Fisheries Innovation & Sustainability

NET ZERO VESSELS CONCEPT DESIGN PROJECT

Stage 1

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FISHERIES INNOVATION & SUSTAINABILITY

CONCEPT DESIGN PROJECT

STAGE 1

BY	D BOAG
DATE	30/01/2023
VERSION	Final 3

ISO 9001:2015 REVISION PAGE

VERSION	DATE	COMMENTS
Draft 1	30/11/2022	.pdf version sent to FIS, FIS industry representative, Exeter University representative and MCA for comment
Draft 2	09/01/2023	.pdf version sent to FIS, FIS industry representative and Exeter University representative comment
Draft 3	13/01/2023	.pdf version sent to FIS
Final 1	19/01/2023	.pdf version sent to FIS
Final 2	19/01/2023	.pdf version sent to FIS
Final 3	30/01/2023	.pdf version sent to FIS for publication

Contents

OVERVIEW

In April 2022 Fisheries Innovation Scotland, now Fisheries Innovation & Sustainability, organised the 'vessels of the future' workshop in Glasgow, which was attended by stakeholders and industry leaders across the fishing industry. This workshop[1] identified the need for the 'creation of a roadmap' towards net-zero for the Scottish fishing sector, and highlighted that key areas of concern were the business case for change, and regulatory barriers.

This report will look at 3 existing parent vessels, analyse the fuelling/energy storage methods and power systems/drivetrains that could be used onboard to achieve net-zero. The analysis will identify TECHNICAL, FINANCIAL and REGULATORY issues with the various options. The aim of this is to identify the most plausible ways for the fleet to develop towards net-zero while indicating areas that need to be improved to allow this.

[1] Report_Vessels-of-the-Future-Workshop_Final.pdf (fiscot.org)

VESSEL DETAILS

Below is an outline specification of the parent vessels that we will be studying to see if a new vessel could be built which replicates the capabilities of the parent vessel utilising alternative fuels, power systems and drivetrains to achieve net-zero. For the purposes of the exercise the aim is to match the fishing gear, space requirements for gear, processing and hold, safety of arrangement and the load cycle of the parent vessels. Parameters which are open to modifications are length, beam, depth and tonnage.

Less than 10m creel boat

GRP displacement hull of 'cygnus GM32'[2] style with forward wheelhouse and open deck
Length Overall – 9.98m
Beam – 3.5m
Draft – 1.6m
Engine abt. 100Kw inboard
Fuel abt. 1200 Litres
Hydraulic pot hauler
Catch / pots stowed on deck

Operating cycle - 3-4 Hours operation (25% transit to grounds, 50% hauling and shooting pots, 25% transit to port).

Daily cycle is to target the same point of tide – typically 3-4 hours operating followed by 8 hours in harbour before next voyage. Refuelling typically takes place every 5-7 days.

[2] CYGNUS GM32 - Cygnus Marine

Approximately 15m Nephrops trawler

Based on ‘Antares BF27’
Designed by Macduff Ship Design, built at Buckie Shipyard in 2000.

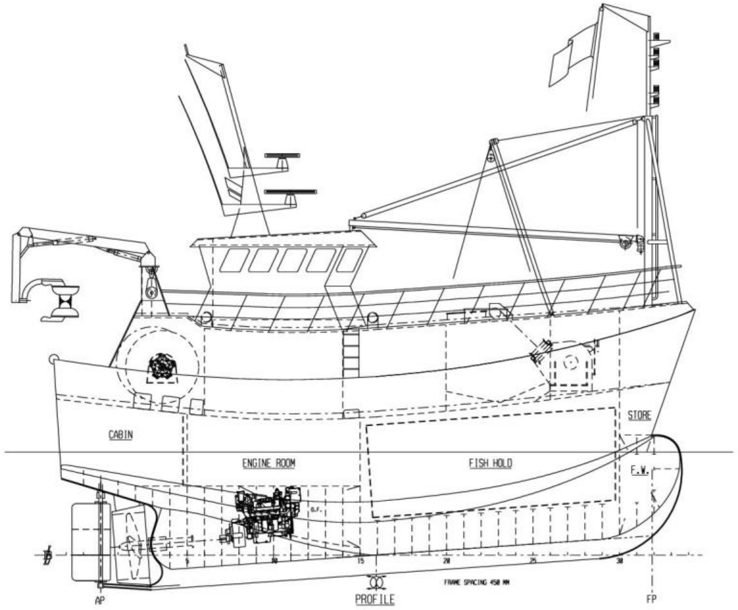
Length Overall		16.70 m
Length BP		14.35 m
Beam Moulded		6.40 m
Amidships Depth Moulded		3.60 m
Fuel Capacity	Abt.	9000 litres
Fresh Water Capacity	Abt.	1500 litres
Main Engine Power		350kW
Auxiliary Engine Power		120kW

Hold, processing and fishing gear/equipment spaces as per General Arrangement plan of vessel. Vessel cycle will assume shore factory ice and has a chilled hold.

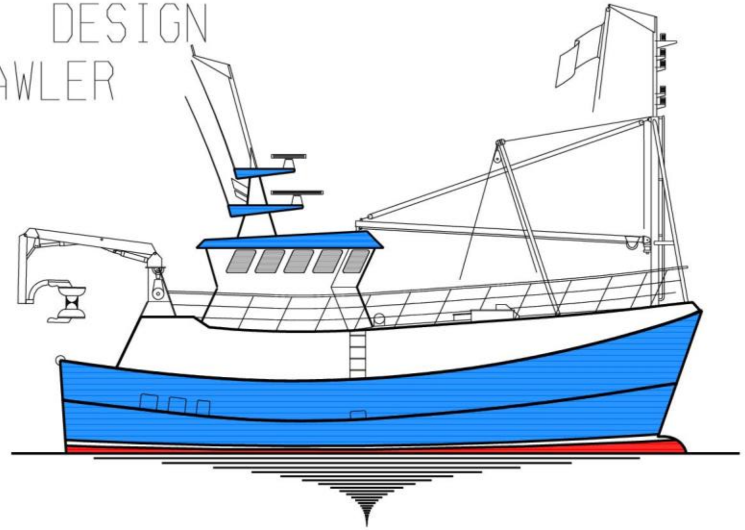
Operational cycle 1. ‘Short trips’ - 3-day trip. Assuming half a day steaming to grounds, 2 days at grounds towing and hauling and then a half day steam back to port. Vessel will spend as little time in port as needed to offload fish, refuel (if needed), fill water (if needed) and take on supplies before proceeding back to sea for another trip.

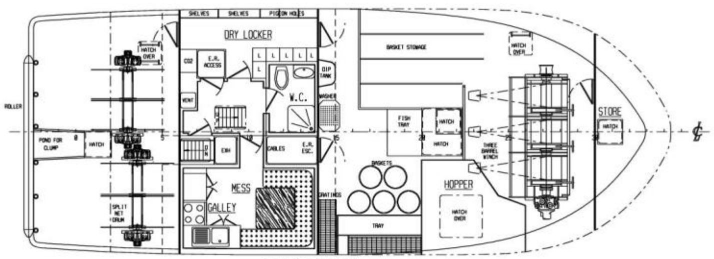
Operational cycle 2. ‘Long trips’ - 6-day trip. Assumes 1 day steaming to grounds followed by 4 days at grounds towing and hauling followed by 1 day steaming back to port. It is assumed that the vessel is not typically turned around for immediate departure when undertaking long trips.

MACDUFF SHIP DESIGN
16.7 M TRAWLER

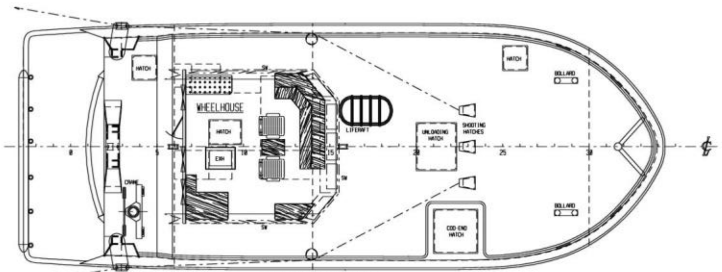


PROFILE

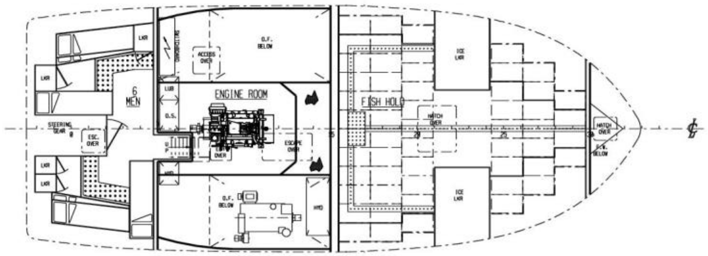




PLAN AT MAIN DECK



PLAN AT SHELTER DECK



PLAN BELOW MAIN DECK

PRINCIPAL DIMENSIONS

LENGTH OVERALL	16.70 M
LENGTH B.P.	14.35 M
BREADTH MLD.	6.40 M
DEPTH MLD.	3.60 M

OWNERS	MCA	LLOYDS	OTHERS	

TITLE:- 16.7 METRE TRAWLER GENERAL ARRANGEMENT

DATE :- 13/9/01

SCALE:- 1 : 50

DRAWN BY:- ALAN

REF:- 1007-0100

PLAN NO.:- 2

MACDUFF SHIP DESIGN LTD. 4 LAING STREET MACDUFF
ABERDEENSHIRE AB44 1RB
TEL 01261 833825 FAX 01261 833835

Less than 24m registered white fish trawler

Based on 'Vision V BF191'
Designed by Macduff Shipyards & Macduff Ship Design, Built at Macduff Shipyard in 2022.
Yard number 697

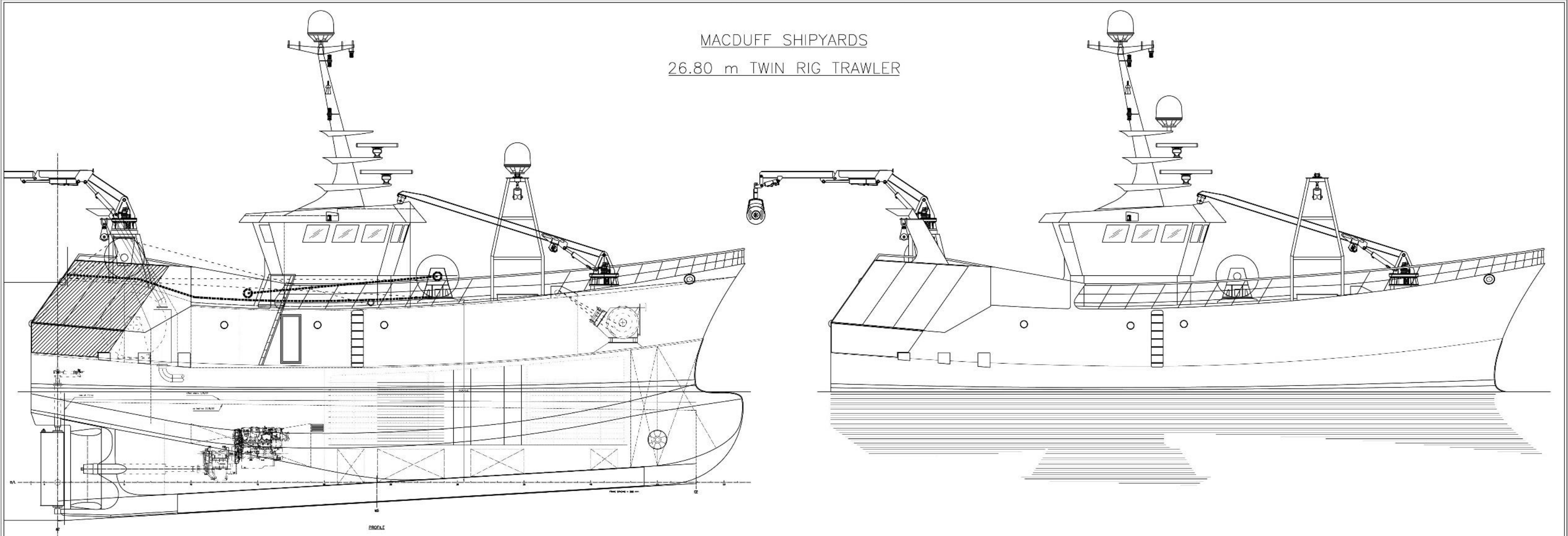
Length Overall		26.800 metres
Length BP (registered)		23.950 metres
Beam Moulded		8.000 metres
Depth moulded midships		4.305 metres to main deck
		6.500 metres to trawl deck
Fuel Capacity	abt.	30,000 Litres
FW Capacity	abt.	20,000 Litres
Main Engine Power		559kW
Auxiliary Engine Power		285kW for Hydraulics
		2x 100eKW electrical

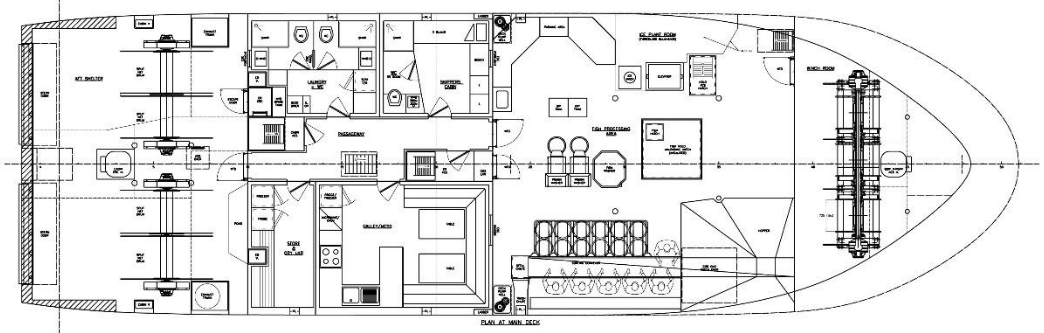
Hold, processing and fishing gear/equipment spaces as per General Arrangement plan of vessel. Vessel has ice plant, blast freezer and both freezer and chilled holds.

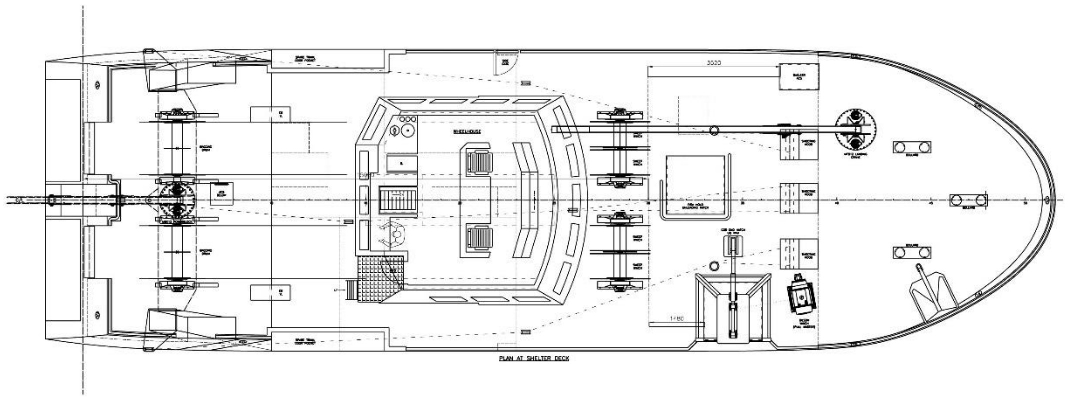
Operational cycle - Trips are assumed to be 8 days long comprising of 1 day steaming to grounds, 6 days towing and hauling at the grounds and a 1-day steam back to port.

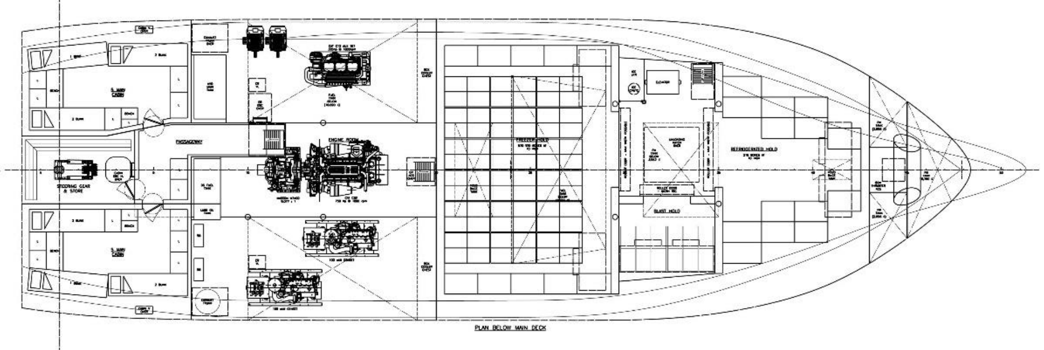
MACDUFF SHIPYARDS

26.80 m TWIN RIG TRAWLER









PRINCIPAL DIMENSIONS

LENGTH OVERALL	26.80 m
LENGTH BP/REG	23.95 m
BREADTH MLD.	8.00 m
DEPTH MLD.	4.20 m
FRAME SPACING	0.50 m
GT	tbc
FRESH WATER	20,494
OIL FUEL	30,374

REV	REVISION DESCRIPTION	BY	DATE
A	LAYOUT AS DISCUSSED WITH OWNER	MW	17.08.20
B	UPDATED TO REFLECT FINAL MODEL, 8.0 m BEAM	MW	16.09.20
C	OWNERS COMMENTS	MW	20.12.20
D	OWNERS COMMENTS, SHELTER DECK ARRANGEMENT FINALISED	MW	09.03.21
E	ER ESCAPE, HYD SPARE TANK WH AFT WINDOWS ARRANGEMENT UPDATED	MW	24.03.21
F	GALLEY DOOR AND WHEELHOUSE STAIR RE-ARRANGED	MW	07.07.21
G	GENERAL UPDATE	JBW	05.05.22

MACDUFF Shipyards

The Harbour
Macduff
Scotland
AB44 1QT
Tel: +44(0)1261832234

TITLE

MSY 697 – 26.50 m TRAWLER
GENERAL ARRANGEMENT

DRAWN BY	DATE	DRAWING NO	SHEETS	SCALE
MW	23.03.2020	697-MSY-001	1 OF 1	1:50, A0

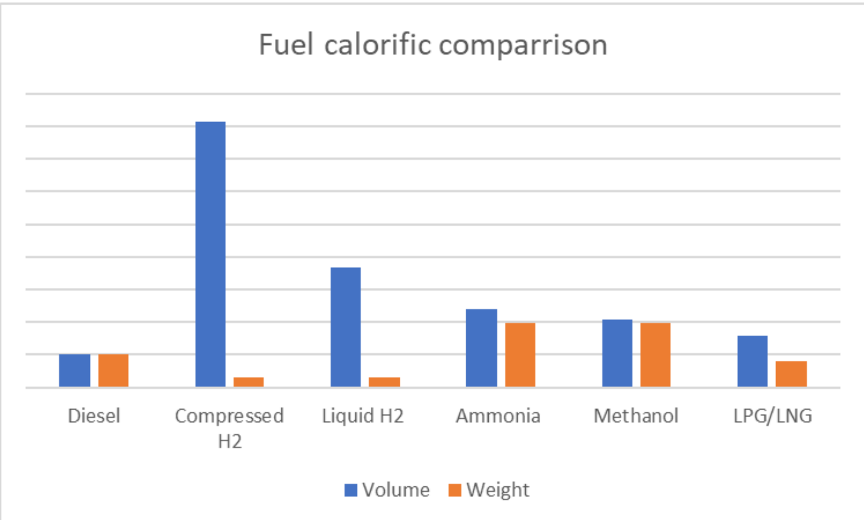
FUELS AND ENERGY STORAGE

Our aim is to identify all reasonable potential ways of carrying the required energy to achieve the operational cycle of the vessels. This energy may be stored as a fuel that will be burnt in an internal combustion engine (ICE), a fuel which can be converted to electricity by a fuel cell or as a battery. This review is only looking at options that can achieve or be close to achieving net-zero. These options will be assessed with specific respect to technical, financial and regulatory issues they may have.

All the options below require a large supply of net-zero electricity for use in the industrial processes to manufacture the fuel. If the electricity used is not from a net-zero source (i.e. fossil fuel power station) the emissions used in producing this must be considered when accounting the lifecycle of the fuel. None of the fuels mentioned in this report, with the exception of electricity to charge batteries, currently have an established industrial scale net-zero lifecycle[3].

Most of the options (except Hydrogen and Ammonia) which are burnt as a fuel in an ICE will produce Carbon Dioxide. To achieve net-zero these fuels need to have sequestered this carbon into the fuel from the atmosphere in their production. This means that the cycle from production to use does not add additional Carbon Dioxide to the environment – it has removed and replaced the same amount of Carbon Dioxide. For this reason, many see Hydrogen as the best option for the environment.

All of the alternative fuels noted below are more difficult to handle and operate than Diesel, due either to the challenges of storage where pressurised or cryogenic and the toxicity or corrosive nature of some of the fuels. It is clear that significant additional training will be required for those both installing and operating the fuel system and machinery.



Above chart of fuels makes comparison of volume and weight for a fuel to achieve equivalent calorific value. It does not take into account factors like tank weight, space to suit tank arrangement or differences in efficiency between internal combustion engines and fuel cells.

[3] that we are aware of at the time of publishing

Hydrogen (H_2)

Hydrogen has been used as a fuel source for a long time due to its high energy potential. However, there are concerns over its safety, due to its combustibility, and known difficulties storing it with space efficiency due to its low density.

Hydrogen has a specific energy (energy per mass) that greatly exceeds most competitor fuels (more than 3 times that of Diesel). Its incredibly low density (mass per volume) means that its energy density (energy per volume) is lower than its competitor fuels. Hydrogen is therefore stored in compressed form, liquid form or in a Liquid Organic Hydrogen Carrier (LOHC) to improve its energy density.

Hydrogen can be industrially produced in a number of ways, the most common of these currently is steam methane reforming. This utilises methane in its production and as the methane is typically from fossil fuel sources it is therefore not supplying a net-zero fuel source. Hydrogen production through electrolysis of water can be a net-zero source but only when all the electricity used in the production comes from a net-zero source. It was reported in 2020[4] that over 99% of Hydrogen produced globally was from fossil fuels. Currently the Orkney Islands have a leading facility demonstrating clean Hydrogen production[5]. In the EU the Power to X project will use the same philosophy as Orkney but on a much larger scale[6].

Hydrogen is typically associated with use in a fuel cell which produces electricity with no emissions. It is also capable of being used as a fuel in internal combustion engines with some manufacturers pursuing this. However, at this time no options are available at the power required for the vessels in this study. While there are a number of established fuel cell manufacturers there is currently only one option[7] with marine use type approval. However, we would expect this to rise in the coming years, with MAN supplier PME group advising they are likely to have a product on the market within 3 years, and a number of offerings from other suppliers expected in a similar timeframe.

When compared to the other fuels, with the exception of electricity to charge batteries, in this report net-zero Hydrogen is forecast to be the most affordable per unit of energy. Depending on trends in oil prices some forecasts suggest better affordability when compared to fossil fuel sourced Diesel significantly before the net-zero deadline.

Compressed Hydrogen

Hydrogen can be stored in compressed containers at between 200 and 700 bar of pressure. Piping and containers have to be of significant strength construction when compared to current Diesel infrastructure onboard where systems operate at 2-4 bar of pressure and the tank is under ambient pressure. While compressed Hydrogen retains its specific energy advantage over Diesel, the energy

[4] Green hydrogen is gaining traction, but it must overcome big hurdles (cnbc.com)
[5] Hydrogen – Orkney Renewable Energy Forum (OREF)
[6] Germany, Denmark, Netherlands and Belgium sign €135 billion offshore wind pact – EURACTIV.com
[7] Ballard - The World's First Type Approved Fuel Cell Engine Powering the Next Generation of Zero-Emission Vessels - Hydrogen Central (hydrogen-central.com)

density would mean 8-14 times the volume for the same level of energy potential as Diesel. The weight of tankage can also be notable for compressed Hydrogen with 400kg of compressed Hydrogen using 37 tonnes of tank on Hydrotug[8]. We understand there is not currently an international standard on fittings for refuelling compressed Hydrogen and no agreed pressure that fuel suppliers will have. Building a boat without knowledge of this could lead to issues should the local fuel suppliers select a different pressure or fitting to that on the vessel.

Liquid Hydrogen

Hydrogen can be cooled to a liquid state at -253 degrees centigrade. It needs to be maintained at this temperature to remain as a liquid. This requires what is known as a cryogenic plant. As a liquid both the density and energy density are higher than when compressed but still needing around 4 times the volume for the same level of energy potential as Diesel.

Currently the cryogenic systems tend to be large heavy and expensive. The supply tends to be higher priced than compressed Hydrogen due to the energy needed during chilling to liquid state and storage of the fuel. The aviation sector has a clear preference for liquid Hydrogen[9] and are already working on improvements in both storage and handling. It is distinctly possible that these developments may be suitable for the marine industry to also utilise, potentially making this solution significantly more viable than with current technology.

Liquid Organic Hydrogen Carriers

There are a number of organic compounds which are categorised as Liquid Organic Hydrogen Carriers (LOHC) which are capable of absorbing and releasing Hydrogen and can therefore be used as a storage method for Hydrogen. The biggest benefit of this method is that the Hydrogen can be carried at ambient pressure and room temperature safely. We understand that this is an area of study currently, specifically for application to use onboard ships. This method has an energy density somewhere between liquid and compressed versions of Hydrogen, needing around 6 times the volume for the same level of energy potential as Diesel – although this will vary depending on the compound used.

Other Hydrogen Carriers

Hydrogen is a key building block in a number of different compounds like Ammonia or Methanol[10]. There is an option that these compounds could be carried onboard and then broken down to their component elements and the hydrogen be used directly.

Ammonia (NH3)

The main concerns and challenges with Ammonia are around safety with the toxic, corrosive and flammable nature of the fuel[11]. Care must be taken in the arrangement and construction of tanks and piping design to ensure this system is safe for operation.

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[8] 2_Alternative_fuels.pdf (dvzpv6x5302g1.cloudfront.net)
[9] FlyZero - Aerospace Technology Institute (ati.org.uk)
[10] Breakthrough In The Reconversion Of Methanol Into Hydrogen For Fuel Cells - FuelCellsWorks
[11] What does an ammonia-ready vessel look like? (wartsila.com)

Ammonia is a gas at ambient pressure and room temperature. It needs to be compressed (10bar) or chilled cryogenically (-33 degrees centigrade) to become liquid and efficiently stored – this pressure or temperature is possible with current technology, resulting in a relatively simple and light solution. We understand the compressed option is largely preferred on all but large LNG carriers. As the fuel is corrosive additional care in tank construction is needed. It has good specific energy and energy density, needing about 2.4 times the volume for the same level of energy potential as Diesel.

Ammonia is an inorganic compound of Nitrogen and Hydrogen. This means there is no Carbon in the fuel and therefore is vastly better than its Hydrocarbon counterparts when CO2 emissions are considered – one of the key factors in achieving net-zero. Ammonia can either be burnt in an internal combustion engine, used directly to power a fuel cell, or be broken down to Hydrogen to power a fuel cell[12]. In this report we have focused on its use in internal combustion engines.

There is a known issue with ignition of Ammonia in engines. Typically, this is overcome using it as a dual fuel option with Diesel to help the ignition. This may make Ammonia less suited to the high-speed engines utilised on the vessels in this report, with some experts suggesting it would not be suitable for the engine powers we are considering in this report.

Ammonia can be produced using Hydrogen and Nitrogen. This can even be done electrochemically where the Hydrogen is input in the form of water, making this potentially a single step process[13]. It is also possible to produce net-zero Ammonia from bio-processes on farm or city waste.

LNG ($CH4 + C_2H_6$)

We are considering LPG (Liquified Petroleum Gas) and LNG (Liquified Natural Gas) together in this analysis, although mainly focussing on LNG as at this time it seems most likely to be produced from net-zero sources. At this stage both are sourced from fossil fuels, although Fossil Fuel LNG is seen as a good stepping stone for many industries as it is the cleanest burning Hydrocarbon[14]. It is possible to synthetically create net-zero LNG from net-zero Hydrogen and Carbon captured from the atmosphere[15][16] or capture net-zero methane given off by food wate or sewage[17].

The main concerns and challenges with LPG/LNG are around safety given the explosivity[18] of the fuel and storage[19], as at ambient temperature and pressure LNG and LPG are gas.

LPG/LNG are mature fuels in the world of shipping and used for many years on a number of large vessels. As this fuel type is a gas at atmospheric pressure / room temperature, it either needs pressurised containers and piping or a cryogenic system to chill this to the point it remains a liquid. For LNG we understand this must be a cryogenic system, which needs to maintain -162 degrees

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[12] Frontiers | Ammonia as a Suitable Fuel for Fuel Cells (frontiersin.org)
[13] Green ammonia electrolysis breakthrough could finally kill Haber-Bosch (newatlas.com)
[14] Liquefied natural gas (LNG) | Shell Global
[15] Synthetic methane could smooth the path to net zero (nature.com)
[16] Synthetic methane: Teréga develops methanation (terega.fr)
[17] Food waste to provide green gas for carbon-conscious consumers | Energy | The Guardian
[18] LNG tanker explosion would be as powerful as 50 atomic bombs – engineer - The Malta Independent
[19] PowerPoint Presentation (onthemosway.eu)

Centigrade, which is significantly simpler system than the -253 degrees Centigrade needed for liquid Hydrogen but still significantly more complicated than solutions which a liquid at room temperature.

LNG has good specific energy and energy density, needing about 1.6 times the volume for the same level of energy potential as Diesel. This is the closest to Diesel of all the fuels in this report, but comes with the caveat of a more complex tank system, which will use more hull volume than Methanol or Ammonia need, reducing its relative advantage over these fuels.

Methanol (CH_3OH)

The main concerns and challenges with Methanol are around safety with the toxic and flammable nature of the fuel. Specific concerns on the toxicity of vapours and safe venting of these must be addressed in the design of the vessel.

Methanol is a liquid at ambient pressure and room temperature which makes tank construction simpler. It has good specific energy and energy density, needing just over two times the volume for the same level of energy potential as Diesel, the closest to Diesel of the fuels in this report with the exception of LNG which needs complex cryogenic system for storage.

Methanol at this time is predominantly produced, at the industrial scale, through steam reformation of Natural Gas[20]. As above, Natural Gas is predominantly from fossil fuel sources at this time therefore this method of production is not suitable for net-zero unless the input gas becomes net-zero. Methanol can be produced through a conversion process which utilises Carbon Dioxide captured from the environment and Hydrogen[21] (for net-zero fuel this has to be net-zero Hydrogen as noted above).

Methanol is a popular choice for large shipping when looking at future fuels with Maersk shipping[22] amongst others investing heavily here.

Battery

The main concerns and challenges with use of batteries for energy storage is the safety risk associated with thermal run away and their low energy density. Batteries achieve net-zero by being charged from a net-zero electricity source.

Battery technology has improved in recent years, especially due to increasing use in the automobile sector as hybrid and full electric cars increase their market share. The batteries used in marine propulsion are typically Lithium (Lithium-Iron-Phosphate) – the same as the newer generation of electric automobiles - which while similar to the Lithium (Nickel-Cobalt-Aluminium / Nickel-Cobalt-Manganese) batteries utilised in the first generation of electric automobiles, have small differences in chemistry that help to significantly reduce the likelihood of Lithium Iron Phosphate batteries

[20] How Methanol is Made | Methanex Corporation
[21] The Revolution of Green Methanol (thyssenkrupp.com)
[22] A.P. Moller - Maersk joins Methanol Institute | Maersk

creating a thermal runaway incident in the case of a failure or unacceptable temperature rise[23]. This added safety is however at the cost of energy density.

Batteries have by a significant margin the lowest energy density and specific energy of the options we are reviewing in this report. These are sized at 30-50 times the volume and weight when compared to Diesel fuel currently fitted. This makes it very difficult to consider batteries as a stand-alone solution for any vessel unless their operation is short and allows sufficient time for recharging.

One of the biggest advantages for batteries is that they have a much wider range of efficient power draws and react significantly quicker to changes in power demand than any of the other options in this report. This makes them a good addition in a hybrid system where they can greatly increase the efficiency of the system by covering the peaks and troughs in power demand, keeping the other power source in its most efficient operating range – a method termed 'peak lopping' or 'peak shaving'.

Another notable issue with batteries is their useful lifespan and degradation of their charge capacity over this life. This means that an oversized battery is typically fitted to the vessel to ensure that over its lifespan it retains enough potential to undertake the intended operation. As noted, battery technology is an area that is currently seeing vast investment, research and development which should lead to improvements in lifespan and a reduction in degradation, however at this time when compared to fuel tanks and engines the batteries will need replaced sooner. It would be reasonable to expect 3-7 replacements of batteries in the expected lifetime of a Diesel engine. Batteries need virtually no maintenance throughout their working life.

Diesel (combination of Hydrocarbons)

Diesel is the current fuel powering for all of the parents we are reviewing in this report. Diesel currently used is a fossil fuel and as such cannot achieve net-zero. Diesel and other Hydrocarbon fossil fuels are at the base of climate change. Their discontinued use has been identified by every international body as a prerequisite for tackling climate change. Net-zero targets are now enshrined in law in Scotland and the UK and therefore continued use of fossil fuel sourced Diesel or gasoline has very limited lifetime.

Professor Christopher Smith from the Centre for Future Clean Mobility at Exeter University warns, "The end of meaningful supply of, and affordable price for Diesel, may be far closer than many people think, since it is driven overwhelmingly by demand from Diesel road cars. Figures from SMMT[24] for end of year 2022 show Diesel car sales now at around 5%, with electric cars above 50%. Today demand for Diesel for road cars massively outweighs all other buyers. In 4-5 years' time this will have dwindled to much less than half, probably towards 30% of today's demand. Does anyone imagine this will have no effect on diesel fuel price and availability?"[25]

There are several alternative fuels which fall into the category of 'Diesel', that would largely be drop-in replacements for fossil fuel Diesel which can be produced in a manner to achieve net-zero. These

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[23] Why LiFePO4 battery is more safe than ternary Lithium battery? | ELB (ecoLithiumbattery.com)
[24] UK new car registration data, UK car market - SMMT
[25] Prof C Smith, Exeter University (personal communication, 19th December 2022)

are grouped as those that meet EN 15940 specification, and typically (although this should be confirmed on a case-by-case basis) are accepted by engine manufacturers as suitable fuel for use in their Diesel engines. Storage and lifespan of the fuels should be confirmed with the fuel and engine supplier. Both HVO[26][27] and Bio-Diesel[28] are commercially available currently although there is a premium cost associated with their supply.

Bio-Diesel

Bio-Diesel is produced from plant or animal oils. Those that meet a certain specification can be used as a drop-in replacement for fossil fuel Diesel with little noticeable effect on engine efficiency or performance. This fuel comes from renewable sources[29] and is therefore considered net-zero.

Bio-Diesel is a contentious fuel though with critics citing environmental and ethical issues. It competes for space with food production and as it is most efficiently produced from palm-oil[30], which is a known cause of deforestation[31]. It also requires a large area of land to produce and we would understand that it would be impossible to match current Diesel use as there is not enough land available.

Hydrogenated Vegetable Oil (HVO)

HVO is a Diesel equivalent fuel made by hydrogenation of vegetable oil. To be net-zero the Hydrogen used should be from a net-zero source. Like bio-Diesel there is an ethical question over the use of a food resource for fuel, and that there isn't enough land available to match current fuel use.

Synthetic Diesel

Net-Zero Diesel can be manufactured from net-zero Methanol using the Fischer-Tropsch process[32]. At this stage we do not understand that this is undertaken on an industrial level. While the possibility may give hope that Diesel could continue to be used as a long-term fuel source, there is significant energy demands to this. Energy is used to make Hydrogen, which then needs more energy to be used to make Methanol, which then needs yet more energy to be used to make this into Diesel. This may ultimately make synthetic Diesel un-economic to produce. Other industry sectors – both maritime and more extensively, that utilise fossil fuel derived fuels are clearly seems to be moving to alternatives like battery, LNG, Methanol and Hydrogen, which while they are less efficiently stored, they burn or are utilised in a much cleaner manner and are easier to produce from net-zero energy.

A similar process to this is being developed by a consortium led by Porsche[33] to produce gasoline, with their Haru Oni plant, located in Chile, which came into operation at the end of 2022[34].

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[26] HVO Fuel FAQ - Your Questions Answered | Crown Oil
[27] About - HVO Fuel UK
[28] BioDiesel Suppliers - 24/7 Nationwide Deliveries | Crown Oil
[29] BioDiesel (fueleconomy.gov)
[30] What's the most energy-efficient crop source for ethanol? | Grist
[31] Palm Oil Deforestation: An Intro - Commodity Trading Guru
[32] Fischer-Tropsch Process - an overview | ScienceDirect Topics
[33] eFuels (porsche.com)
[34] Porsche pumps first synthetic fuel as Chilean plant finally starts producing | TechCrunch

Other Options

There are a number of other options that have been investigated in the wider marine sector such as nuclear, wind, and solar, however we believe these are simply not feasible as the primary power option at this time on fishing vessels of the size discussed in this report. It should be noted that the alternative fuel and powering options is an expanding sector and therefore it is prudent to review all new ideas on an ongoing basis but be aware that many of these will be unsuitable for the challenges presented by small vessels and fishing operations.

Fuel cost and availability

The world, UK and Scottish fuel market for both Diesel and the above-mentioned alternative fuels is at this time volatile. In the last year there have been significant increases in Diesel price. Looking into the future, the automobile market – the primary Diesel users in the UK – are starting to move away from Diesel to other options and it is unclear how the price of Diesel will trend as demand and production reduce in the coming years. As per Professor Christopher Smith's warning (see Diesel section above) there is a real possibility that Diesel prices could increase significantly, and there could be significant difficulties with supply, before the net-zero deadline arrives, as other industries move away from this fuel.

The alternative fuels mentioned are also not typically available in large quantities in the UK currently, as demand is low for these alternative fuels which are seen as specialist items with high cost. It is reasonable to assume that, in general, as demand increases, production will follow, potentially bringing these to mainstream supply and reducing the cost. The notable exceptions to this are Bio-Diesel and HVO which due to the land requirements for production are unlikely to be scaled up to the level required to make their cost competitive with the alternatives.

When considering net-zero, it is expected that electricity (to charge batteries) and Hydrogen will be the cheapest fuels. As Hydrogen is the chosen fuel for Aviation, and is a component in the process for making most of the other net-zero fuels it is reasonable to assume that there will large supply available. Ammonia, Methanol and LNG all require an additional processing after Hydrogen production which will increase their cost, and which of these will be most competitive is likely to be dependent on which has generated sufficient demand that their production benefits from the economies of scale. Synthetic Diesel, which requires additional industrial processes after Methanol production, along with Bio-Diesel and HVO are likely to be most expensive fuels.

The issue the fishing sector has is that it simply does not have the volume of fuel use required to drive this, and the market will be reliant on the usage of other sectors to drive the economies of scale and make costs manageable. This makes it very difficult to predict the most cost-effective fuel solution for the fishing sector as this will be reliant on wider transport, shipping, construction and agriculture sectors' solutions to the net-zero conundrum.

It is also important that port facilities for refuelling match the selected fuel choice of the industry across all ports. It would not be beneficial if, for example, Peterhead had only facility for Compressed Hydrogen, Fraserburgh for Methanol, Lerwick for Ammonia and Scrabster for fast recharge of batteries. This would make it difficult or impossible for vessels to operate further afield and could seriously hurt the re-sale cost of vessels. It is important to remember that fishing vessels are not the exclusive users of most ports and that ports will decide infrastructure to suit what they believe is needed. Pressure from other industries may lead this away from the best solution for fishing.

Availability of Alternate Fuel powered Internal Combustion Engines

We wrote to several engine suppliers to see what alternative fuel engines they have available and if they have any in development, specifically focussing on the power requirements of the parent designs.

	Fuel Type			
	Hydrogen	Ammonia	Methanol	LNG
CAT (Finning)	N	N	D	N
Yanmar	N	N	N	N
Cummins	no response at this time			
Volvo Penta	N	N	N	N
Scania	N	N	N	N
Baudouin	N	N	N	N
Mitisbishi	no response at this time			
Doosan	N	N	N	N
ABC	Y	N	Y	N
Rolls Royce/MTU	No engines in size range			
MAN (PME)	Y	N	D	N

Y	options available
D	in development
N	no option available or in development

As can be seen from the above table the responses were predominantly negative. It is possible that engines are under development at more of these manufacturers and the agent we spoke to is unaware or for commercial reasons unable to discuss these.

CAT dealer Finning were able to confirm that CAT are currently in development to offer their full line up of marine engines as Methanol[35]. At the moment there is no timeframe for this development and they were not able to advise when these may come to market. It is likely that the development will begin with the largest engines and work down towards the smaller engines over time.

ABC were able to confirm that they have an engine option that can be operated as dual-fuel[36] Diesel + Hydrogen/Methanol. Unfortunately, the lower power range of these is 749kW although they may be able to offer versions derated. Despite this, their offering would only be suitable for consideration for the main engine on the <24m whitefish vessel as it is too powerful for the other parent designs. ABC confirmed that due to the lower energy density of Hydrogen and Methanol, when these engines are running in dual fuel mode there will be a small drop in the power curve of the engine.

MAN dealer PME power systems group were able to confirm that as well as offering Diesel/electric hybrid solutions they also have a Hydrogen-Diesel dual fuel engine on the market. This will always run using Diesel to stabilise the combustion but could utilise up to 70% Hydrogen. At the moment this is available at 741kw, with 1066kw available soon and 290kw and more to fill the spaces in the

[35] Caterpillar Marine Invests in Methanol Engines | Cat | Caterpillar
[36] We power your future | Anglo Belgian Corporation (abc-engines.com)

pipeline. They are also developing Methanol engines, both as dual fuel with Diesel and stand alone. At the moment there is no timeframe for these coming to market and are likely to follow the order the Hydrogen versions have been developed.

While we have not had any information confirmed from Cummins, they are active in the alternative fuels market, having a Hydrogen fuel cell option on the market[37] (we understand not marine type approved at this time), and have recently announced development of 'fuel-agnostic' engines[38]. It is unclear at this stage if this development includes marine propulsion engines, and if not whether these would be: included in later expansion of the 'fuel agnostic' engine range, under separate development currently, or if there is no planned alternative fuel option for these.

There are aftermarket options with companies who will convert normal Diesel engines to run on Methanol[39] [40] or LNG. While this may be a workable solution in the short term or to prove a concept works, it does not offer the owner of a vessel as good an option. The warranties on the engine from manufacturer may be lost and sourcing spare parts could be more costly and challenging. There may also be issues surrounding regulation and the approval of these engines from the MCA which would need investigated should this option be utilised.

It should be noted that most larger engine manufacturers who focus on slow speed, medium speed, or two stroke engines with powers significantly higher than those considered in this report already have numerous alternative fuel options available. The difficulty is that few high speed, low power engine manufacturers have seen the need yet to develop products that operate on alternative fuels.

The lack of availability makes it challenging to assess the financial suitability of the options. The capital expenditure on an engine is a significant part of any project and lack of clear information on pricing makes it impossible to draw conclusions between the alternative fuels. It is clear that currently any options available will be at a premium cost when compared to Diesel equivalents.

With CAT focussing on Methanol as its preferred option, and ABC and MAN focussing on both Hydrogen and Methanol for marine engine development, this may drive the fishing industry towards the use of Methanol or Hydrogen over Ammonia or LNG. Hydrogen options are supplemented by availability and current development of Hydrogen fuel cells.

[37] Fuel Cell | Cummins Inc.

[38] Cummins unveils industry-first fuel-agnostic internal combustion powertrain solutions, helping fleets decarbonize today with low-carbon fuels | Cummins Inc.

[39] Engine work completed for Port of Antwerp-Bruges methanol-fuelled tug retrofit - Ship & Bunker (portnews.ru)

[40] Methanol Engine - The face of a green future (nordhavn.dk)

DRIVETRAIN OPTIONS

Mechanical Internal combustion drive

This setup of drivetrain couples an internal combustion engine to a gearbox, propeller shaft and propeller. It is one of the simplest ways of setting up a drive train and is what is utilised by almost the whole Scottish fishing fleet. It is a very mature technology, which is robust and relatively simple to maintain.

With developing technologies, it may be suitable to have a dual fuel engine in this set up. This does add some complexity to the system. This may be a good solution in the short term where a vessel could continue to run on Diesel while the alternative fuel source selected develops a reliable, competitively priced supply. In this scenario it would be best if fuel tanks were also dual fuel to minimise install space.

On vessels with propulsion power less that 750kW (approx. 1000 bhp) there is no requirement for a certified engineer to be onboard. Typically, at sea and routine alongside maintenance is done by a crew member who is well experienced in the machinery.

Electric drive

Electrical drive can either be by the propeller turned only by an electric motor, or by a hybrid system where an electric motor can add or remove power from an engine driven shaft. Electrical drive systems create benefits in efficiency over pure mechanical systems. Internal combustion engines are very inefficient when outside of their optimum rev and power range where the same is significantly less impactful on an electrical motor. Electrified drive means the power source, whether engines or fuel cells, can be run consistently in their most efficient range. Leaving the shorter-term peaks and troughs to be handled by batteries which are well suited to this. This improves efficiency both when considering very short time periods, where the vessel may be surging in waves creating instantaneous peaks and troughs in power or when considering the full cycle of operation where their vessel may have periods operating at powers outside optimum, for example when hauling nets or pots. This efficiency saving means less energy can be used for the same operation.

A number of the items in electric drive systems - batteries, high power switchboards, electric motors - are not items that fishing vessels owners or crew have experience of. While at the helm these will be simple to operate and will not significantly change the behaviour of the vessel, the maintenance side and working of the systems will be vastly different. It has been noted that electrical systems require significantly less maintenance than the ICE equivalent, with electrical cars needing approximately 50% of the maintenance that Diesel cars require. The issue is that if a failure occurs at sea, there is very little repair beyond a basic checklist – fuses, switches and breakers - that can be done to bring the system back online. Working on batteries, high voltage wiring or fuel cells is something that should only be undertaken in the safety of a harbour by suitably qualified and experienced technicians. It is likely some backup or redundancy will be needed on the first electrified vessels to mitigate the risks from failures on the electrical drive system, with the hope that this is never utilised and systems prove themselves sufficiently robust.

Maintenance and installation of these systems from shore side professionals is also different and more complex than for mechanical internal combustion drive vessels. Companies currently undertaking this work will either need to upskill their employees to become suitably qualified and experienced in these systems or hire new staff with a suitable level of experience and qualification. When driving the vessel, the control system will do the main decision making on where to draw power from, and for a skipper it will be very similar to operate to a mechanical drive vessel with a single control which controls the power delivered to the propeller. With a relatively small amount of training – as is needed with any new vessel and system - they should be able to drive and monitor the system effectively. Crew and skipper will need training on procedures for starting, shutting down and problem solving the system, but this will mainly be in the form of checklists and will be limited as maintenance or repair on most of the components of the system at sea is impossible. As noted above, the electrical systems in other industries have had less failures and need less maintenance than ICE alternatives. If this carries true in fishing, the crew should have more time available for their other duties onboard.

Additional efficiencies can be made on vessels with electrical power if they utilise systems like electrical winches which can generate energy for the vessel when shooting nets – an operation that typically requires power to be spent on hydraulics.

Fuel cell system

A fuel cell powered by Hydrogen or Ammonia produces electricity. This is normally supplemented by a battery which helps with peaks and troughs in power consumption, covering shortfall in supply or recharging when there is an oversupply, allowing the fuel cell to operate at its most efficient level. This electrical supply powers an electric motor connected to stern gear for propulsion. It also supplies the vessels' hotel and service loads.

Battery electric drive

A battery supplies electrical power to an electric motor which is connected to stern gear for propulsion. This battery may also supply power to both hotel and service loads of the vessel.

This is the simplest version of an electric drive vessel but due to the energy density of batteries is only suitable for certain trips with low energy use, typically short operations.

Internal combustion / Electrical hybrid

This system is utilising a battery, with or without a fuel cell to provide electrical power. This is used in conjunction with an ICE. There are then two main options:

Electric motor drive - the ICE can power a generator, and electric motor be used to provide drive power to the stern gear. The vessel system will utilise power options to keep the ICE generator and fuel cell if fitted in their most efficient range, with batteries removing excess power to charge themselves or adding additional power to the motor when needed.

Hybrid shaft - ICE can be connected to a gearbox/clutch/sandwich box which also PTI/PTO (power take in / power take out – motor can add power or take power from the system) electric motor input. This PTI/PTO can solely drive the shaft from electrical power, add power to the shaft to boost the ICE power delivered or remove ICE power from the shaft to charge the batteries.

Both ultimately aim to keep the ICE running at its most efficient rating and use the electric to help with peaks and troughs in usage.

All electric drive systems can greatly improve the efficiency of the drive system when compared to mechanical internal combustion drive but exact savings will be determined by the operating cycle of the vessel. Due to the increased complexity, upfront cost, additional weight and safety issues around high voltage systems, it is only worth employing these systems where it is certain that they will notably improve the efficiency of the system. It is possible that the upfront cost of the vessel could be significantly higher if an electric drive system is installed, but that through life cost, due to the lower fuel usage, will be significantly lower. This certainly will not be the case for all vessels and while it is possible to, with relative accuracy, compare fuel usage in either system, uncertainties on availability and price for both Diesel and alternative fuels make estimates on through life costs at the design stage vulnerable should forecasts used in these estimates not meet with reality.

Regulations

At this point in time the MCA regulations for fishing vessel construction are based on Diesel engines on a direct mechanical drive, with no allowance or regulation specifically for either using alternative fuels or electric propulsion. It was clear from discussion with the MCA future technology and fishing vessel safety teams that they want to see and assist the industry in its progress towards net-zero but are not willing to compromise on the safety of vessels.

To incorporate alternative fuels or electric propulsion into a vessel design, a 'one-off' approval process is needed, typically by the use of MCA notice MGN664[41] 'certification process for vessels using innovative technology'. The basis of this is established through clear and early communication with the MCA. Any areas where the existing MCA regulations do not have a regulation will be identified and a path for approval of these items will be agreed. The MCA will work with the designer and yard to produce a risk register highlighting the areas that are not covered by existing MCA regulation, identify what the risks are and mitigate against these.

The best mitigation is use of 'equivalence' where the designer/yard propose an acceptable set of rules be they class society, IMO or other flag state rules. These are assessed by the MCA team to ensure all parties are satisfied that they suitably mitigate the risks of the item and are then agreed. Its important to understand during this process that not all rules are made with the level of safety required by the MCA and that in these cases the MCA may add additions to selected rules to bring them up to the safety standard required.

Where the technology is very novel it may be addressed on an exemption basis where all the risks are assessed and mitigation measures built into the design to reduce the risk to the accepted safety standard. This is likely to be more difficult to achieve and as class rules now exist or are in the process of being compiled to cover all the fuels and setups in this report it is thought equivalence is an easier direction to take for approval.

It is understood that the additional time spent by the MCA and designer on this 'one off' approval process will likely make a notable increase in the cost of the project. Further to this the output of this approval may enforce significant additional spending on safety systems onboard.

Professor Christopher Smith from the Centre for Future Clean Mobility at Exeter University advises[42] that the use of MGN664 for alternative fuel vessels, especially Hydrogen projects, has been very challenging, somewhat due to the current lack of evidence base from which the MCA can assess safety. For this reason, they are working on a project funded by the regulators pioneer fund, named 'Maritime Regulatory Innovation Framework (MRIF) - Developing regulatory frameworks to support maritime innovation'[43] alongside project lead Plymouth County Council which aims to create a regulation framework for prototype vessels for research and development. The intention for this is to help get first in class vessels through approval more smoothly and then use the evidence base from their operation to assist in future vessels approval via MGN664.

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[41] MGN 664 (M+F) Certification process for vessels using innovative technology - GOV.UK (www.gov.uk)
[42] Prof C Smith, Exeter University (personal communication, 19th December 2022)
[43] Projects selected for the Regulators' Pioneer Fund (2022) - GOV.UK (www.gov.uk)

Currently machinery on fishing vessels less than 24m registered which are not certified by a class authority will typically have some sort of type approval and workshop certificate. Class authority certified equipment is more expensive – due to the more stringent testing protocol and associated witnessing by class surveyor – significantly so in some cases, and we understand where class rules are used as equivalence the MCA may request the class authority certified version of the equipment be purchased.

There is potential that a safety issue could be overlooked by all parties during the design and build of a vessel and may only come to light once the vessel is in operation. While this is of course possible with the current status-quo in fishing vessel design, the maturity of systems and level of experience makes the likelihood very small. On newer and developing technology it is certainly possible although still unlikely. The MCA position is that in no case can an unsafe vessel proceed to sea. This could increase costs through life as additional safety features are added to the vessel to mitigate against these newly identified risks. It would also be prudent for designer to leave some additional capacity – both weight and space – for additional safety systems through life, which will increase vessel size and cost.

It is fair to assume that the first batch of boats built to a new alternative fuel or powering system will be more challenging from a regulatory perspective than those that follow on where they can utilise the experience gained by MCA, designers, builders and suppliers to smooth the process and utilise more mature risk register understanding and knowledge of acceptable and safe mitigations to the utilisation of the fuel.

There are a number of regulations which are based on length or tonnage, where moving up a category will typically have an impact on a vessel. This may need additional safety equipment, systems like sewage treatment, increased crew and skipper qualification requirements or the need for the vessel to be in class instead of MCA survey. Some of these rules are enforced internationally and therefore the MCA would have no option to relax these where vessels may operate outside UK waters. There is a good chance that in some cases the additional hull capacity needed for fuel volume to match a Diesel equivalent will increase the length or volume of the boat to the point it is in a higher category. The costs of this can have a significant effect both on the build and through life costs of the vessel.

Ammonia & Methanol regulations

There are recently produced new class regulations for Ammonia[44] and Methanol[45]. This section will discuss some of the key issues in these new rules which will must be understood for designing a vessel on these fuels.

Due to the toxic, corrosive and flammable nature of Ammonia, and the toxic and flammable nature of Methanol, the system onboard will need to be set up to minimise the risk of contact between the fuel or its fumes and the personnel onboard. For both fuels the tanks need to be well isolated from other spaces with this boundary being able to be 'inerted' – a drench of inert gas to reduce the risk

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[44] NR671 ammonia-fuelled ships - tentative rules | Marine & Offshore (bureauveritas.com)

[45] NR670 methanol & ethanol fuelled ships | Marine & Offshore (bureauveritas.com)

to personnel from the fuel – and vented safely, should there be a leak from a tank. The fuel system will also need to be predominantly ducted in vented enclosures or be from double-walled pipe to reduce the risk of any single point of failure. Technically this is all possible and has been done on a number of Methanol vessels that are operating today, but does significantly increase the complexity and cost of the piping design, fitting and through life maintenance when compared to Diesel.

Analysis

We have undertaken a basic analysis of the parent vessels to develop voyage cycles, power usage and duration to determine how much fuel will be needed onboard based on operation using an alternative fuel. We have then used this information, review of the vessels arrangements and loading profile and understanding of the potential fuel systems to make an assessment of their technical suitability for a replacement to the parent vessel.

We could not find good information on LHOC or other Hydrogen carriers to undertake this analysis therefore they have not been included but are worth investigation as their use in the marine industry becomes more mature.

We have not looked at the full range of dual/multi fuel options that could be employed. There are a number of permutations and different percentages of storage that make this very difficult to assess in a basic first analysis. It is safe to assume that a Diesel/alternate fuel dual fuel would be as possible or more possible that using that alternate fuel alone. In the case that two alternate fuels would be used it is likely to be less practical than using the most likely fuel source.

We have assumed some saving by use of electrical drive vs mechanical drive. More detailed analysis of the vessels power cycle would be needed to get accurate details on this saving therefore the versions with electric drive may make some savings. These are impossible to quantify without more information.

This analysis is undertaken at a high level and intended to feed into further stages in this project where the most likely options can be developed as concept design vessels. This more detailed analysis may find the changes need to be more or less significant than noted here. It should also be noted that this analysis is based on what is technically possible based on current information and trends. Our analysis characterises each option as:

Possible with minimal changes to parent vessel - This means that the General Arrangement, hull shape and dimensions would need minimal changes to suit this option. In general, we have capped this at about 10% change in dimensions and minimal change to the arrangement design.

Possible with moderate changes to parent vessel - This means that the General Arrangement, hull shape and dimensions would need minimal changes to suit this option. In general, we have capped this at about 20% change in dimensions and moderate changes to the arrangement design while maintaining a similar operational layout.

Vessel not comparable to parent vessel – This means that the anticipated design is further from the parent vessel than the above categories. Therefore, the design is now too far from the parent vessel to be comparable. While there is not necessarily anything technically impossible about building this design, the level of departure and likely increased size make it unlikely to be an option. Should vessel specification - range, propeller power and electrical draw - be open to reduction, coupled with an analysis of savings that could be made through efficiencies of systems or electrification, there may be a suitable vessel. Improvements in technology, especially on items like cryogenic systems for liquid Hydrogen, could make a notable difference to the suitability of some fuels.

<10m creel boat

		Fuel calculator			
		Cygnus GM32 creel boat			
		Single Trip		Week of trips	
fuel	Drivetrain	L	kg	L	kg
Diesel	mechanical drive	50	42	700	588
Compressed H2	electric drive	281	9	3,937	128
Liquid H2	electric drive	127	9	1,780	128
Ammonia	mechanical drive	119	83	1,669	1,168
Methanol	mechanical drive	104	83	1,458	1,160
LNG	mechanical drive	79	34	1,106	474
Battery	electric drive		1,527		21,382

		suitability	
		Cygnus GM32 creel boat	
fuel	Drivetrain	Single Trip	Week of trips
Diesel	mechanical drive	M	M
Compressed H2	electric drive	S	U
Liquid H2	electric drive	U	U
Ammonia	mechanical drive	S	S
Methanol	mechanical drive	M	S
LNG	mechanical drive	U	U
Battery	electric drive	M	U

M	possible with minimal changes to parent vessel
S	possible with moderate changes to parent vessel
U	Vessel not comparable to parent vessel

As can be seen above there is a big difference in the number of options available and level of change required to the vessel depending if refuelling is undertaken after each trip or is done on a weekly basis.

Looking at refuelling the vessel after each trip the two most promising options are Methanol and battery, with compressed H2 and Ammonia looking plausible but with more significant changes to the parent vessel design to suit their more complex tank requirements. From an operational perspective refuelling with Ammonia or Methanol every trip is not practicable, especially given the hazardous and toxic nature of these fuels, and is unlikely to make this a good option for the operator.

Battery would be a very easy option to recharge as it would just need plugged into a suitably sized fast charger. The battery would only be a little larger capacity than those found on a large electric car currently so distinctly possible to be recharged in the 6-8 hours between trips if similar ‘fast charge’ technology is utilised. The issue here is creating the portside infrastructure, where if all the vessels of this size and type changed to battery it could be a significant electrical draw, especially when compared to current shore power facilities.

Compressed Hydrogen could be an option although, like Methanol, refuelling every trip may be an operational barrier. The weight needed to be added is only 9Kg but this equates to 281 litres. If you could make this as 9 x 33L bottles these may be handleable with shoreside craneage to take off and on vessel and re-fill at on-land Hydrogen station, but it certainly increases the difficulty and time spent on the refuelling procedure. These tanks will be very heavy, and when coupled with the small battery to make the electrical system run will need 15-20% increase in hull volume to support this.

Looking at the vessel refuelling every week, Ammonia and Methanol are the only real and practicable options. Even these will need changes to the vessel to allow for the increased tank size and also create the safe space around this tank for the inert gas system. It would be important to keep the fuel piping system as simple as possible, as there will be significant weight increases for this when compared to a Diesel system. Methanol is a more suitable option as the tank design is simpler (no need to compress or chill), better energy density means less volume is required and likely availability of Methanol engine in the required power range when compared to the difficulties of producing a suitable Ammonia engine in this power range.

The complexity of cryogenic system on a vessel this size rules LNG and Liquid H2 as unlikely to be possible on this vessel. The volume required for Compressed H2 for weekly trips makes it unlikely to be a possible suitable. For battery, the weight of this when sized for a full week of operation makes this unlikely to be a possible solution

Diesel has been shown as a possible option with minimal changes. The parent vessel operates on Diesel and therefore little to no change would be needed to operate on a net-zero EN 15940 standard fuel. The two main issues with this as a solution are availability and cost of the fuel. The land-based net-zero Diesel options (Bio-Diesel and HVO) will likely have supply issues as there is not enough land to support the production of these on a large enough scale. They also do not reduce costs as significantly as other fuels when production is scaled up. These factors coupled together will lead to a premium cost fuel. Net-zero synthetic Diesel is not currently seen as a widespread solution and as such there is not likely to be a large supply of this. As the process to produce this fuel has more steps and requires more energy than the production of the other alternative fuels mentioned in this report it is likely to be the highest cost fuel. The high cost and likely low availability of these options may make these options uneconomic to operate.

~15m Nephrops trawler

		Fuel calculator			
		Antares BF27			
		3 day trip		6 day trip	
fuel	Drivetrain	L	Tonnes	L	Tonnes
Diesel	mechanical drive	4,335	3.64	8,670	7.28
Compressed H2	electric drive	24,379	0.79	48,758	1.58
Liquid H2	electric drive	11,026	0.79	22,053	1.58
Ammonia	mechanical drive	10,333	7.23	20,666	14.46
Methanol	mechanical drive	9,028	7.19	18,056	14.37
LNG	mechanical drive	6,851	2.93	13,702	5.87
Battery	electric drive		132.41		264.83

		Suitability	
		Antares BF27	
fuel	Drivetrain	3 day trip	6 day trip
Diesel	mechanical drive	M	M
Compressed H2	electric drive	U/S	U
Liquid H2	electric drive	U/S	U/S
Ammonia	mechanical drive	S	S
Methanol	mechanical drive	M	S
LNG	mechanical drive	S	S
Battery	electric drive	U	U

M	possible with minimal changes to parent vessel
S	possible with moderate changes to parent vessel
U	Vessel not comparable to parent vessel

The above shows that the options suitable for 3-day trips are also the solutions most suitable for the 6-day drip. There is a slight advantage to the Methanol solution due to its slightly better energy density when compared to Ammonia and simpler tank/system design than LNG and Ammonia. The tank arrangement and boundary space requirements are likely to be the biggest challenge to the new arrangement for alternative fuel. It is likely this will cause a notable increase in length. For the Methanol version we would estimate 5-10% dimension increase if only 3-day trip and about 10-20% dimension increase for 6-day trip version. Ammonia and LNG will be perhaps 5% longer again than the Methanol versions.

Battery weight makes this option seem impracticable. The vessels' lightship is about 140T and an additional 130/260T would be needed for 3/6day operation. For the 6-day operation this would need about triple the hull volume to support this which is too significant a change from the existing vessel.

Hydrogen is very difficult to assess as the main issues are around the weight and complexity of the tank system. At the moment we believe these to be too heavy and challenging to fit with current tank technologies.

There is a distinct possibility that improvements in liquid Hydrogen storage systems – potentially driven by aviation – may make this a more technically suitable option. This would look most plausible if a vessel was running only on 3-day trips and refuelling every trip, but depending on the level of improvement 6-day trip could become possible within a moderately similar vessel to the parent vessel. The issue with relying on technology advances from aviation is that these may be notably more expensive and increase capital cost on the vessel.

For compressed Hydrogen, the volume for 3 days is likely the upper limit the vessel could accommodate before becoming too significantly different to the parent vessel. Based on information from the Hydrotug project (see Compressed Hydrogen section above) the likely tank weight for the 3-day version would be about 80 tonnes. If this could be reduced through improvements in tank design to about 25 tonnes, the 3-day version utilising compressed Hydrogen may become a plausible solution.

Diesel has been shown as a possible option with minimal changes. The parent vessel operates on Diesel and therefore little to no change would be needed to operate on a net-zero EN 15940 standard fuel. The two main issues with this as a solution are availability and cost of the fuel. The land-based net-zero Diesel options (Bio-Diesel and HVO) will likely have supply issues as there is not enough land to support the production of these on a large enough scale. They also do not reduce costs as significantly as other fuels when production is scaled up. These factors coupled together will lead to a premium cost fuel. Net-zero synthetic Diesel is not currently seen as a widespread solution and as such there is not likely to be a large supply of this. As the process to produce this fuel has more steps and requires more energy than the production of the other alternative fuels mentioned in this report it is likely to be the highest cost fuel. The high cost and likely low availability of these options may make these options uneconomic to operate.

<24m registered whitefish trawler

		Fuel Calculator	
		Vision V	
		8 day trip	
fuel	Drivetrain	L	Tonnes
Diesel	mechanical drive	27,000	22.68
Compressed H2	electric drive	151,840	4.93
Liquid H2	electric drive	68,676	4.93
Ammonia	mechanical drive	64,357	45.04
Methanol	mechanical drive	56,229	44.76
LNG	mechanical drive	42,669	18.27
Battery	electric drive		824.73

		Suitability
		Vision V
fuel	Drivetrain	8 day trip
Diesel	mechanical drive	M
Compressed H2	electric drive	U
Liquid H2	electric drive	U
Ammonia	mechanical drive	S
Methanol	mechanical drive	S
LNG	mechanical drive	S
Battery	electric drive	U

M	possible with minimal changes to parent vessel
S	possible with moderate changes to parent vessel
U	Vessel not comparable to parent vessel

The above shows that similarly to the nephrops vessel the most suitable solutions are Ammonia, Methanol and LNG. These tanks do need to be significantly larger than the Diesel tanks fitted in the parent vessel and will also need to be located differently due to the issues of storage of these fuels. This means that the vessels length is likely to need a 10-20% increase. Methanol holds a clear advantage over Ammonia and LNG, with simpler tank design requirements, with no need for compressed or cryogenic tanks. We would stress that this is an initial estimate and better detailing on systems, weight analysis and capacity calculations would be needed to produce a concept design which would confirm this thinking.

Battery weight makes this option seem impracticable. The vessel’s lightship is about 300T and an additional 825T would be needed – this is too significant a change from the existing vessel.

Compressed Hydrogen does not seem to be a practicable solution either. For compressed Hydrogen an additional 8-10m length (30-37%) would likely be the minimum needed for tankage and systems, and with the uncertainty on tank weight this could easily be significantly more. At this point the design is too far removed from the parent vessel to be comparable.

As noted in the nephrops vessel analysis, there could be significant improvements in liquid Hydrogen storage systems with aviation actively developing this technology currently with an emphasis on weight reduction. Should this be developed to a significant level there is a chance that liquid Hydrogen may become possible for a moderately similar vessel to the parent vessel (15-20% dimensional increase).

Diesel has been shown as a possible option with minimal changes. The parent vessel operates on Diesel and therefore little to no change would be needed to operate on a net-zero EN 15940 standard fuel. The two main issues with this as a solution are availability and cost of the fuel. The land-based net-zero Diesel options (Bio-Diesel and HVO) will likely have supply issues as there is not enough land to support the production of these on a large enough scale. They also do not reduce costs as significantly as other fuels when production is scaled up. These factors coupled together will lead to a premium cost fuel. Net-zero synthetic Diesel is not currently seen as a widespread solution and as such there is not likely to be a large supply of this. As the process to produce this fuel has more steps and requires more energy than the production of the other alternative fuels mentioned in this report it is likely to be the highest cost fuel. The high cost and likely low availability of these options may make these options uneconomic to operate.

Conclusions

As can be seen from the analysis, as the vessels get larger and have longer trips there is a clear advantage to Ammonia, Methanol and LNG over Hydrogen and battery. However, due to the lower energy density of all the fuels when compared to Diesel, coupled with all having more complicated requirements when it comes to storage, systems and handling it is clear that no solution will be as simple and compact as Diesel.

HVO and Bio-Diesel are unlikely to be available in the quantity or at a cost to make them a suitable option long-term. Net-zero synthetic diesel may be possible in the future but limited investment and likely high cost of production means at the moment it is not likely to become widespread or economic enough to be a suitable solution, although should be kept under review. Therefore, looking forward to try and create a net-zero fishing fleet we will have to look at the alternative fuels despite their disadvantages to Diesel.

All the fuel systems are more complex and dangerous than Diesel and it is clear that shipyards, maintenance professionals and crew onboard will all need additional training to safely fit, maintain and operate these systems. There is significantly more risk to either crew or the vessel should there be a fuel spillage and this will have to be clearly understood by owner skipper and crew who will need to be pro-active on maintenance and replacement.

The research and analysis we have undertaken also clearly shows that from an economic, infrastructure, regulatory and equipment availability perspective the first batch of vessels operating on alternative fuels will not be a competitive option when compared to Diesel vessels currently in operation.

One of the key difficulties is the lack of impetus for an owner to invest in this technology. With the net-zero deadline more than 20 years away and the perceived cost benefit and simplicity of remaining on Diesel an owner could see investing in Diesel and dealing with net-zero when the deadline happens as a significantly more attractive option. We believe that this is a risky approach to take, both for industry as a whole and for individual owners, for three key reasons. Firstly, if the industry collectively fails to invest and develop solutions when time is available it could be catastrophic if the deadline arrives and no vessels are compliant and therefore may be prevented from operating. Secondly, if other industries push technology and infrastructure that is not suitable for the best solutions for fishing vessels, UK fishing vessels will still be constrained to these options and have to make more compromises on design and operation. Thirdly, as per the warning of Professor Christopher Smith, it is difficult to predict what will happen with Diesel price as demand from other industries – especially auto-mobiles – reduces in the coming year. It is very possible that the increase in cost could make much of the current fleet un-economic - unless there is a similar increase in fish price – to operate and effectively make vessels stranded assets.

The investment in alternative fuels vessels is also more difficult for the fishing sector where the majority of vessel owners are the owner/operator of one vessel. In other marine sectors where vessels have been built for alternative fuels the owner has a large fleet and the budget to invest in a trial vessel, from which they can analyse the performance and operation and make better purchasing decisions during the transition of their fleet.

On a larger scale, for any of these fuels to be net-zero there needs to be a large supply of net-zero energy for their production. This means a significant transition in the energy production, in Scotland, the wider UK and across the world to net-zero sources. This not only needs to cover the current electric grid load but also needs to cover the energy needed for the production of the fuels that are currently also sourced from fossil fuels. This may be the biggest challenge, as failure to achieve this leaves the fuels used not meeting net-zero requirements.

Phase 2 – further analysis

The next step in this study, Phase 2, is the development of concept designs based on the most likely solutions shown in this report. A more detailed analysis will then be undertaken of the financial, regulatory and technical issues associated with moving these concepts forward to production and operation. Fisheries Innovation & Sustainability and Macduff Vessel Design are grateful to the Marine Fund Scotland for supporting Phase 2 of this project.

To assist the study full power data will be recorded for a voyage cycle of the parent vessels. This information will make it easier to identify the savings that could be made through the cyclic nature of the operation. These savings may make Hydrogen or battery energy storage and electric propulsions a stronger option than our analysis has shown.

The following options will be assessed as concept designs in the short term:

<10m Creel boat:

1. Battery, electrical drive. Based on recharging after every trip
2. Methanol, based on re-fuelling after 1 week of operations

~15m Nephrops

1. Methanol based on 6-day trip
2. LNG based on 6-day trip

<24m registered whitefish trawler

1. Methanol
2. LNG

As noted above, if power data shows that Hydrogen fuel or utilising electrical hybrid drive made significant savings, these options should also be added to the list for consideration for developing a concept design.

Should there be notable improvement in Liquid Hydrogen or compressed Hydrogen tanks and storage systems, a re-analysis of the suitability of these and then more detailed concept designs created for the most plausible vessels should be undertaken. Technologies like LOHC, Hydrogen carriers or any new fuels should remain under review with intention of analysing their suitability and developing a concept design.

Annex 1 – List of issues

Below is a list of the issues identified in the report. While this list and report are not exhaustive or fully detailed in all challenges, they provide a good overview of the scale of the issues faced in the transition to alternative fuels.

Large quantity of net-zero energy needed to produce net-zero fuels [technical / financial]

Fuel storage for all options is more complex than Diesel [regulatory / technical]

Fuel systems for all options is more complex than Diesel [regulatory / technical]

All hydrocarbons burnt in ICE will create emissions (although accounted for in fuels production) [technical / financial]

Availability/cost of marine use Hydrogen fuel cells [technical / financial]

Hydrogen has significantly lower energy density than Diesel [technical]

Hydrogen is more explosive/dangerous to handle than Diesel [technical / regulatory]

Compressed Hydrogen tanks may be excessively heavy [technical]

Lack of standardisation in pressure and fittings for compressed Hydrogen [technical]

Liquid Hydrogen needs cryogenic system for -253 degrees C [technical]

LOHC or other Hydrogen carriers are new options and not enough information is available [technical]

Most Hydrogen produced currently is not net-zero [technical / financial]

LNG needs cryogenic system for -162 degrees C [technical]

LNG is more explosive/dangerous to handle than Diesel [technical / regulatory]

LNG has a lower energy density than Diesel [technical]

At this time most LNG is from fossil fuels and therefore not net-zero [technical / financial]

No proven LNG engines at the power/speed range we are considering in this report [technical / financial]

Ammonia is toxic, corrosive and flammable and more dangerous to handle than Diesel [technical / regulatory]

Ammonia has a lower energy density than Diesel [technical]

Ammonia is known to have ignition issues in engine so solution may need to be Diesel dual fuel to ensure ignition [technical]

No proven Ammonia engines at the power/speed range we are considering in this report [technical / financial]

Ammonia is currently not produced on industrial scale from net-zero resource [technical / financial]

Methanol is toxic and flammable and therefore more dangerous to handle than Diesel [technical / regulatory]

Methanol has toxic fumes which are very dangerous to crew [technical / regulatory]

Methanol has a lower energy density than Diesel [technical]

Methanol is predominantly from fossil fuels currently so not achieving net-zero [technical / financial]

Batteries have risk of thermal runaway [technical / regulatory]

Batteries energy density is too low to be sole energy source on anything other than short voyages [technical]

Batteries have shorter lifespan and will need replaced more regularly than other energy storage options [technical / financial]

Batteries degrade over their lifecycle so must be oversized to ensure they remain fit for purpose [technical / financial]

BioDiesel is not likely to be available in sufficient quantities [technical / financial]

BioDiesel is seen as environmentally and ethically challenging, especially on industrial scale [technical / financial]

HVO is not likely to be available in sufficient quantities [technical / financial]

HVO is seen as environmentally and ethically challenging, especially on industrial scale [technical / financial]

Synthetic Diesel will be costly to produce [financial / technical]

Synthetic Diesel creates more emissions (although accounted for in fuels production) than other options [technical / financial]

Uncertainty in future pricing of Diesel and alternative fuels [financial]

Uncertainty in future availability of Diesel and alternative fuels [technical / financial]

Current low demand for alternative fuels leaves low supply and high cost [technical / financial]

Uncertainty over long term solutions for other industries / marine sectors [technical/financial]

Port infrastructure development to suit fishing sector solutions [technical / financial]

Risk influence of other marine sectors will develop port infrastructure away from fishing sector solution [technical / financial]

Lack of engine options available on market [technical / financial]

Lack of engine options being developed for Ammonia or LNG (in the power/speed range considered in this report [financial / technical]

Cost of alternative fuel engines [financial]

Problems with aftermarket modification to alternative fuel [financial / technical / regulatory

Risk qualified engineer will be required onboard fishing vessels when equivalent Diesel vessel would not need an engineer [technical / financial]

Size/weight of electrical drive system [technical]

complexity of electrical drive system [technical]

Crew/shipyard training required for installation, operation and maintenance of electrical drive system [technical]

Danger of high voltage systems on electrical drive system [technical]

Additional capital costs for electrical drive system [financial]

Crew/shipyard training required for installation, operation and maintenance of Hydrogen fuel cells [technical]

System complexity, cost, weight and space issues with hybrid system [technical / financial]

MCA does not have specific regulations for alternative fuels [technical / regulatory]

Difficulty selecting and agreeing rules to be applied to ‘first of type’ vessels [technical / regulatory]

All alternative fuels have more challenging risks to mitigate than Diesel [technical / regulatory / financial]

Additional safety equipment may be required to mitigate risks of alternative fuels [technical / regulatory / financial]

Some equipment may need higher level of type/class approval than Diesel alternatives [technical / regulatory / financial]

Increased cost of design and approval process [financial]

Future issues from unforeseen risks [technical / regulatory / financial]

Need to design in space for increased safety systems that may need to be added through life [financial / technical]

Possible detention of vessel due to unforeseen risk [technical / financial / regulatory]

Possibility alternative fuel vessel will be in a larger regulation bracket than Diesel equivalent needing more equipment/more qualified crew/class involvement [technical / financial / regulatory]

Ammonia and Methanol regulations likely to need significantly more complex systems and arrangement than Diesel [financial / technical]

Lack of information available on marine use of LHOC or other Hydrogen carriers [technical]

Charging infrastructure needed should batteries be utilised in vessels [technical / financial]

Increased time and difficulty re-fuelling [technical / financial]

Most options for alternatives to three parent vessels will increase vessel size, increasing hull cost [financial]

No option offers as simple and compact a solution as Diesel currently provides [technical / financial]

All options will need pro-active maintenance and replacement schedules [technical / financial]

Vessels operating on alternative fuels currently would not be able to compete financially with Diesel equivalent [financial]

Difficulty of investing in what seems currently un-economic alternatives to Diesel vessels [financial]

Lack of investment in industry solution means there is no pressure on suppliers to develop suitable solutions for fishing sector. [technical / financial]

Difficulty of owner/operator of single vessel to invest in unproven option [financial]

Potential clean energy production will not be sufficient to produce the alternative fuels as net-zero [financial / technical]

Potential high cost of liquid Hydrogen solutions developed for aviation industry [financial]

Uncertainty over how technology will develop both in fuel production, storage and systems [financial / technical / regulatory]

No action taken and Diesel price rises leaving owners with stranded assets [financial]

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Fisheries Innovation & Sustainability

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