media and the community.

Communications from the SIA, Austral, FRDC and the project team will hit a number of target audiences, as profiled further below, with the key communications objectives of:

Profile and publicise the scope of this project and expected outcomes with target audiences;

Generate engagement and establish networks from within industry and other relevant stakeholders;

Communicate key dates, milestones and announcements to the target audiences;

Communicate meaningfully and effectively with FRDC and other stakeholders, as relevant;

Profile and raise awareness of the project with industry, stakeholders, government and the general public;

Promote the sustainability, ingenuity and good management of Australia's commercial fishing sector;

Promote and generate positive stories and media coverage related to the project which may include the following topics:

- Building Climate Resilience in the commercial fishing industry
- Alternative fuels to power future fishing fleet
- Seafood Directions Conference
- End of project summary including a recap of the project, learnings and next-steps

Target Audience

The primary target audiences for this project are:

Industry

- Domestic wild-catch sector
- Domestic aquaculture sector
- Domestic state/territory/sector bodies
- International peak-industry bodies
- International Coalition of Fisheries Associations

Stakeholders

- Government (State and Commonwealth) Ministers

- Government Departments e.g. Department of Agriculture, Fisheries and Forestry, Department of Climate Change, Energy, the Environment and Water
- Regulators
- NGOs and eNGOs
- Third-party certifiers e.g. MSC
- Commercial peak-industry bodies

Media

- Commercial seafood
- Agriculture and primary production
- Climate and energy

The secondary target audiences for this project are:

- Primary producers
- Agriculture sector
- Recreational fishers
- Public interested in alternative fuels

Brand Guidelines

The SIA and FRDC logos were adopted and used across communication resources and outcomes.

The project was acknowledged with the following words at the end of relevant formal communications and press releases:

This Climate Change Resilience project is funded by the Fisheries Research and Development Corporation (ABN 74 311 094 913) as set out in the Project Agreement for the Climate Resilient Wild Catch Fisheries, Project Number: 2021-089.

Communication Outputs

The planned communication outputs:

- Industry communications
    - SIA newsletters: Inside SIA, Aqua News, Great Australian Seafood News
    - State/territory and sector newsletters
    - FRDC newsletters, engagement of the FRDC extension officer network
    - As appropriate develop industry communication updates
- Media
    - Comms will be assessed based on project milestones
    - End of project wrap including recap, findings, and next steps
- Social media
    - SIA and sub brands
    - Austral
    - State/territory and sector associations

- FRDC

- Seafood Directions – video, visual display and panel
- A register of interested parties for future projects

Figure 57: Seafood Directions 2022 Panel

Extension Plan

To support the extension of this project, this plan was developed to assist in the planning of the extension strategy for this project.

Objectives

The objectives of the extension plan are to ensure the project delivers an understanding of the range of challenges and opportunities experienced in supporting adoption and brings critical perspectives to extension opportunities for this project and the industry more broadly.

The co-design with the 'extension ecosystem' (industry, researchers, technology owners, extension officers and media) an impact model/process for extension which supports increased adoption, effectiveness and reach of research and technology.

The aim of these activities is primarily to engage participants but also to provide opportunities to learn about the outputs from the previous Energy Use and Emissions project (2020-089) and build upon this with additional and actionable information relating to assessing options that progress the industry towards climate resilience.

Key Messages

The challenges facing the industry around climate change and resilience is below where it needs to be and by increasing industry awareness by discussing the opportunities that climate resilience represents in the long term, will help protect the industry moving forward.

Understanding what solutions and technologies are available to industry will identify what's viable, feasible, desirable, and scalable.

Pathways for leaders and innovators in industry are open, now is the time to share and tackle shared challenges around climate resilience.

Methods

The extension plan utilised a range of methods to ensure it captured the widest reach, these included but not limited to:

- Attendance at Electric and Hybrid Marine Expo Europe 2022
- SIA Industry Webinar August 2022
- Attendance and Presentation at Seafood Directions Conference
- The networks of FRDC extension officers
- Meetings and workshops with relevant stakeholders
- Interviews with industry
- Meeting and Workshops with climate change and resilience experts both Nationally and Internationally

Further Work and Extension of FRDC 2021-089

To extend the impact of FRDC 2021-089 the FRDC and its partners should:

- Create clarity in the commercial wild catch fishing industry about the energy transition options that are most appropriate for them to consider.

- Raise awareness amongst Government, the alternative fuel industry, and engine manufacturers of the specific needs of the Australian commercial wild catch fishing industry.

- Begin the process of creating an Alternate Marine Fuels network map for the Australian commercial wild catch fishing industry that helps fuel producers, fuel distributors, and fishers identify clusters of demand and supply that will help match them together.

- Establish guidance for fishers on what sort of transition strategy might be most appropriate for their category and type of vessel.

- Make the Energy Transition Roadmaps publicly available, easily consumable, and shareable.

- Direct attention to the next most addressable challenges:

- Creating baseline GHG emissions profiles to allow for carbon credit claiming later (and to help establish a more accurate GHG emissions profile for the industry as a whole).
- Reducing fugitive refrigerant emissions and address refrigeration efficiency.
- More efficient use of vessels and fishing gear.
- Promoting the development of a fish waste to biofuel feedstock pathway.

Key Messages

The key messages from this extension work are:

- There are practical steps that the commercial wild catch fishing industry can take in the next few years to reduce their net GHG emissions.
- Important requirements for self-sufficiency and economical solutions can and should be prioritised in developing alternate fuel solutions for the commercial wild catch fishing industry.
- Government intervention will be required to help the commercial wild catch fishing industry transition successfully, but the transition roadmaps will help focus that intervention where most useful.
- Other countries and jurisdictions are on the same or similar journeys and can be looked to for examples of how to handle energy transition challenges.

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https://www.volvopenta.com/about-us/news-page/2022/jun/volvo-penta-case-study-on-hvo-fuel-in-all-demo-and-test-boats/

https://www.volvopenta.com/about-us/news-page/2022/sep/top-5-tips-using-hvo-100-fossil-free-fuel-instead-of-diesel/

https://www.zerocarbonshipping.com/fuel-pathways/

https://yaramarine.com/windwings/

Appendices

Appendix 1 - Challenges Reviewed

Challenge	Immediacy	Importance	Addressability	Opportunities
C1. National GHG Emissions Targets There is a national target to reduce net GHG emissions to 43% below 2005 levels by 2030.	Soon	While the Government may not impose penalties or mandate change to a small and relatively low GHG emitting industry such as commercial wild catch fishing, there could be consumer behaviour changes if the industry is seen as a laggard. Given the industry is so affected by climate change there is also some value in it leading the way for others.	With an ageing fishing fleet and limited ability to fund capital intensive expenditures the industry will find this challenging, but it is possible to do something to increase resilience to the challenge.	46% of total GHG emissions are from fuel used for propulsion and powering auxiliary systems on vessels, so focus on that: 1. Fuel Switching 2. Engine Retrofitting 3. Engine Replacement 4. Vessel Replacement
C2. Fisher Profitability Operating costs for the industry are forecast to increase as a) other industries decarbonise and pass on costs, b) workers see other opportunities as more attractive so seek higher pay to remain, c) ongoing regulation increases equipment costs, and d) carbon pricing increases costs of fossil fuels. At the same time there appear limited ways that fishers can produce more fish or increase the prices they receive.	Already happening	A key aspect of climate change resilience is the ability for a fisher's business to be able to afford to make the adaptations necessary to deal with rising input costs, the need to decarbonise, and fisheries management changes. Fishers that have more profitable and more diversified businesses will be able to adapt better than ones who are more constrained in their financial and operational options.	Hard to address cost increases in equipment. Identifying where the industry is using gear inefficiently is important, but refrigerant changes are unlikely to be easily addressable. More standardisation across fishing vessel designs might reduce the cost of new vessels and the cost of retrofits.	Decreasing costs is an element that fishers can easily address. Reducing operating costs by adopting new technology can help when there is awareness of how it can help, and so education and community shared learnings can help. One of the key issues for the industry is the increasing cost of fuel, particularly diesel. Process improvements that consider innovating around how to fish so as to reduce costs, and

				operational changes to improve fuel efficiency are addressable.
C3. Ecological Changes Climate change is pressuring marine ecosystems through ocean acidification, ocean warming, and other ocean changes and this creates present and future challenges for the industry.	Already happening[184]	The greatest climate challenges for the Australian wild catch fishing industry come from the ecological changes that are already happening due to ocean acidification and ocean temperature change. These range from significant short-term impacts to fish stocks and the economics of the industry, to the existential threat of whole fisheries being lost.		
C4. Fisheries Management Adaptations Fisheries management will need to adapt to climate change impacts on their fishery, and the industry will likely find it challenging to adapt to new rules and regulations.	Already happening	While these are important, by their nature they do consider the ability of the industry to make the adaptations required. So, the potential of future changes should not be regarded as a very important issue.		
C5. Consumer Changes Consumer behaviour changes due to attitudes towards climate change and	Soon[185]	Attitudes towards wild-caught protein may become negative, with farmed product preferred, likewise alternative protein		

184 Fulton, E.A., van Putten, E.I, Dutra, L.X.C., Melbourne-Thomas, J., Ogier, E., Thomas, L. Rayns, N., Murphy, R., Butler, I., Ghebrezgabhier, D., Hobday, A.J. (2021) Guidance on Adaptation of Commonwealth Fisheries management to climate change. CSIRO Report for FRDC. Hobart. CC BY 3.0
185 The MSC found that in 2022 only 23% of Australian consumers had made a change in purchasing behaviour to buy more sustainable seafood – GlobeScan Inc., MSC Consumer Insights 2022: Australia, May 2022.

sustainability will create challenges for the industry.		sources with lower net GHG emissions may become much more popular (e.g. chicken, insects, lab-grown meat). These are important to address at some point, but do not yet show signs of being significant risks to resilience.		
C6. Market Access Countries adding carbon taxes to imports, a growing interest in locally harvested foods over distant ones, and political limitations to trade in response to climate change actions or rhetoric could all challenge the industry's economic future.	Eventually but not soon	As the COVID-19 pandemic showed, losing access to key markets can severely impact part of the industry that rely significantly on exports to a few key markets (e.g. China). Resilience requires this is addressed.		
C7. Sea Level Changes Sea levels around Australia are predicted to rise over the foreseeable future, with the rate varying with changes in GHG emissions. Specific local areas may experience less rising, or even falling sea levels, but in general the melting of land ice and warming of the oceans means they will rise everywhere. This potentially puts at risk coastal infrastructure that fishers rely	Already happening[186]	Adaptation to rising sea levels will be important for Australian society as so much of our infrastructure and lifestyles are at risk. The long-time scales of sea level change mean that there is time to act and create more resilient coastlines, but the best mitigation may be limiting our GHG emissions.		

[186] Fulton, E.A., van Putten, E.I, Dutra, L.X.C., Melbourne-Thomas, J., Ogier, E., Thomas, L. Rayns, N., Murphy, R., Butler, I., Ghebrezgabhier, D., Hobday, A.J. (2021) Guidance on Adaptation of Commonwealth Fisheries management to climate change. CSIRO Report for FRDC. Hobart. CC BY 3.0

upon, such as wharfs, boat ramps and fuel stations. It also could dramatically affect estuarine fisheries.				

Appendix 2 - Project Webinar 31 August 2022

Figure 58: Webinar Title Screen

The webinar has been published on YouTube under SIA's account:

https://youtu.be/7T_dOezF_pg

Attendee list:

- Veronica Papacosta, Seafood Industry Australia
- Jessica McInerney, Seafood Industry Australia
- Tom Cosentino, Margo Consulting
- Allen Haroutonian, Blue-X
- Andy Myers, Oysters Australia, and NSW Farmers' Federation
- Alice McDonald, AFMA
- David Sterling, Commercial fisher
- Clayton Nelson, Austral Fisheries, and Seafood Industry Australia
- David Carter, Austral Fisheries
- Steve Eayrs, FRDC
- Todd Levine, Agricultural Innovation Australia
- Kelly Pyke-Tape, Spencer Gulf Prawn Association
- Garry Barnes, Barnes Seafood
- Donna Wells, Finest Kind
- Rosie Love, Seafood Industry Australia
- Julie Willis, Seafood Industry Australia
- Sarah Langton, Culturise

Appendix 3 - Technology Assessment and Recommendations

Attached separately in XLS format.

Appendix 4 – Comac Enterprise Specifications

Figure 60: Photo of Comac Enterprise

Vessel Description

The hull is a single chine mono hull. Decks have slight sheer and slight camber. The vessel is a single screw motor fish trapping trawler. The vessel is constructed of steel with raised bow, transom stern and raised wheelhouse on a forecastle deck. Vessel has been modified from a beam trawler to a fish trapping vessel.

Principal Particulars

Owner	Austral Fisheries
Address	Level 4, 50 Oxford Close West Leederville WA 6007
Builder	ASI In South Coogee, WA
Built	1982
Length (OA)	22.8 metres
Breadth (MLD)	7.42 metres
Depth (MLD)	3 metres
Draft (Max/Operating)	2.8 metres
Flag	Australia
Port Of Registry	Cairns
Call Sign	VM6829
Svc Category (Class)	3B
Operating Area	Seagoing fishing vessel for use in all operational areas up to and including offshore operations within a limit of 200 nm to seaward of the coast.
Crew Number	6
Gross Tonnage	170.44
Service Speed	10 knots

Capacities

Fuel	49,580 litres
Fresh water	12,500 litres
Brine	2 x 6250 litres
Bait	1.8 tonnes
Freezer/Hold	16 tonnes
Deck Area	Approx 75 m^2

Main Engines

Type	Single screw Inboard diesel
Manufacturer	Cummins
Model	KTA 19M
kW	448

Reduction Gearboxes

Type	Hydraulic reversing reduction marine gearboxes
Manufacturer	Twin Disc
Model	MG220S
Ratio	6:1
Propeller Shaft Dia.	125mm

Auxiliary Generators

	No.1	**No.2**
Prime Mover	Zenith/Isuzu	Cummins
Alternator	Meccalte	Magnaplus
kVA	100	175
Hours	<200, new	42,259

Appendix 5 – Industry-Wide Scenarios

Attached separately in XLS format.

Appendix 6 – Examples of Government Policy and Investment

The Kearney Energy Transition Institute reviewed how different countries implemented regulatory changes to promote biofuels and found very mixed results in terms of the maturity of each (see Figure 59). They looked at the policies required to not just affect demand for alternative fuels, but also ones that supported the supply of them.[187]

Policy examples split by legislation category and assessment

	Waste management regulations	Decarbonization targets and blending mandates	Land use and planning regulations	Fiscal incentives/ government subsidies	Other sustainability policies
Lagging	India – In 2016, the Solid Waste Management Rules (SWM) replaced the Municipal Solid Wastes Rules of 2000, which had never been implemented	US – Withdrawal of the Paris Agreement in 2017 (effective in 2019); no specific renewable energy target at federal level	Argentina – Minimum Standards for the Protection of Native Forests set up in 2007, but the law lacks enforcement	Japan – No substantial tax incentive for biodiesel, which is subject to the same diesel tax as on-road diesel	Mexico – Regulatory issues and lack of an established supply chain prevented the country from fully establishing its "clean-fuel" strategy
Emerging	Russia – Set up of a Russian Ecological Operator by the State in January 2019 to ensure sound regulation of household waste is in practice, build adequate infrastructure for waste management, and raise awareness among consumers and producers	Canada – Intent accounted in December 2016 to develop Clean Fuel Standard to achieve 30 million tons of annual reductions in GHG emissions by 2030	India – Aim to create an additional carbon sink of 2.5 to 3 billion tons of CO_2 equivalent through additional forest and tree cover by 2030 (NDC to the UNFCCC)	Mexico – Clean Energy Certificates (CELs) scheme where energy producers must acquire a given amount of certificates by producing clean energy	US – Currently, 23 states and the District of Columbia (out of 51) have implemented statewide GHG targets
Advanced	UK – Waste Framework Directive requiring the United Kingdom to recycle at least 50% of household waste by 2020 and 65% by 2035	France – The Law on Energy and Climate sets climate emergency and the objective of carbon neutrality by 2050 in the law	Indonesia – Temporary moratorium (made permanent in 2019) on granting permits to clear primary forests and peatlands for plantations or logging	US – Set of federal tax incentives or credits for renewable energy projects (Production Tax Credit, Investment Tax Credit, Residential Energy Credit, Modified Accelerated Cost-Recovery System)	Germany – National Sustainability Strategy, which was adopted in 2002, sets out quantified goals for 21 key areas related to sustainable development

Source: Kearney Transition Institute

Figure 59: Regulatory framework maturity is country-specific and depends on government environmental targets. Source: Kearney Transition Institute

California, USA

The USA's State of California has long been a leader in addressing climate change and technology development. With a population of 39 million and a Gross State Product (GSP) of US$3.3 trillion its nominal GDP is the fifth largest in the world.

The California Air Resources Board (CARB) "is charged with protecting the public from the harmful effects of air pollution and developing programs and actions to fight climate change."[188] Since the Global Warming Solutions Act of 2006 was passed it has been creating regulatory and market mechanisms to reduce GHG emissions in economical ways. In 2022 amendments were made to "the Commercial Harbor Craft (CHC) Regulation require the use of at least 99 percent Renewable Diesel ("R100" or "R99")".[189] From the 1st of January 2023 this has been made compulsory for all commercial harbor craft, including all commercial fishing vessels.

[187] 'Biomass to Energy Handbook', Kearney Energy Transition Institute, 2020
[188] https://ww2.arb.ca.gov/about
[189] https://ww2.arb.ca.gov/resources/fact-sheets/chc-factsheet-renewable-diesel-r100-or-r99

Renewable diesel will help reduce net GHG emissions, but CARB has additional measures to encourage vessel operators to start using zero emission propulsion and auxiliary power systems. These Zero Emission and Advanced technology (ZEAT) credits allow that operator to delay compliance of one other vessel in their fleet by a number of years. If the operator does not want to use ZEAT credits, they can instead submit that vessel as part of an Alternative Control of Emissions (ACE) plan that can give them compliance under the rules.

Interestingly, the regular reporting that CARB has done on the Commercial Harbor Craft (CHC) emissions inventory shows how old many of the commercial fishing main and auxiliary engines are (see Figure 60). Whilst the vessels can be very old (30-40 years) the main and auxiliary engines are mostly under 20 years old.

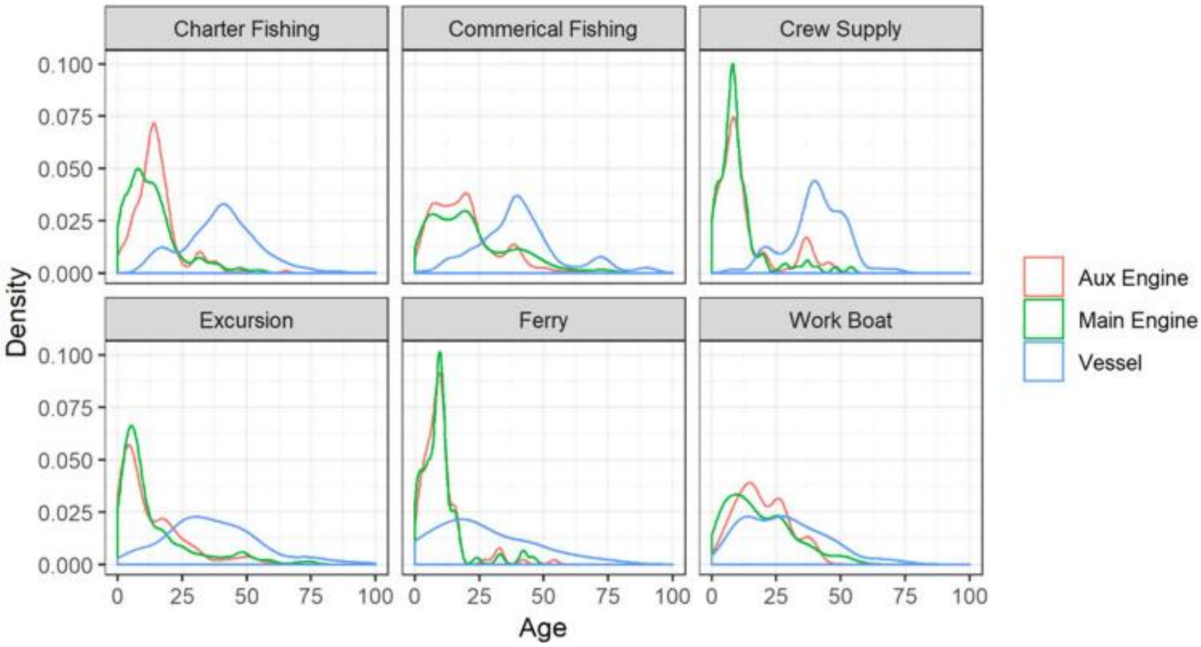

Figure 60: CARB Reporting Data on Vessel, Main Engine and Auxiliary Engine Ages. Source: CARB CHC Emissions Inventory 2021

The CARB plan is to implement renewable diesel in all vessels from 2023 onwards, but to stage the mandatory upgrade of Tier 1 (or pre-Tier) engines to at least Tier 2 from 2030 onwards. Tiers have been used by the USA as a way of specifying what the next level of engine design should live up to and specify dates when they should be introduced. By mandating migration away from Tier 1 CARB is ensuring their CHC implement cleaner and newer engines, but in a slow and measured way.

USA (Outside California)

Public funding for climate resilience and energy transition projects became a top priority in federal spending packages such as the 2021 Bipartisan Infrastructure Act and the 2022 Inflation Reduction Act.

The Inflation Reduction Act authorises USD $391 billion (total) towards climate action investments, USD $270 billion of which are embedded in the US federal tax code. As part of the overall $158 billion investment into clean energy, it invests $20 billion in climate-smart agriculture, and $13 billion in electric vehicle incentives.

The Inflation Reduction Act also amended the Clean Air Act to create a new program: the Greenhouse Gas Reduction Fund (GGRF). The program provides competitive grants to mobilise financing and leverage private capital for clean energy and climate projects that reduce greenhouse gas emissions. The GGRF lends to businesses and households across America through “green banks,” or mission-driven institutions that leverage public and private capital to accelerate the transition to clean energy.

The Greenhouse Gas Reduction Fund provides $27 billion to the US Environmental Protection Agency (EPA), including:

1. Nearly $12 billion for competitive grants to eligible entities to provide financial and technical assistance to projects that reduce or avoid greenhouse gas emissions; and
2. A combined $15 billion for competitive grants towards low-income and disadvantaged communities to enable, deploy or benefit from zero-emission technologies – and- to provide financial and technical assistance to eligible entities for projects that reduce or avoid greenhouse gas emissions.

In June 2022, there was an announcement of the $2.6 billion investment into the National Oceanic and Atmospheric Administration (NOAA) relating to climate resilience initiatives. The funding is to be directed towards improving habitat restoration, coastal resilience, and weather forecasting infrastructure to make communities more resilient in the face of climate change.

A few months after the NOAA investment announcement, in November of 2022, over 190 U.S. fishing businesses and organizations submitted a letter to NOAA asking that $100 million of the $2.6 billion that the agency received in the Inflation Reduction Act for expenses related to “coastal communities and climate resilience” be used to “support and/or finance clean energy opportunities for the nation’s small-boat fishing fleet, including vessel retrofits and electric conversions, pilot projects demonstrating new technologies and outreach and education.”[190]

Then in December 2022, commercial fishing associations from New England, the West Coast, and Alaska asked the US Environmental Protection Agency (EPA) to include vessel emissions reduction innovations as an eligible investment in the Greenhouse Gas Reduction Fund (GGRF)[191].

The letter stated: “To support practical, cost-effective, and voluntary emissions reductions within the fishing industry,” the letter stated. “We recommend the streamlining of existing federal programs as well as the establishment of new and diverse dedicated funding streams to support bottom-up planning and innovation.”

The letter continued: “Funding for energy efficiency and conservation, alternative fuels technology development, and engine upgrades can fill a niche gap and increase industry resilience not only by reducing vessel emissions but also by achieving cost savings, safety improvements and fleet modernization,”

On the heels of these calls for policy action, the Pacific Coast Federation of Fishermen’s Associations (PCFFA) is sponsoring a series of fishermen interviews to better understand the immediate and long-term needs of the fleet and inform detailed policy recommendations to make fuel efficiency and alternative fuels innovations cost-effective and deployable at scale[192].

Norway

Norway has also been a world leader in addressing climate change and reducing GHG emissions. Their 2030 target is a 55% net GHG emissions reduction compared to 1990 levels. Norway introduced one of the

[190] https://static1.squarespace.com/static/61f078e62a3a280fae160061/t/638f5021ef504a5cd87848be/1670336546171/Commercial+Fisheries+GHGRF+Comment+Letter+EPA-HQ-OA-2022-0859.pdf
[191] https://www.fisheryfriendlyclimateaction.org/statements
[192] https://fishermensnews.com/article/an-energy-revolution-in-the-commercial-fishing-fleet/

world's first CO_2 taxes on fuels in 1991 and has one of the highest carbon tax rates in the OECD[193]. Certain sectors like commercial fishing have been granted protection from the economic effects of this, and vessel operators can request refunds on the carbon tax for fuel used to fish in fisheries less than 250 nautical miles from the coast[194]. The government was considering abolishing this if the industry does not show success in reducing emissions on their own.

The average age of fishing vessels in Norway is estimated as 25 years (smaller ones are older). Enova SF is a Norwegian government entity that funds changes to reduce GHG emissions and adopt new technology for many fishers. Norway has a large and technologically advanced shipbuilding capability that is increasingly building advanced new fishing vessels. Battery-hybrid has been the main development pathway for fishing vessels, with diesel used during steaming operations and batteries used while fishing, however very few vessels exist that function this way at present. Other ways they are looking to improve the efficiency of these vessels is through heat transfer (lowering boiler needs), and electrification of fishing gear.

One way the Norwegian government is helping fishers to commission new vessel builds is by providing assistance and/or incentives to finance new vessel builds at local shipyards. This has resulted in their local boatbuilders taking on much more work for fishing vessels than they did previously when they specialised in building offshore support vessels for the offshore wind, oil and gas industries.

Global Carbon Pricing

There are currently over 40 countries that have some sort of carbon price, which equates a dollar amount per ton of CO_2e. The policies can be split into Carbon Tax, and Cap & Trade.

Carbon Tax 101

A carbon tax is a tax that is levied on carbon and is a form of carbon pricing. It is a proven policy to reduce greenhouse gas emissions.

The carbon tax sets the level of demand and supply at the social optimum and avoids an externality if set on the right price.

Prices lower than the actual social cost of carbon still lead to an undesirable level of pollution but will still help to reduce emissions.

Cap & Trade 101

This is a form of emissions trading that limits emissions and puts a price on them.

CAP: - This element places a 'limit' on the amount of GHG emissions. Subsequently, it is projected to become stricter over time.

TRADE: - This element is a market for companies to buy and sell allowances that let them emit only a certain amount, as supply and demand set the price. Trading provides companies a strong incentive to save money by cutting emissions in the most cost-effective ways.

Governments set the cap across a given industry, or ideally the whole economy. It also decides the penalties for violations. Carbon dioxide and related pollutants that drive global warming are main targets of

[193] https://en.wikipedia.org/wiki/Carbon_tax
[194] 'The Government's action plan for green shipping', Norwegian Ministry of Climate and Environment, 2019

such caps. Other pollutants that contribute to air pollution can also be capped. Many countries around the world have set these up (see Figure 61).

The EU trading system is one of the most well-known cap and trade systems. The EU ETS exposed the weakness of such a market-based system, which is now being analysed and addressed. The economic crisis in 2008 meant there were reduced greenhouse gas emissions and so the EU ETS built up a surplus of allowances. This in turn led to lower carbon prices and created a weaker incentive to reduce emissions.

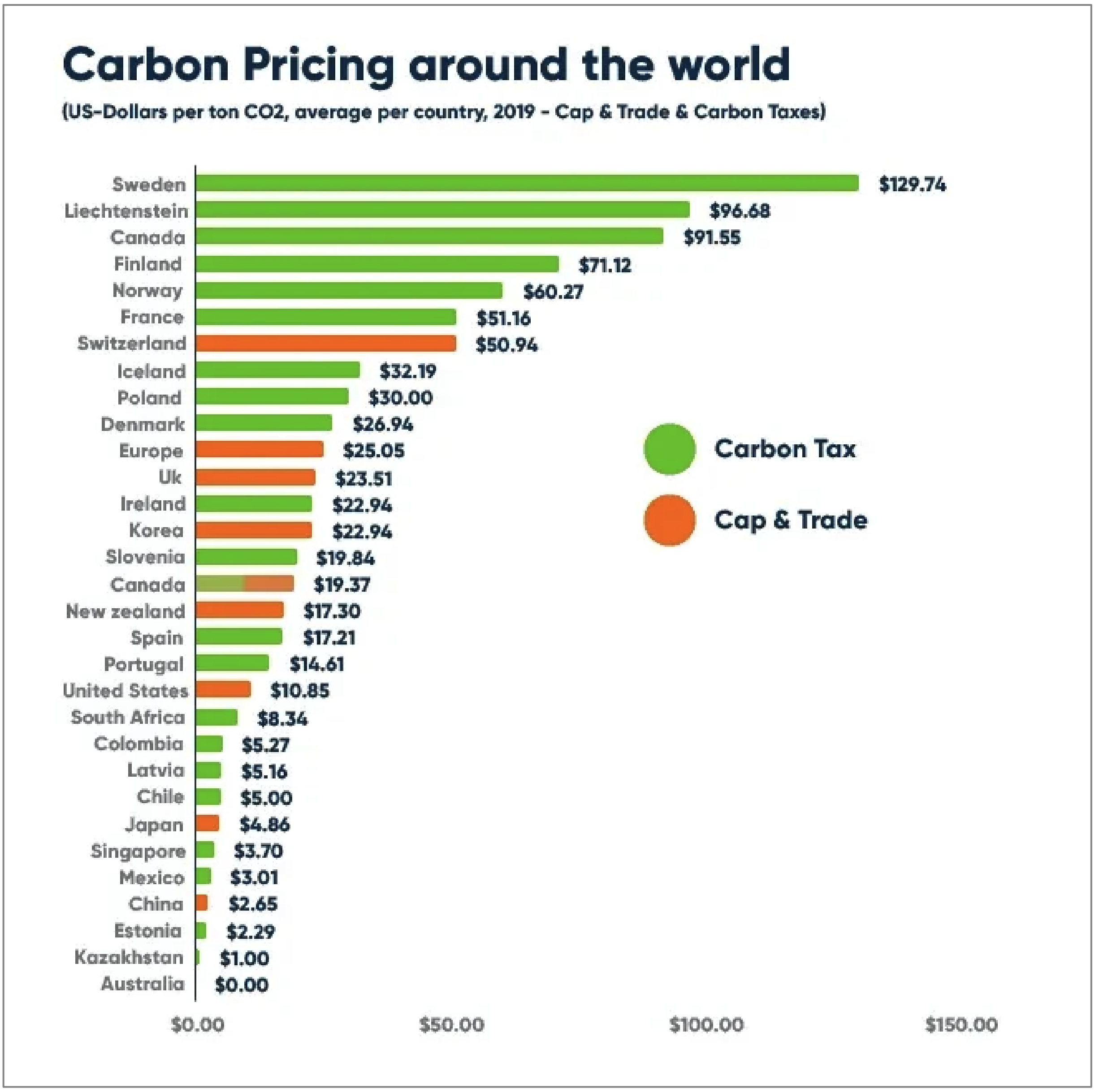

Figure 61: Carbon prices around the world. Source: ecochain.com.

Appendix 7 – Energy Carriers Summary

Attached separately in XLS format.