Application of Commercial Advances to Support the Naval Energy Transition

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Synopsis

Developments in the commercial marine industry to support the energy transition away from fossil fuels is picking up pace. There is a division within the industry of the future fuel selection and the application of Energy Saving Technologies (ESTs).

With no clear "winner" coming out front, ship owners in various parts of the world are hedging their bets with different technologies.

Naval Platforms are more complex to shift to future fuels for a number of reasons, one primary reason is fuel energy density and range requirements. This paper explores developments in the commercial marine industry in the EST space and assesses the impact on fuel selection on BMT's Venator 110 concept platform.
Future fuel availability is also becoming increasingly regional of type and bunkering locations. The impact on vessel range and currently available and predicted future bunkering locations is also considered.

Keywords: ESTs; Decarbonisation; Future Fuels; Fuel Transition.

1. Introduction

Across commercial shipping there is pressure to meet incoming and future environmental regulations; the introduction of IMO's Carbon Intensity Index (CII) and the European Commission's FuelEU Maritime Regulation has incentivised ship owners to start reducing their vessel's carbon intensity. With forthcoming stringent regulations, commercial shipping is on the eventual path to decarbonisation. A significant number of new build commercial vessels are being specified as dual fuel, providing owners with flexibility into the future. In June 2023, the shipping giant Maersk had 25 methanol-enabled vessels on order (Maersk, 2023).

To support future fuel adoption, Energy Saving Technologies (ESTs) can enable the reduction of carbon intensity of a vessel whilst maintaining or improving performance. Existing ship owners are increasingly turning to ESTs to meet current CII legislation, this legislation dictates the pace of EST adoption across the maritime industry. ESTs can be broadly categorised as warm, wet and windy:

- Warm: Improvements to thermal efficiency or the recovery of waste heat.
- Wet: Hydrodynamic improvements.
- Windy: Wind assisted propulsion or aerodynamic improvements to the super-structure.

Naval vessels can benefit from commercially available ESTs, providing an environmental benefit, cost saving and increased capability. Alongside regulations, energy security will also govern naval strategic thinking and future capabilities; 'transitioning from fossil fuels to renewable energy yields more electrified, decentralised, and digitalised energy systems' (IRENA, 2024). To maintain current capabilities, navies must proactively transition towards implementing ESTs and the incorporation of future fuels.

Whilst navies may be content with operating fossil fuels such as F-76, a distillate marine fuel, regulations are enforcing the transition to future fuels for the global merchant fleet. Demand for maritime fuel is dictated by the commercial market; therefore, fossil fuel availability for naval applications could consequentially suffer.

This study explores the currently available ESTs that could be integrated on to naval vessels using BMT's light frigate concept Venator-110 as the baseline vessel, assessing both F-76 and methanol variants of Venator-110.

By incorporating selected ESTs onto Venator-110, this study demonstrates that a conservative 13% reduction in the energy demand across the proposed operational profile and a 21% reduction at a 15kn cruising speed could be achieved.

Author's Biography
Benjamin Scott is a Naval Architect at BMT UK. Ben is actively involved in research associated with the energy transition, having recently published an investigation into the feasibility of molten salt reactors for the propulsion of surface ships. His previous work includes research quantifying the added resistance due to biofouling using a fully turbulent flow channel.

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2. Baseline Vessel

BMT's Venator-110 is a general-purpose light frigate able to provide adaptable and cost-effective capabilities for various mission needs such as: maritime security, naval boarding, and consort defence (BMT, 2024).

Venator-110 is powered by F-76, a NATO fuel standard, which is similar in makeup to marine gas oil (MGO) (Ministry of Defence, 2013) and has a Combined Diesel and Diesel propulsion solution with two independent shaft lines. Each shaftline is powered by x2 MTU 16V8000M91L diesel engines and fitted with a controllable pitch propeller. Principal particulars for Venator-110 are detailed in Table 1.

Figure 1: Render of BMT's Venator-110 light frigate (BMT, 2024).

Table 1: Principal particulars of Venator-110.

Item	Value
Length (m)	117
Beam (m)	18
Draught (m)	4.3
Displacement (t)	4000
Range at 15kn (nm)	6000
Top Speed (kn)	> 25
Main Engines	x2 MTU 16V8000M91L
Electrical Generation	x2 MTU 16V2000
Crew	85
Total Personnel	106

Figure 2 illustrates the operational profile for Venator-110. This profile has been generated assuming transit speeds of 10kn, with Venator-110 spending most time at sea patrolling with the occasional sprint.

Based off this the operational profile, every year Venator-110 will consume 4892t of F-76 over 73550nm, and emit 15,190t of CO_2 whilst underway at sea for 5000hrs/year.

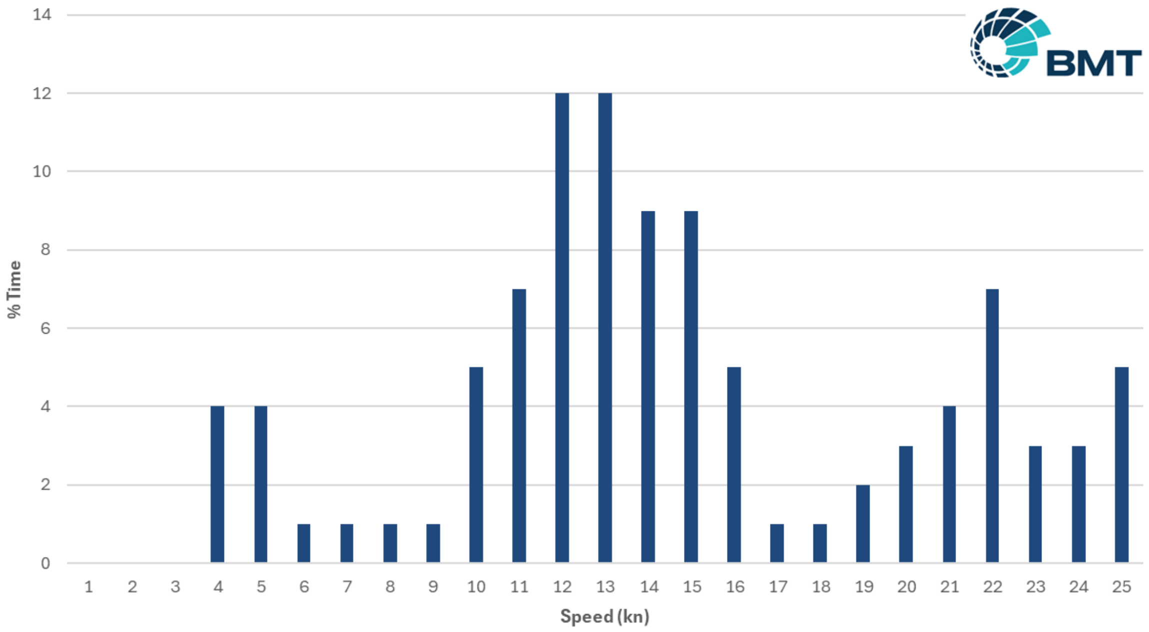

Figure 2: Typical operational profile for Venator-110.

3. Energy Saving Technologies

3.1. *Options*

Whilst the list is non exhaustive, Table 2 provides a classification of available ESTs with suitable Technology Readiness Level (TRL) 6 and above. The methodology used for assigning TRL was taken from TWI's TRL scale diagram (TWI, 2024). Notably, TRL 6 implies the EST has been demonstrated in the commercial shipping domain, and TRL 7+ have been utilised in a naval setting.

The effect of combining multiple ESTs of a similar categorisation type has seldom been explored, this may adversely affect performance and is a clear gap in the literature. For example, installing hull air lubrication may hinder the effectiveness of a Hull Vane®. By categorising ESTs into warm, wet and windy, the EST selection process for Venator-110 allows for segregated selection.

Table 2: Classification of available ESTs

Category	Energy Consumer	EST	TRL
Warm	Ship Services	Absorption Chiller Plants	7 (Spector, 2017) (Heinen & Hopman, 2024)
		Variable Frequency Drives	9 (General Electric, 2020) (ABB Marine and Cranes, 2012)
		Wärtsilä Low Loss Concept (power distribution)	6 (Wärtsilä, 2024)
Wet	Hull Resistance	Hull Air Lubrication	6 (Alfa Laval, 2024) (Silverstream Technologies, 2024)
		Hull Vane	7 (Hull Vane®, 2024)
		Fixed/Retractable Bow Foil	6 (Wavefoil, 2024) (AQUILA, 2024)
Windy	Propulsion	Flettner Rotor	6 (ANEMOI, 2024) (Norsepower, 2024)
		Fixed/Deployable Sails/Wings	6 (BAR Technologies, 2024) (Oceanbird, 2024)
		Deployable Kites	6 (Airseas, 2023) (Beyond the sea®, 2024)

3.2. *Selection*

For naval vessels, complex requirements can be broadly simplified into ‘Fight, Move, Float’; one EST from each category summarised in Table 2 was selected based on suitability for these requirements.

The effects of combining hull air lubrication with Flettner rotors on Venator-110 have previously been assessed by BMT, providing “a conservative estimate of 6% reduction in fuel” (Buckingham, 2023). For this reason, the addition of hull air lubrication and Flettner rotors on Venator-110 has not been reassessed during this study.

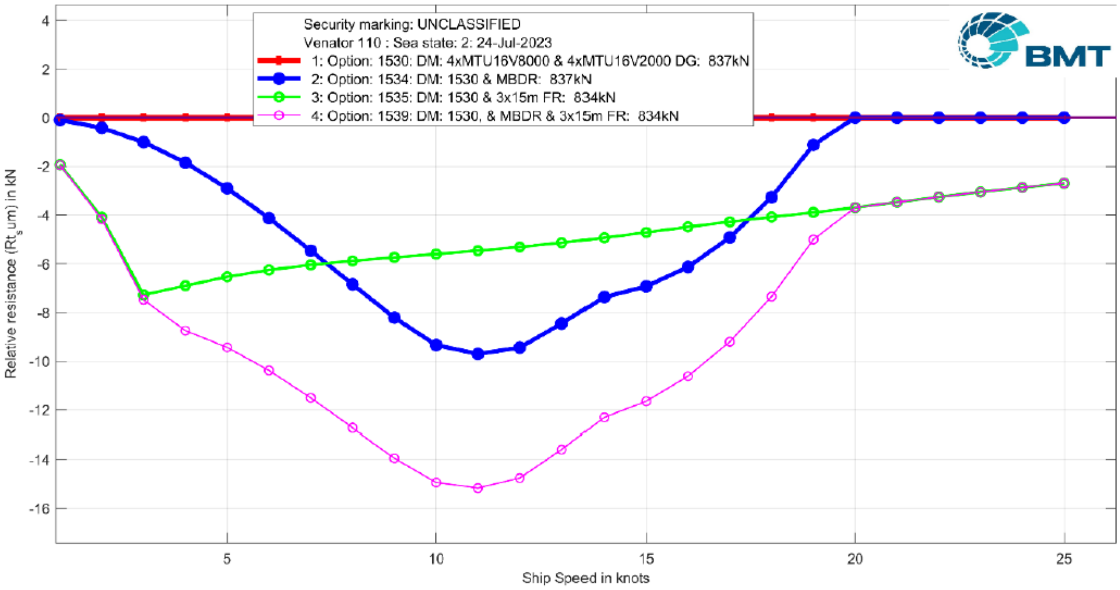

Figure 3: Reduction in relative ship resistance (kN) at sea state 2 with 3 Flettner rotors and micro bubble drag reduction (Buckingham, 2023).

3.2.1. Warm

Through power electronics, variable frequency drives alter the frequency and voltage of electrical supply to motors, subsequently controlling motor speed and torque to match system demands. These drives have a high TRL and are proven to provide fuel savings (ABB Marine and Cranes, 2012).

The Wärtsilä low loss recovery concept reduces the need for supply transformers to frequency converters, this configuration can result in a 2-3% higher system efficiency (Wärtsilä, 2024). Whilst substantial, the low loss concept was not investigated as it is best suited for ships with electric propulsion and has a lower TRL (Table 2).

Both variable frequency drives and the Wärtsilä low loss concept significantly impact system design and outfit, with variable frequency drives demanding additional volume onboard.

Through waste heat recovery there is the potential to save energy by incorporating an Absorption Chiller Plant (ACP) without significantly impacting the vessel’s layout and outfit; an ACP could potentially replace a Chilled Water Plant (CWP) (Section 3.3.1). ACPs and CWPs are both used to provide cooling for various ship services. CWPs use a vapour-compression refrigeration cycle, which is electrically driven, to absorb heat from the chilled water loop and subsequently release the heat into a condenser. In contrast, ACPs are predominantly driven by heat and use an absorption process instead of a compressor, as a mixture of water and lithium bromide enables the cooling.

3.2.2. Wet

The energy saving performance of fixed/retractable bow foils is dependent on wave energy, wave direction and vessel route (Bowker & Townsend, 2022), which are less predictable when considering the operational requirements of a light frigate. Operationally, the bow foils are also likely to negatively impact the capability of the sonar dome. Hydrodynamically, Venator-110’s waterline length is only optimal for bow foil performance in certain wave conditions (Bowker & Townsend, 2023). As Venator-110 is required to operate globally and maintain a sonar capability, bow foils were deemed unsuitable.

Fixed/retractable bow foils are reliant on wave energy; in contrast, a Hull Vane is dependent on vessel speed. A hull vane can be optimised for the specific vessel and corresponding operational profile. A Hull Vane can also reduce pitching accelerations, which can improve crew comfort and potentially increase the operational window for naval operations. Therefore, a Hull Vane fitted to the stern on the vessel, was considered most appropriate for application on a light-frigate.

3.2.3. Windy

Despite being able to provide significant thrust and energy savings (Buckingham, 2023) (Shukla & Ghosh, 2009) (Hussain & Amin, 2021), deployable/fixed sails and Flettner rotors were not considered for this study due to their large physical envelope and significant deck area requirements. Instead, deployable kites were selected for investigation, offering access to faster wind speeds through high altitude flight (Formosa, et al., 2023).

3.3. Analysis

3.3.1. Warm

Venator-110 requires four Chilled Water Plants (CWPs) to provide sufficient cooling. During chemical, biological, radiological, and nuclear closedown, there is a maximum cooling requirement of 2600kW. This load must be met with just three of the four CWPs, as the fourth CWP is required for redundancy for the chilled water system. For Venator-110, the air treatment unit and CWP sizing calculations state each CWP must therefore have a minimum cooling rating of 867kW, with approximately 250kWe electrical load per plant.

One of the four CWPs could be replaced by an ACP of an equivalent rating. ACPs convert low-grade heat into chilled water, requiring a significantly lower electrical load compared to CWPs, as ACPs are predominantly powered by thermal energy.

The feasibility of running an ACP is dependent on waste heat availability, and a large source of waste heat is generated by the main engines. Currently, waste heat is removed from the main engines via the exhausts, High Temperature (HT) lines and intercooler lines. As most ACPs at sea are either hot water or steam driven (Johnson Controls, 2019) (York, 2018) (Heinen & Hopman, 2024), it was investigated whether 90°C hot water from the HT lines could power a suitable ACP, and at which vessel speeds there would be sufficient waste heat available from the HT lines.

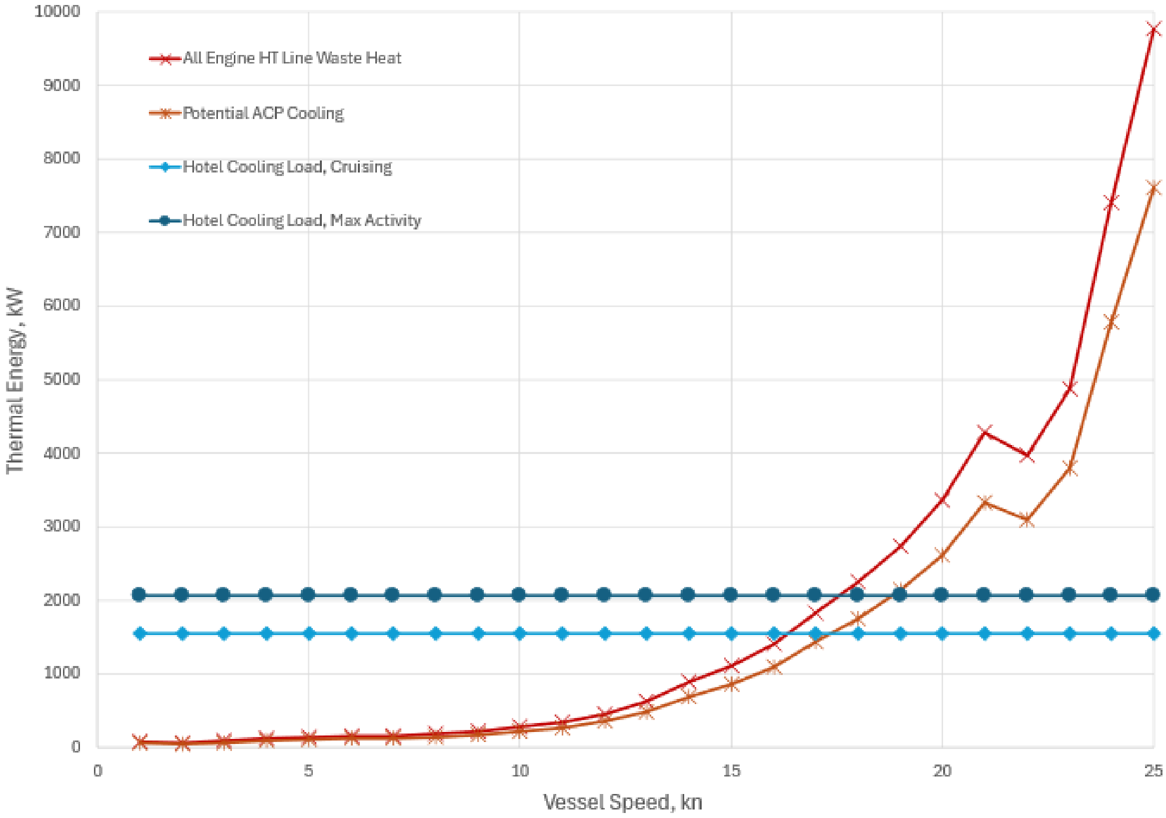

Figure 4: Graph of Thermal Energy Availability vs Vessel Speed for the Absorption Chiller Plant.

As each CWP is required to deliver 867kW cooling capacity, a replacement ACP must also provide at least 867kW of cooling. When considering the coefficient of performance for a Heinman & Hopman maritime ACP can be up to 0.8, a coefficient of performance of 0.78 was assumed implying the SWM-320 model would suffice (Heinen & Hopman, 2024).

At 15kn and above, there is sufficient waste heat available from the HT lines for this ACP to deliver the 867kW cooling requirement (Figure 4). This implies the SWM-320 could only be fully utilised for 43% of the vessel's operational profile (Figure 2), which would limit the redundancy in the chilled water system. Nevertheless, the ACP could be operated at vessel speeds lower than 15kn, but the subsequent effects to coefficient of performance during partial load were not explored.

Each CWP currently consumes 250kWe at full load. In contrast, the equivalently rated ACP consumes <10 kWe (Heinen & Hopman, 2024). The potential electrical load saving is therefore ~240kWe, which equates to a 3% fuel reduction when the ACP is running at full load, and a 1% reduction across the operational profile. For this study, waste heat from the main engine exhausts was not considered as available due to other ancillary pre-heating requirements during chemical, biological, radiological, and nuclear closedown. However, maritime ACPs can be set up to receive waste heat from multiple sources (Figure 5), which implies the ACP selected could sufficiently operate at lower loads for vessel speeds below 15kn.

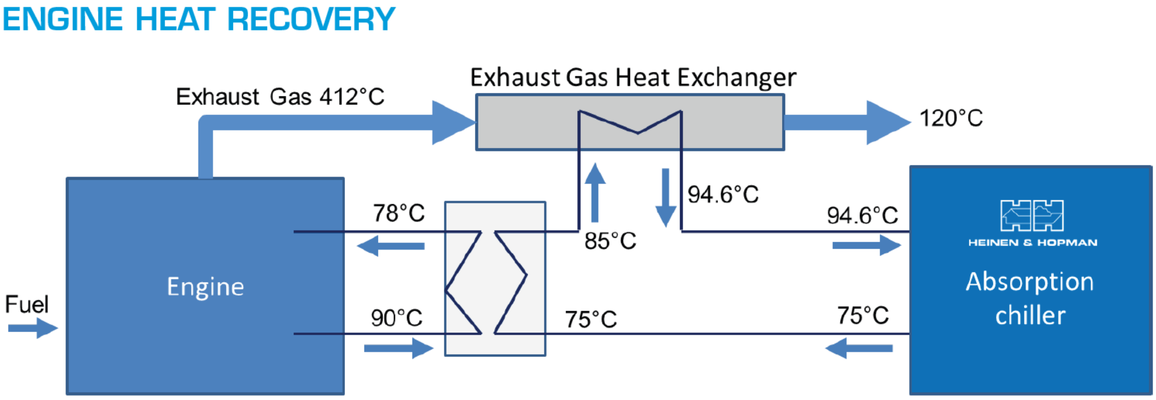

Figure 5: Optimised system layout for maritime absorption chiller plants (Heinen & Hopman, 2024).

3.3.2. *Wet*

Located on the stern, a Hull Vane creates a low-pressure region to suppress the stern wake (Çelik & Danışman, 2023). By accelerating fluid flow at certain speeds, a Hull Vane can generate forward thrust, stabilise trim and reduce the vessel's stern wake (Figure 7), all of which contribute to reducing overall hull resistance. A reduction in resistance and subsequent effective power requirements can further allow for reduced propeller loading and improved propulsive efficiency accordingly.

The energy saving potential from a Hull Vane depends on vessel type, waterline length and nominal operating speeds; vessels equipped with a Hull Vane and of similar characteristics to Venator-110 were identified, with the corresponding reported resistance reduction profiles captured in Figure 6.

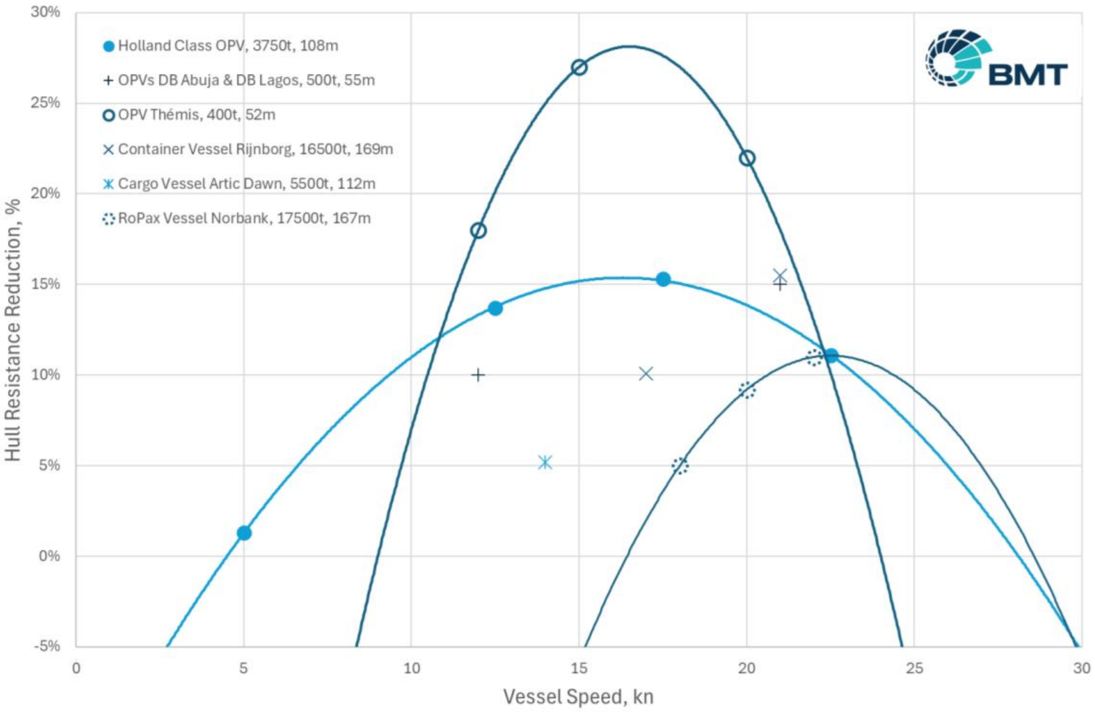

Figure 6: Graph of Hull Resistance Reduction vs Vessel Speed comparing vessels fitted with a Hull Vane (Hull Vane®, 2024)

There is poor convergence across the different vessels (Figure 6), caused by the appended (or simulated) Hull Vane being optimised for each specific vessel. However, the resistance reduction profiles all follow a negative second-degree polynomial in shape, going negative at the extremities of the vessels' nominal speed ranges. Of the vessels identified, the 108m Holland Class OPV is the closest match to Venator-110 in terms of vessel type, length and tonnage; therefore, it was assumed that a comparative resistance reduction profile could also be achieved for Venator-110.

Figure 10 illustrates the potential power saving of appending a Hull Vane to Venator-110. From this analysis, a Hull Vane could potentially reduce hull resistance by approximately 9% across the defined operational profile. . Whilst a Hull Vane can damp pitch accelerations, there is minimal impact to roll dampening implying naval manoeuvrability requirements could still be achieved (Bouckaert, et al., 2016).

Figure 7: Demonstration of Hull Vane stern wake reduction (Van Oossanen Naval Architects, 2020)

3.3.3. *Windy*

Wind has been harnessed to propel ships for centuries, and contemporary sports such as kite surfing and kite boating exemplify the potential to use kites for at sea propulsion in the modern era. Unlike fixed/deployable sails and Flettner rotors, kites provide a compact and deployable solution which is perhaps more suited for warships. Companies such as 'Airseas' and 'Beyond the seas' are utilising kite assisted propulsion for medium-large vessels, offering up to 1000m^2 and 1600m^2 sized kites respectively (Airseas, 2021) (Beyond the sea®, 2024).

Kites can provide vessels with both thrust and lift, there are various approaches for determining these aerodynamic forces. Whilst physical experimentation and computational fluid dynamics are desirable for validation, there is also merit in implementing a simple Newtonian approach. NASA provides a guide for determining the aerodynamic forces acting on a kite (NASA, 2021), which supplemented the analysis conducted in this study when deriving kite thrust (Figure 8). Table 3 contains the particulars for the assumed kite installed on Venator-110; a 900m^2 kite surface area was deemed most appropriate when comparing vessel tonnage to commercial ships also utilising kite assisted propulsion.

Table 3: Kite Particulars.

Item	Value
Kite Surface Area (m^2)	900
Kite Aspect Ratio	4.5
Wind Speed over Oceans @ 100m - 300m (m/s)	10
Air Density at flight altitude (kg/m^3)	1.21
Angle of Attack (degrees)	5< AoA < 20

Kites only provide forward thrust in a tailwind, forces generated in headwinds would contribute to overall resistance. It was assumed that the probabilistic wind direction in relation to vessel direction was equal in all directions, implying Venator-110 only experiences tailwinds 50% of the time.

The useful component of kite thrust depends on the angle between prevailing wind direction and the vessel's direction of travel, so a Centreline Angle (CA) was used to account for the useful kite thrust component; a perpendicular crosswind provides no useful thrust component (Figure 8). Also, as vessel speed increases, the apparent wind speed diminishes, so a linear reduction to apparent wind speed was incorporated (Figure 9).

The kite generates both lift and thrust, the vessel could subsequently experience unwanted heave and surge. At this stage, a study into the total seakeeping impact was not conducted.

The kite's Angle of Attack (AoA) also effects the useful thrust generated; the kites lift coefficient must be greater than the drag coefficient for the kite to remain airborne under stable flight conditions. For this kite (Table 3), an AoA higher than 24° would cause back stall and lower than 0° would cause front stall. The safe operating range was determined to be AoAs between 5° to 20°, with 20° providing the optimum thrust point (Figure 8).

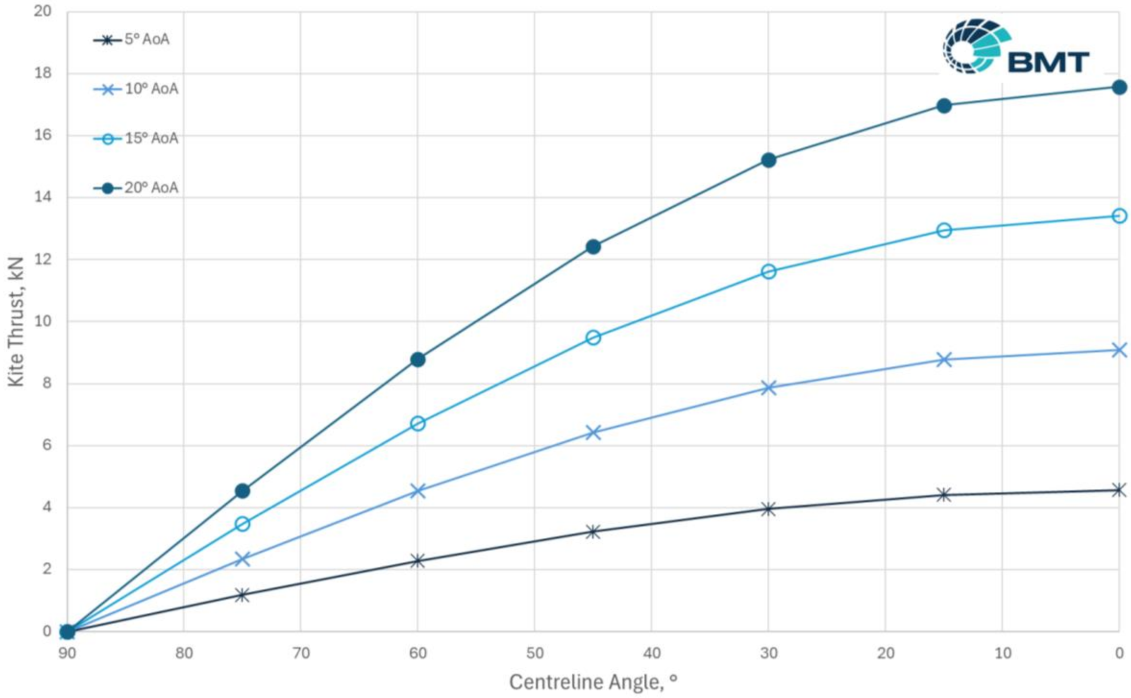

Figure 8: Graph of Kite Thrust vs Centreline Angle.

With a 50% chance of tailwinds, Figure 9 shows this kite could significantly contribute to reducing the vessel's delivered power demand for vessel speeds below 10kn. By contributing thrust, the kite reduces the vessels overall resistance and effective power requirements at a given speed, further allowing for reduced propeller loading and improved propulsive efficiency accordingly. The benefit of deploying a kite quickly diminishes beyond Venator-110 speeds of 10kn, as the apparent wind speed continues to reduce linearly and required power increases exponentially (Figure 10).

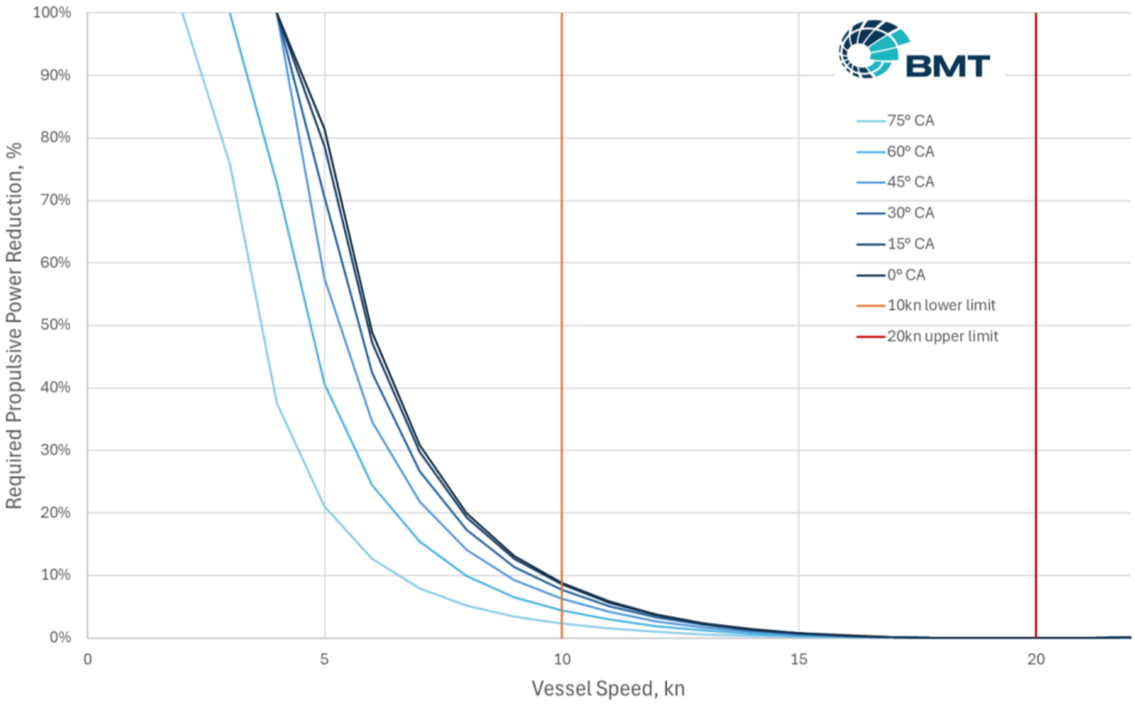

Figure 9: Graph of Required Propulsive Power Reduction vs Vessel Speed for kite assisted propulsion, at 10m/s wind speed.

Whilst this kite only offered favourable fuel savings at low speeds, several articles suggest that the Irish Navy were investigating the use of kites to extend passive radar range (Engineers Ireland, 2015) (Irish Independent, 2015). This highlights a potential strategic advantage for early warning detection, but there is limited evidence to suggest these kites have been developed further. Realistically, fuel savings at low speeds have a negligible impact to overall power reduction, especially for a medium-high speed operational profile (Figure 2).

For this kite, a theoretical 10% average power reduction could be achieved across the operational profile. This analysis assumed the kite is in static flight, whereas 'Airseas' suggest a parafoil wing forced to fly in "figure of 8 loops" can multiply the dynamic flight speed and subsequent thrust (Airseas, 2023).

However, when considering naval operational limitations, the kite would not be deployed for speeds lower than the in-harbour pilotage speed of 10kn, or above the sprint/pursuit speed of 20kn when Venator-110 is travelling with urgency (Figure 9). Naval operational limitations for when the kite could be deployed result in a <1% energy saving across the operational profile.

3.4. *Performance Overview*

Figure 10 illustrates the potential benefits when an ACP, Hull Vane and kite is incorporated into the design of Venator-110. Across the operational profile, a Hull Vane is expected to represent the largest efficiency gain, and the kite the least. For vessel speeds of 4kn and below, the Hull Vane has a negative efficiency impact, whereas the kite is most effective at these speeds; the kite could potentially offset the Hull Vane losses at 4kn and below if deemed suitable for naval operations at these speeds.

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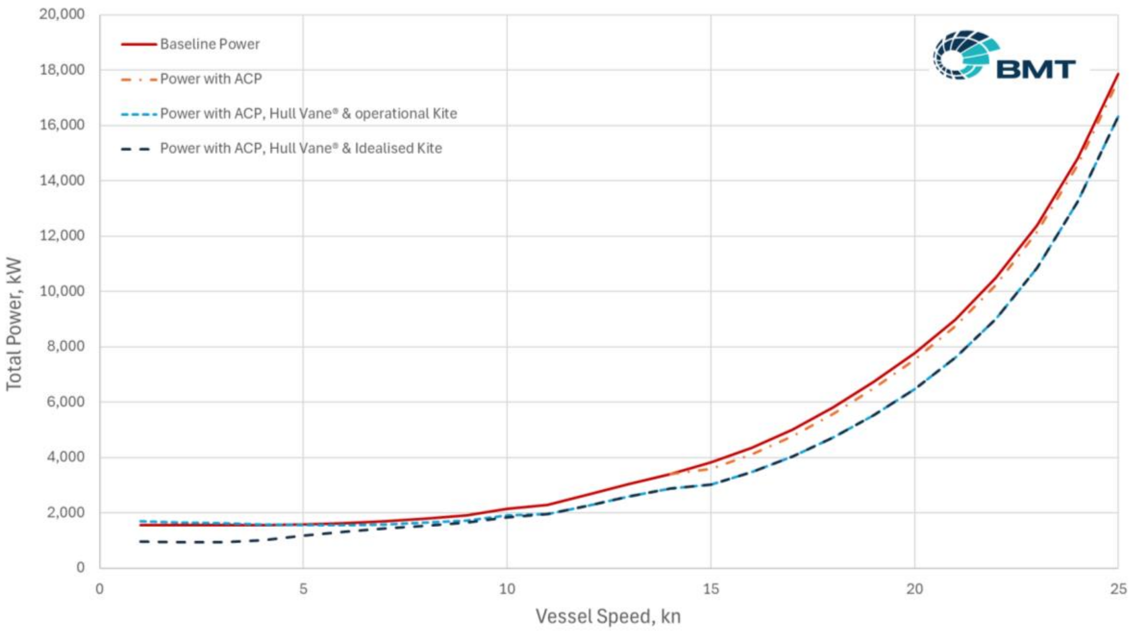

Figure 10: Graph of Total Power vs Vessel Speed for Venator-110 comparing the selected ESTs.

When considering the operational profile, potential fuel savings peak at 15kn, caused by the Hull Vane resistance reduction and the ACP operating at full cooling capacity (Figure 11). Due to the added drag of the Hull Vane at low speeds, additional fuel would be required for vessel speeds below 4kn as shown (Figure 11). Fortunately, when time spent at each speed is also considered (Figure 2), these losses are negligible.

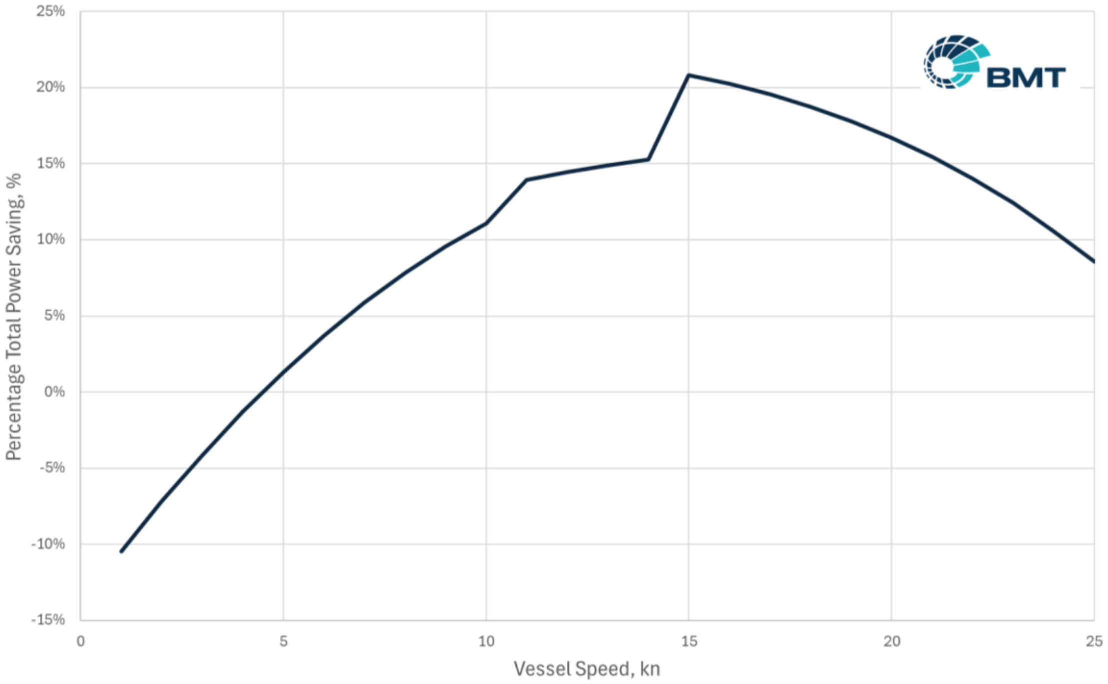

Figure 11: Graph of Percentage Total Power Saving vs Vessel Speed for the selected ESTs.

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4. Future Fuels

4.1. *Overview*

Figure 12 illustrates the bunkering availability of methanol, ammonia, hydrogen, and LNG. With future fuels offering reduced bunkering availability compared to commercial marine fossil fuels, the range in terms of nautical miles of future fuel powered vessels, alongside potential for Replenishment at Sea (RAS) must reflect this fuel availability.

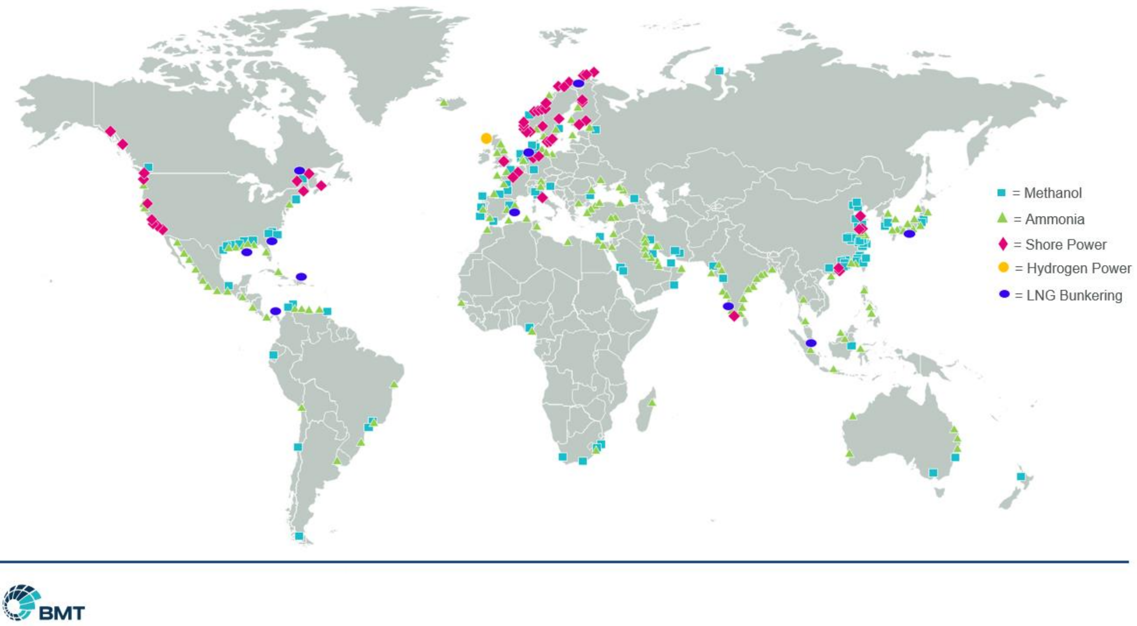

Figure 12: Future fuel availability (Dr Beard, 2023).

In January 2023, 105,500 ships of 100 gross tonnes or more were registered in the global fleet (UNCTAD, 2023). In comparison, the UK’s Royal Navy and Royal Fleet Auxiliary (RFA) consisted of a combined 71 vessels in 2022 (House of Commons, 2022).

Switching to future fuels could represent a significant cost yet represent minimal environmental benefit for the Royal Navy in comparison to the environmental impact of the commercial fleet.

However, if a switch to an alternative energy source is not made, the Royal Navy may face future fuel availability implications, especially considering IMO’s Green House Gas (GHG) reduction strategy which aims to achieve net-zero GHG emissions for commercial shipping by 2050 (International Maritime Organization, 2024). Therefore, to maintain operational capability it is imperative to assess the impact that future fuels will have upon naval vessels.

Whilst drop-in fuels could be integrated into Venator-110, Table 4 offers a comparison of Ammonia, Methanol and Hydrogen.

Table 4: Fuel Suitability for naval vessel (Dr Beard, 2023).

	Hydrogen, H_2	**Liquified Natural Gas (LNG), CH_4**	**Ammonia, NH_3**	**Methanol, CH_3OH**	**F-76**
With Tank (Gross) Volumetric Energy Density (MJ/l)	2.7-7.9	13.2	11.5	14.2-15.1	27.3-31.0
General Storage Conditions	Cryogenic or Pressurised	Cryogenic	Cryogenic or Pressurised	Ambient	Ambient
Space Requirement	7.7-15.7	3.2	3.4-6.4	2.3	1.0
Flast Point (^{O}C)	-253	-162	-33	+12	+61.5
Minimum Ignition Energy in Air (mJ)	0.02	0.29	8.0	0.14	20.0
Explosion Risk	Large flammability range with low ignition energy	Medium flammibility range with reasonable ignition energy	Medium flammibility range with high ignition energy	Medium flammability range with high ignition energy	Small flammability range with high ignition energy
Toxixity	None	None	Highly toxic to humans and aquatic life	Toxic to humans, but very low toxicity to aquatic life	Refence Fuel
Combustion Emissions	NO_X	NO_X & Lower CO_X	NO_X	NO_X & Lower CO_X	CO_X, NO_X, SO_X & PM

4.2. Future Fuel Performance Assessment

Before the impact that both ESTs and future fuels has upon Venator-110 can be assessed, a baseline performance assessment of a future fuel powered Venator-110 is required. This baseline assumes that ESTs are not implemented.

The future fuel baseline for Venator-110 is based on methanol, which offers both good TRL and integration into the Venator-110 platform. This paper does not offer a performance comparison for Ammonia or Hydrogen variants.

4.2.1. Methanol Assumptions

When assessing the performance of a methanol Venator-110 variant, the following assumptions have been applied:

- Venator-110 methanol retains the same capabilities, other than range, as the base vessel Venator-110 F-76.
- Current F-76 tanks have been converted to methanol, cofferdams are needed where methanol tanks are not adjacent to ballast water tanks (Lloyd's Register, 2023). Although, companies are developing solutions which significantly reduce cofferdam size requirements.
- Venator-110 methanol retains the same displacement and installed power as the base vessel.
- Venator-110 methanol uses 95% methanol and 5 % diesel as a fuel emulsion to improve combustion (Shukla, et al., 2021).
- The methanol combustion engines have a SFC of 380g/kWh (Shukla, et al., 2021).

- The dual fuel methanol engines have a comparable or improved delivered density when compared to the current MTU 16V8000M91L installed on Venator-110 F-76 (Shukla, et al., 2021).
- Values for the annual bunkering frequency are based on the operational profile (Figure 2) assuming tank capacities do not drop below 40% for typical operation.

4.2.2. Performance Baseline

Table 5: Comparison of Venator-110 Methanol and F-76 variants without EST Installed.

Item	**Value**		**Performance of Methanol as a Percentage of F-76 (%)**
	Methanol	**F-76**	
Range at 15kn (nm)	*2880*	*6000*	*48*
Annual Bunkering Frequency	*30*	*20*	*150*
CO_2 Emissions Per Nautical Mile (tCO_2/nm)	*0.0103*	*0.2065*	*5*

Assuming green methanol is bunkered, CO_2 emissions are associated with the use of the 5% diesel fuel as an emulsion, as methanol internal combustion technology matures this proportion should significantly decrease (Shukla, et al., 2021). However, even when 100% methanol is combusted, CO_2 emissions will still be generated by the ship; therefore, green methanol must be used. This will create a carbon cycle, meaning that the resulting CO_2 ship emissions are net-zero.

Without the use of ESTs, Venator-110 methanol offers a significantly reduced range, and increased bunkering frequencies when compared to the F-76 variant.

ESTs are imperative to mitigate the need to trade-off operational capabilities when integrating future fuels into the future naval fleet. Table 6 and Table 7 provide insight into the need for ESTs at 15kn cruising speed and across the operational profile accordingly.

4.2.3. Performance of Venator-110 with ESTs.

Table 6: Venator-110 EST Comparison at 15kn

Total EST Saving	**Range at 15kn**	
	Methanol (nm)	**F-76 (nm)**
All Off, 0%	*2880*	*6000*
All On, 21%	*3480*	*7260*

Table 7: Venator-110 Methanol EST Performance Based on Operational Profile

Operational Profile (nm)	*73550*	
Total EST Saving	*All Off, 0%*	*All On, 13%*
Annual Bunkering Frequency	*34*	*30*
Total CO2 Emissions (tCO2)	*759.5*	*660.8*

At 15kn, Table 6 shows that the assessed ESTs can provide a conservative increase in range of 600nm and 1260nm for methanol and F-76 variants accordingly. This both significantly increases the viability of future fuel powered variants and allows for increase operational capability of F-76 powered variants.

Across the operational profile of 5000hrs/year underway at sea, Table 7 shows the that the use of ESTs reduces the annual bunkering frequency from 34 to 30, further improving the viability of a methanol variant of Venator-110.

Across the operational profile, ESTs offer a reduced energy saving when compared to when the vessel is underway at 15kn. If the operational profile was optimised for this speed, the difference in EST energy saving could be significantly less.

5. Conclusions

Commercially available ESTs can be integrated onto naval vessels to enable improved operational capability, reduced running costs and lower emissions via efficiency improvements.

For this study, the effects of adding an absorption chiller plant, a Hull Vane, and a deployable kite to Venator-110 powered by both F-76 and methanol were investigated. No detailed physical ship integration or interface studies were undertaken.

The assessed combination of ESTs reduced the power requirements of Venator-110 by 13% across the defined operational profile. The Hull Vane provided the greatest potential energy savings for Venator-110; however, this may not be the same for all vessel types with EST suitability and selection being unique for every vessel type.

With all of the selected ESTs being utilised, at 15kn the F-76 powered Venator-110 has a range of 7260nm; a 21% improvement when compared to the 6000nm range when the assessed ESTs are not engaged. This study also investigated the performance of a Methanol powered Venator-110, and without ESTs, Venator-110 running on methanol at 15kn offers a range of 2880nm; this range is increased to 3480nm when utilising all of the assessed ESTs. Therefore, ESTs will significantly contribute to the successful integration of future fuels onto naval vessels. By implementing ESTs alongside future fuels, the need to trade operational capabilities is reduced when developing future fuel powered vessels; however, even with all assessed ESTs being utilised, the range of the methanol powered Venator-110 at 15kn is only 58% that of the range of the F-76 powered Venator-110 with no ESTs.

To mature this study, further technical development of the Venator-110 methanol variant is required. This would enable the selected ESTs to be further optimised for Venator-110's operational profile. To validate the potential fuel savings, CFD or model towing tests of a bespoke Hull Vane designed for Venator-110 is required.

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