Pacific Blue Shipping Partnership – Technical Working Group

Technical Working Paper 2: Potential shipping emissions abatement measures

Purpose of Paper

The Governments of Fiji and Marshall Islands have identified an urgent need for large-scale financial investment to catalyse a multi-country transition to sustainable, resilient, and low carbon shipping. The PBSP targets domestic shipping to zero carbon by 2050 with a 40% reduction by 2030.

This paper provides a summary of the most recent UMAS assessment of available abatement measures and uses this to offer an initial assessment of abatement measures applicable to Pacific country transitions.

Structure of Paper

This paper has been prepared for the Technical Working Group providing advice to a coordinating committee chaired by RMI/Fiji. The TWG Terms of Reference includes a request for delivery of the following outputs:

- Analyses that identify and rank potential measures (operational and technological) available internationally for decarbonisation and the Marginal Abatement Cost (MAC) Curves associated with these
- Review analyses against a Pacific operating scenario to determine: (i) what are the most effective available measures we can take in the target countries now/very near future (and the Marginal Abatement Cost (MAC) Curves associated with these) and (ii) what are the potential measures for Pacific deployment that require research and development (and the Marginal Abatement Cost (MAC) Curves associated with these)

This paper first summarises the latest UMAS technical reports on abatement measures[i] prepared for the UK's Clean Maritime Plan: Maritime 2050 environment route map[ii], and associated MACC, and considers the international evidence against Pacific scenarios to identify short and long term priorities for action. It quotes heavily from the latest research available. [i, ii, ix and xi]

The International Research on Abatement Measures

A number of studies on abatement options for international shipping have been conducted since the release of the 2nd and 3rd IMO GHG reports from a variety of sources (in particular CE Delft, UCL, UMAS, DNV-GL, Lloyd's, ITF-OECD). More recently this has included domestic shipping studies for northern European countries. The first MACC for the global fleet was created in 2009 alongside the 2nd IMO GHG Report. A number of additional curves have been constructed at global fleet, a small number of national fleets and individual vessel types (although none at Pacific fleet or country scale to date).

Studies to date have primarily focussed only on emission reduction potential for operational vessels. There is growing recognition that this assumes all up and down stream emissions are being considered and captured in other sectors and further studies are needed to address full "well to wake" (and "well to break") logistics chains. Studies to date have also focussed predominately either on global fleet scenarios or developed and major shipping interest state scenarios. The applicability of such findings to Pacific operating scenarios, given their often unique characteristics has yet to be established. This is discussed further in chapter four.

The international science is becoming more concise and industry innovation more competitive and advanced. For Paris Agreement targets to be met, Zero Emissions Vessels need to be demonstrated as operational by 2030. Numerous operational and technology interventions are available at market which can collectively produce significant efficiencies in fuel and emissions, potentially upwards of 50% reductions by 2030. Uptake is dependent on economic viability with some initial measures available at negative abatement cost and others at close to equivalence for projected carbon cost. For greater decarbonisation, ultimately alternative fuel(s) are required with methane, hydrogen and ammonia as preferred candidates.

The UMAS study considers that the different options for reducing GHG and air pollution from both UK domestic and international shipping are, for the most part, the same and can be considered in four categories[1]:

- Technologies that can increase energy efficiency;

[1] For more detailed description of each individual category see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

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- Operational or behavioural change that can increase efficiency;
- Technologies specific to the capture/treatment of exhaust emissions (GHG and air pollutant emissions); and
- Alternative fuels and energy sources and related machinery.

It is noted that there are many available technologies and operational changes that can increase efficiency and could be used now for both new and existing ships (i.e. retrofits). However, these will not be able to achieve deep reductions in GHG and air pollutant emissions on their own, and so new fuels (with associated machinery) will be needed.

The impacts of the abatement options presented in the four tables below are summarised as a total reduction potential per annum for each category of abatement options. The scale of possible impacts is categorised as: low impact on emissions (e.g. 0-10% reduction), medium (10-30% reduction) and high (30%+ reduction), relative to today's levels. There is a 'full' impact category, which corresponds to an option that fully abates an emission. There is also a 'negative' impact category, where an option that abates one type of emission causes an increase in another.

The assessment also included consideration of additional technologies specific to the capture/treatment of exhaust emissions controlling air pollutant emissions may also be required. This is because the rate of introduction of new fuels and machinery may not be high enough to sufficiently displace continued use of the existing fuels and machinery and, by association, their higher levels of air pollutant emissions (EEA, 2013). In many cases, there are co-benefits from the use of such technologies because some options that reduce GHG emissions also reduce air pollutant emissions. However, some options that reduce air pollutant emissions can reduce energy efficiency and therefore increase GHG emissions.

The tables also show:

- The estimated level of maturity (or 'technology readiness level' (TRL))[iii] for widespread implementation. A high TRL (e.g. 9) indicates that the technology is mature and available, and lower values are associated with full-scale demonstrators, pilots or laboratory prototypes
- The expected date by which the category of options is expected to be commercially available
- The 'cost reduction potential', which is an estimate of the potential for further research, development and demonstration effort to achieve significant cost reductions (whether reductions in capital or recurring costs). Cost reductions are categorised approximately as low (0-20% reduction), medium (20-50% reduction) and high (50%+ reduction) relative to today's levels

Category 1: Technologies that increase efficiency

Options	Impacts/benefits			Commercialisation		
	GHG abatement	**Local air pollutant abatement**	**At sea air pollutant abatement**	**TRL**	**Expected commerc. date**	**Future cost reduction potential**
Propulsion devices, including modifications to the propeller and adjacent area (ducts, fins etc.)	Low	Low	Low	TRL9	Currently available	Low
Ship design (changes in the shape of the hull, addition of bulbous bows etc.)	Medium	Low	Medium	TRL9	Currently available	Medium
Main machinery & engine modifications (design improvements to the diesel engine, energy recovery from waste heat etc.)	Low	Low	Low	TRL7-9	Up to 10 years	Medium
Auxiliary (energy management and recovery systems, design improvements and control systems for machinery such as pumps etc.)	Low	Medium	Low	TRL7-9	Currently available	Medium

Category 2: Operational or behavioural change that can increase energy efficiency

Options	Impacts/benefits			Commercialisation		
	GHG abatement	Local air pollutant abatement	At sea air pollutant abatement	TRL	Expected commerc. date	Future cost reduction potential
Speed/voyage optimisation related	Medium	Low	Medium	TRL9	Currently available	Low
Condition related (trim, hull coating selection and maintenance etc.)	Medium	Low	Medium	TRL9	Currently available	Low
Port related (just in time arrival/turnaround at berth)	Low	Medium	Low	TRL9	Currently available	Low

Category 3: Technology specific to the capture/treatment of exhaust emissions

Options	Impacts/benefits			Commercialisation		
	GHG abatement	Local air pollutant abatement ***	At sea air pollutant abatement ***	TRL	Expected commerc. date	Future cost reduction potential
NO_x emissions control: Selective catalytic reduction (SCR) and Exhaust gas recirculation (EGR), exhaust gas technology, water in fuel (emulsion fuels)	Negative-Low	High	High	TRL9	Currently available	Medium
SO_x emissions control: Exhaust gas cleaning systems	Negative	High	High	TRL9	Currently available	Medium
Particulate matter (PM) (including black carbon (BC)) control: diesel particulate filters for reducing PM and BC, diesel oxidation catalyst for reducing SO_x, PM and BC, electrostatic precipitator	Negative-Low	High	High	TRL8*	Currently available **	Low
Methane catalysts for removal of methane (CH_4) in exhaust	High	Low	Low	TRL 5	Approximately 5 years	Medium
On board carbon capture, for storage and sequestration (CCS)	High	Low	Low	TRL 4	Approximately 10 years	Medium

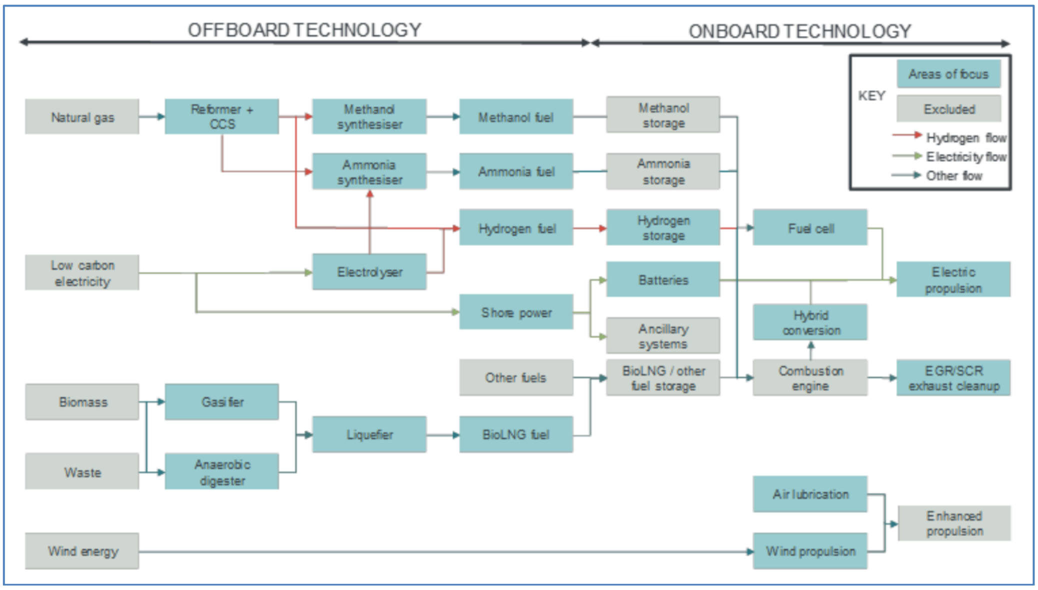
Note: * *for 4-stroke diesel engines. ** Applications in smaller vessels, more developed applications in trains and tractors, which can be marinized (made suitable for the marine environment). *** The abatement estimation is specific to the emissions that the technology is designed to abate (as specified in the row header).*

Category 4: Alternative fuels and energy sources and related machinery.

Options	Impacts/benefits			Commercialisation		
	GHG abatement ***	Local air pollutant abatement	At sea air pollutant abatement	TRL	Expected commerc. date	Future cost reduction potential
Wind propulsion	Medium	Low	Medium	TRL7-8	Next 5 years	High
Solar	Low	Low	Low	TRL9 **	Currently available	Medium
Battery	Low-Full*	High	Low-High*	TRL8-9	Currently available	High
Shore power (cold ironing)	Low	High	N/A	TRL9	Currently available	Medium
LNG/CNG	Low-Medium	Medium	Medium	TRL9	Currently available	Low
Biofuels (crop-based)	Full	Medium	Medium	TRL9	Currently available	Low
Biofuels (waste-based)	Full	Medium	Medium	TRL4-8	Next 5 years	Medium
Renewable hydrogen (including when stored as ammonia)	Full	Medium	Medium	TRL6-8	Next 5 years	High
Electro-fuels (including methanol)	Full	Medium	Medium	TRL5-8	Next 5 years	High

Note: * *Dependent on route length and battery application e.g. load levelling or full propulsion. ** Seen in sailing boats but not in commercial shipping. *** These assessments are for GHG emissions in operation, some options can have significant upstream emissions, see discussion in text.*

Summary of future energy technologies and machinery for shipping[iv]

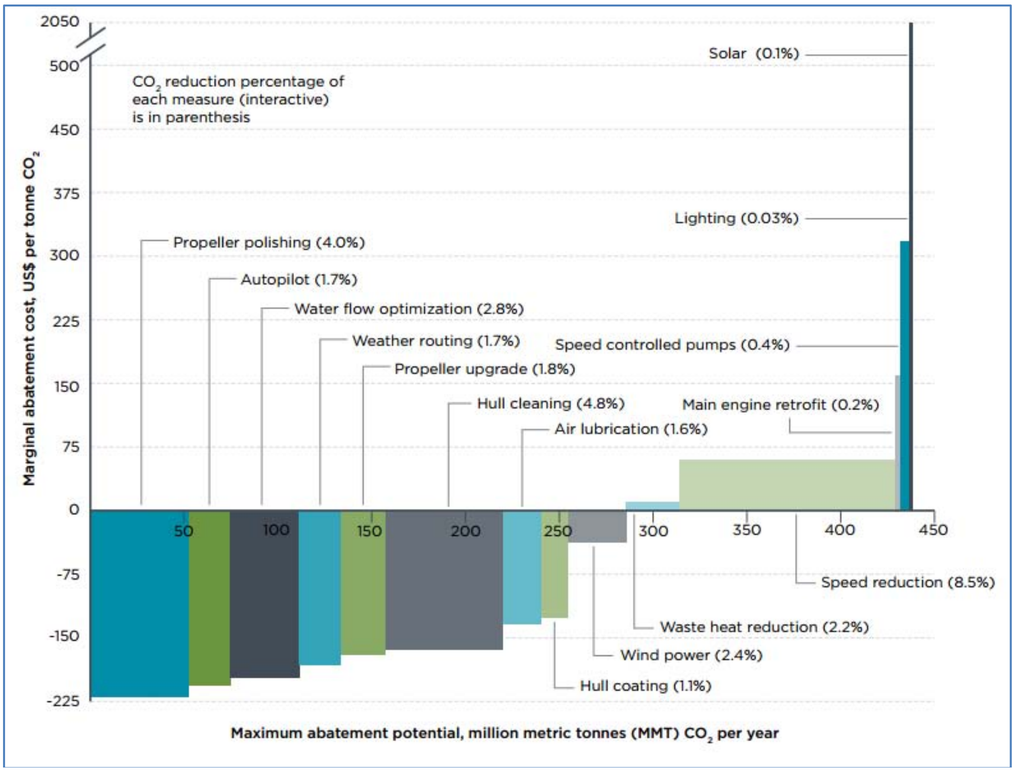


Marginal Abatement Cost Curves

A Marginal Abatement Cost Curve (MACC) is a function that shows the cost in terms of dollars per unit tonne of GHGs, which is associated with the final unit of reduced emission[v]. This last unit of emission abatement is measured in amounts of CO_2 equivalents reduced.

This 2017 version of the global fleet abatement potential is typical and shows abatement costs for a range of measures to achieve 50% of current fleet emissions. The measures below the horizontal line are considered net-negative; those above the line incur additional cost. This cost then needs to be considered against the project market price of carbon. The MACC output is entirely dependent on input. In this example, no MAC is included for alternative fuels, slow streaming or emissions reduction technology (e.g. catalysts, scrubbers).

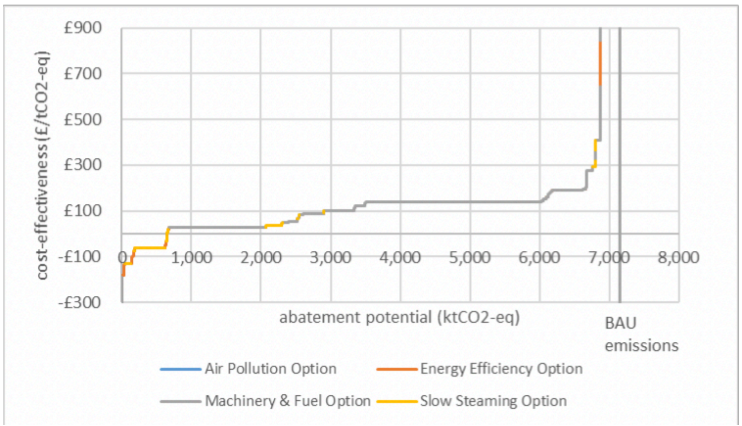
Marginal CO_2 abatement costs of analysed technologies[vi]



The UMAS UK study constructed MACCs inclusive of the emissions reduction (or 'abatement') potential and cost-effectiveness of all four categories discussed above to 2031 and 2051[2]. The abatement potential is illustrated in terms of MACCs. In this context, marginal abatement costs refer to the cost of reducing one additional tonne of GHG emissions from UK shipping in comparison to the BAU scenario. The BAU scenario includes both operational emissions and emissions from ships when they are berthed at port.

MACCs are essentially 'what-if' analyses that show by how much emissions could be reduced by implementing different abatement options and at what cost for each additional tonne of emission. They assume that the order in which those options are implemented is such that the cheapest option is implemented first, followed by the next cheapest, and the next cheapest and so on.

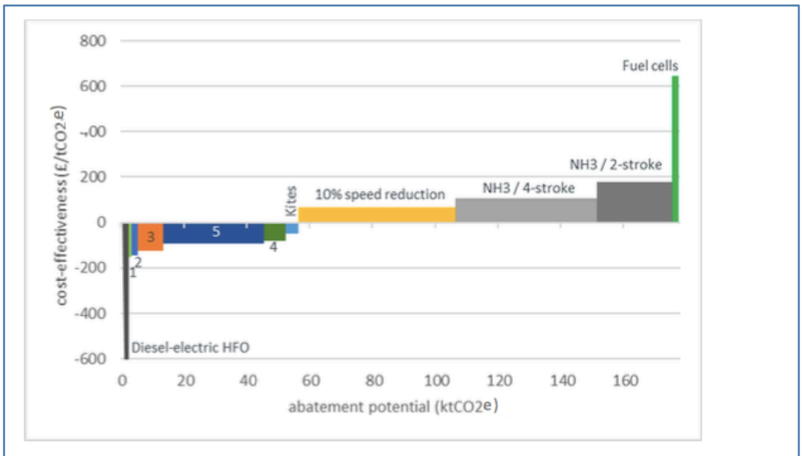
MACC of UK domestic shipping in 2051 (2018 prices)



Note: BAU emissions include both operational emissions and emissions at port. Source: CE Delft analysis of UMAS model

The MACC shows that, for UK domestic shipping in 2051, it is estimated that 9% (7.2 $MtCO_2e$) of total UK domestic shipping emissions could be saved by implementing options with a negative net cost per tonne of CO_2e. In addition, it is estimated that 6.0 $MtCO_2e$ could be saved at a net cost of less than £239/tCO_2e (2018 prices) (the price of CO_2e in that year as projected by BEIS). The reason that this potential is so high (84% of total emissions under BAU) is that it includes many zero carbon fuel options, such as ammonia and methanol.

UMAS also constructed individual selected representative ship types at UK domestic and international scale. While none are directly representative of typical Pacific shipping, the results are illuminating and the MACC for 10,000-34,999 dwt bulk carriers in 2051 (real 2018 prices) is given below. This shows that for this vessel type, around 30% of abatement is available through operational, technology (primarily propeller and wind hybrid interventions). Slow steaming, with a cost premium for additional voyage time pushing it into the cost-positive quadrant, provides more than 50% of total emission reduction after which ammonia, at varying levels of efficiency and cost are needed and fuel cells at high cost provide the final savings.



Notes: 1 – Energy saving lighting; 2 – Boss cap fin; 3 – Turbo-compounding in Series; 4 – Solar power; 5 – wind assistance (wings/rotors/sails).

[2] For more detailed explanation on the UMAS MACCs, consult https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

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Lessons from the International to Inform Pacific Applicability

The Pacific domestic shipping scenario has unique characteristics which combine to result generally in a below par shipping service. There are various compounding factors which affect Pacific SIDS, making sustainable, cost-viable sea transport particularly challenging, including: minute narrow economies, often long distances and small loads with high imbalance of import/export loadings and extreme dependency on imported fossil fuels. All except PNG are net importers. Domestic shipping is often only marginal economically, with severe constraints on access to affordable financing and insurance. There is a lack of commercial shipping service providers willing to service “uneconomic” routes, often the most remote and vulnerable communities.

Our transport scenario is unique. Our priorities are different – we don't have rapid rail, megacities, super ports or inland waterways. Some of countries don’t have roads or airports. It is not just a case of taking the front running measures from the international sector and scaling them down to fit our countries needs.

Despite being described as micro-states and micro-economies. Pacific transport lines are as long as any in the world. While our ships are small in comparison, they still have to operate on long blue water routes. We already have the highest shipping cost per capita in the world. Our lack of economies of scale means we will probably never have the bunkering capacity to introduce new fuels. So measures such as wind and hybrid engines are likely more important here than in Europe.

Key knowledge from the UMAS work to inform Pacific scenario decision-making on transition pathway abatement measures planning are summarised below:

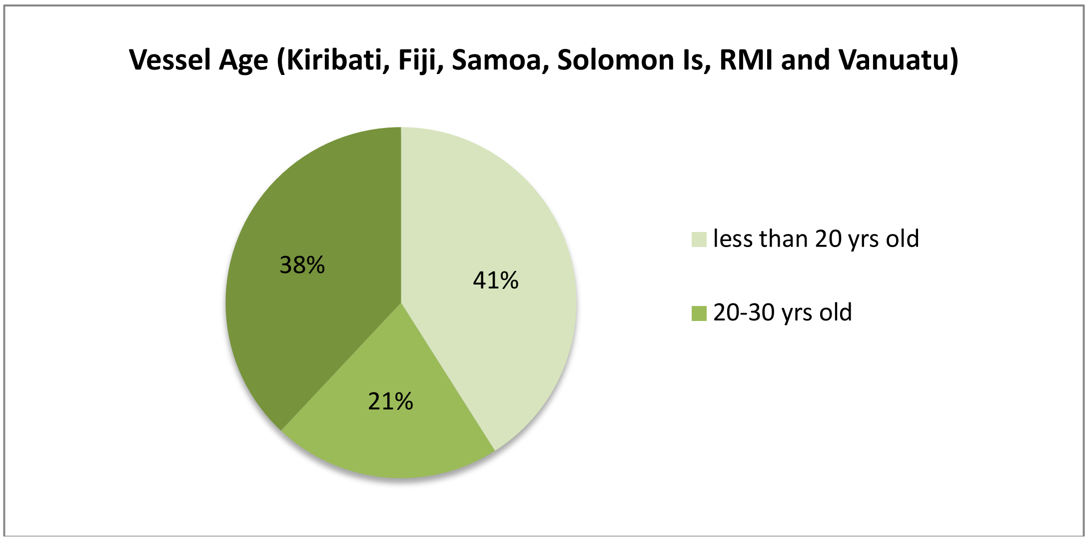
UMAS finding/observation	Comment regarding Pacific scenario
Substantial GHG emissions reductions could be achieved while also reducing the overall operating costs of the ship (i.e. at negative cost-effectiveness). These are typically options, which improve energy efficiency. However, there are barriers that would need to be overcome for the uptake of these options to increase in practice.	No comprehensive analysis is yet available at regional or country domestic fleet levels for Pacific countries. There are systemic data collection and access issues, although there is sufficient data availability to commence in RMI and Fiji There is also sufficient case study literature to assume that, while highly ambitious and dependant on a variety of economic and capacity factors, there are no insurmountable technology barriers to achieving a 40% reduction by 2030. Although using different abatement measures and combinations, it is predicted a significant portion of this (initially operational/behavioural change, propeller, hull, auxiliary power, wind hybridisation) is probably achievable at negative or near neutral cost effectiveness as well.
The cost-effectiveness of abatement options varies substantially across ship types, reflecting the diversity of ships in operation. Common across all ship categories is the finding that a shift to low or zero emission fuels is needed for material emission reductions to be realised of the scale required to achieve zero emission shipping.	Pacific scenarios also encompass a variety of ship types, albeit with less range and of much smaller scale than UK fleets. Small boat fuel use and emission make up a proportionately large sub-sector. Operational environments are of course quite divergent physically and economically. Cost effectiveness analysis has not yet been done in Pacific environments, but it is assumed that there will also be wide variance across the Pacific fleet. Low or zero emission fuels will also be needed for material emission reductions to be realised at scale.
Alternative low emission fuels will be essential to achieve zero emission shipping, particularly beyond 2030. There are a number of fuels that could be used. Bio-fuel has the lowest cost and assumed zero emissions but wasn't considered further in the UK study due to issues of upstream and supply emissions and competition. Ammonia, methanol and hydrogen are considered and are included in the modelling in combination with a variety of compatible machinery options (for example, internal combustion machinery and fuel cells). The analysis suggests that: ○ ammonia and methanol are the preferred options over hydrogen for most of the fleet because of the higher costs of on-board storage for hydrogen and ○ ammonia is generally preferred over methanol for the majority of ship types and sizes, though an adverse side-effect of this is the scale of associated NO_X emissions that would need to be addressed. There is, however, substantial uncertainty around both the costs and efficiency of low emission fuels in both the near and long terms. This is important to recognise as even small changes in the costs and efficiency of the low emission fuels could change the commercial incentives to shift towards any of these three options – hydrogen, ammonia and methanol. This points to facilitating the flexibility to keep open multiple options for alternative low emission fuels until there is greater clarity over the potential pace of technology development and cost reduction and the magnitude of potential changes in the costs if using these fuels in the maritime sector.	No full assessment of preferred alternative fuel has been undertaken in the Pacific. LNG as a transition fuel has been discounted. Biofuel from farmed sources has been considered but generally would require high carbon process to bring to market at any scale. Bio-fuel from waste, either from terrestrial feedstock on high islands with suitable arable land or marine algae/seaweed in atoll states is a possibility that should not be discounted in the medium term but will require substantive R&D and synergy with other energy sector decarbonisation pathways. Ammonia, methanol and hydrogen would require supply from outside the region or a greatly improved penetration of excess clean electricity to produce locally. This is unlikely to happen in the short term. However, it is possible to conceive that if the geo-thermal potential of Vanuatu was harnessed or OTEC proved viable at scale in atoll states for example, these could provide future regional production nodes. Considerable barriers would exist. As with the UMAS UK findings, with no obvious Pacific front-runner in the search for a preferred alternative fuel, the logical track is to keep open multiple options for alternative low emission fuels until there is greater clarity over the potential pace of technology development. This does not create a barrier to transitioning with other abatement measures immediately given sufficient measures exist at relatively low cost to deliver on the 2030 target.
There are similar transition pathways for achieving zero emission shipping for both the UK domestic shipping and UK international shipping fleets, except for a small subsector of the UK domestic shipping fleet (and a very small subsector of the UK international shipping fleet). For these fleets (a subset of the short- range passenger ferries (Ferry-RoPax) and	This reflects that short range and passenger ships are a small sector of the UK fleet. Advances in battery technology and electric propulsion are currently limited to this range and are being aggressively developed, primarily in northern Europe though there is recent interest from China for containerized river feeder traffic and some specialist applications. In large part, this reflects access to surplus renewable electricity

short-sea freight ships (Ro-Ro)), a shift towards battery electrification (as opposed to the use of a liquid fuel) is likely.	production (primarily hydro/geothermal in Scandinavia and advanced renewable penetration in some European economies. The Pacific lacks such infrastructure, not all the region even has full access to electricity and the region has the highest global dependency on imported fuel. Renewable electricity is highly desirable and the focus of most country NDA's. However, most grid supplied power for maritime charging would not be emissions free under current scenarios and dedicated charging facilities would be a political decision between allocating electricity to transport at the expense of other sectors. There are some niche areas where there is potential for high uptake of e-drives, particularly in the tourism sector and potentially outer islands fitted with micro charging-systems from Wind/PV. However, electrification for main propulsion faces significant barriers for scalability in the short term. For similar rationale, cold ironing is also likely not a Pacific priority. Renewable electricity for auxiliary power supplements (solar and wind) has higher applicability though consideration needs to be given to the abatement cost of this measure. Given the rapid advances in both electric propulsion and auxiliary systems and battery technology and price, this situation needs to be regularly reviewed.
The costs to [UK] business associated with achieving different levels of GHG and air pollution emission reduction include capital costs (the costs associated with the purchase of, or investment in, ships and equipment); voyage costs (which are dominated by fuel costs); non-fuel operating costs (e.g. costs to maintain ships and equipment); and opportunity costs (e.g. reductions in revenue that can occur as equipment is fitted to a ship that takes up space that could be used for cargo or because of changes in operating speed). The costs to business of the scenarios are explored in detail, recognising that costs to individual businesses (i.e. those who would be responsible for implementing the abatement options) are likely to vary substantially depending on the nature of their shipping activity each year and the characteristics of the vessels they operate. The costs to business are explored by aggregating across the ship types and sizes, with more detail provided in the Technical Annex.	No analysis of the costs to Pacific business has been undertaken. It is an essential early step and highlights the technical capacity that must be built and retained in region across all aspects of the sector, regulator and industry, to backstop a successful transition. It is also clear that carbon pricing will play an increasing role in any shipping decarbonisation pathway. The implications of this in a Pacific scenario are not fully understood and also need urgent analytical work.
There is a significant penetration expected of primary renewables technology in all these scenarios. Primary on-board renewables technologies (solar and wind) are included as a selection of energy efficiency options as they reduce the demand for energy from the main and auxiliary engines. The fuel used in those main and auxiliary engines is then quantified separately, modified to account for reduced demand if primary renewables are used on board. Solar energy and wind propulsion (both kites and rotors/sails/wings) are used across all four scenarios, with the strongest take-up in the most stringent GHG reduction scenario. The penetration of these options is affected by their respective compatibility; for example, it is assumed that rotors/sails/wings are not compatible with container ships and ferry Ro-Pax (due to lack of availability of deck space), which explains why they see take-up for the oil tanker ship type only.	Historic and current work finds many Pacific scenarios with close to ideal wind abatement potential to achieve direct savings of in excess of 20% (and with potential for greater) for selected vessels types. Wind hybrid is expected to play a significant role at the scale of shipping common in Pacific domestic scenarios. Individual vessel configuration will limit choice in regards retrofits but this is not expected to be a major restriction for new build options. Greatest savings will occur where alternative energy interventions, hybrids and auxiliary generation will be most effective when included at the outset of the design process and combined with other measures (including hull design, coatings, rudders and propeller choices. Current modelling for retrofits of wind assist in RMI are indicating possible overall reductions of up to 50% dependant on measures (see RMI case study below).

Pacific Case Studies

There are distinct country profile differentials consistent with the size, population and economic capacity ranging from Fiji to Tuvalu[3]. Consistent across the range however a number of core commonalities:

- Size – vessels are small with all vessels under 10,000 tonne and most under 1,000 tonnes. Vessels under 15m are usually outboard motor powered and make up a significant proportion of all national maritime emissions and fuel profiles.
- Age – there are a larger proportion of older vessels, which allows for consideration of fleet replacement over time.
- Type – all including vessels, including those under 15m are used in blue water conditions. Amongst larger craft there is a preponderance of landing craft type vessels for moving heavy cargo and multi-purpose passenger/cargo Ro-Ro vessels.



Source: SPC[vii]

Accurate domestic maritime data has been consistently identified[viii] as a barrier in the region and remains an on-going challenge for future planning in this sector.

Fiji and RMI are both progressing national action plans, in Fiji's case via its Low Emission Development Strategy. The maritime chapter of the LEDS sets out a range of emission reduction scenarios, the most ambitious of which is aligned to a 40% reduction by 2030 and recommend initial targets for emission reduction via operational and technology intervention.

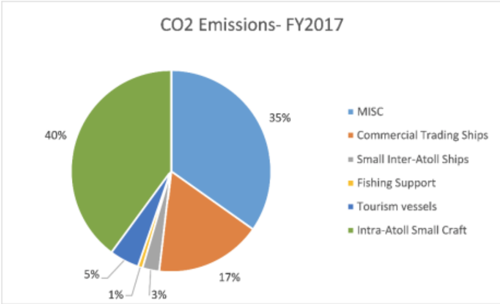
Republic of Marshall Islands

In 2015 RMI announced its intention to develop a national programme of work to decarbonise its own shipping in line with its submission to the IMO for international shipping reduction commensurate with 1.5 degrees C and established a regional Centre of Excellence to drive this transition. The consequent MCST Framework sets out a pathway for decarbonisation and a number of projects and programmes are now active under the Framework for various aspects of the strategy. In this regard, RMI presents as the market leader in the Pacific.

Recent work by ADB[ix] and under the German funded TLCSeaT project[x] provides an accurate baseline for RMI's fleet and an initial estimation of national maritime fuel use and emissions by subsector. Subsequent analysis by the Hochschule Emden/Leer[xi] assesses potential for retrofitting government shipping assets and finds that savings of up to 50% can be projected from a combination of measures centred around either Flettner Rotor or soft sail retrofits.

3 See country profiles PBSP-TWG Technical Working Paper 1

Shipping Activity	Distance pa (nm)	Consumption (litres pa)	CO2 emissions (t CO2)
MISC	49,535	989,074	2,648
Commercial Trading Ships	29,740	486,719	1,303
Small Inter-Atoll Ships	26,721	77,452	207
Fishing Support	6,678	21,682	58
Tourism vessels	-	136,260	365
Intra-Atoll Small Craft		1,277,000	3,038
Grand Total	**112,674**	**2,988,188**	**7,619**



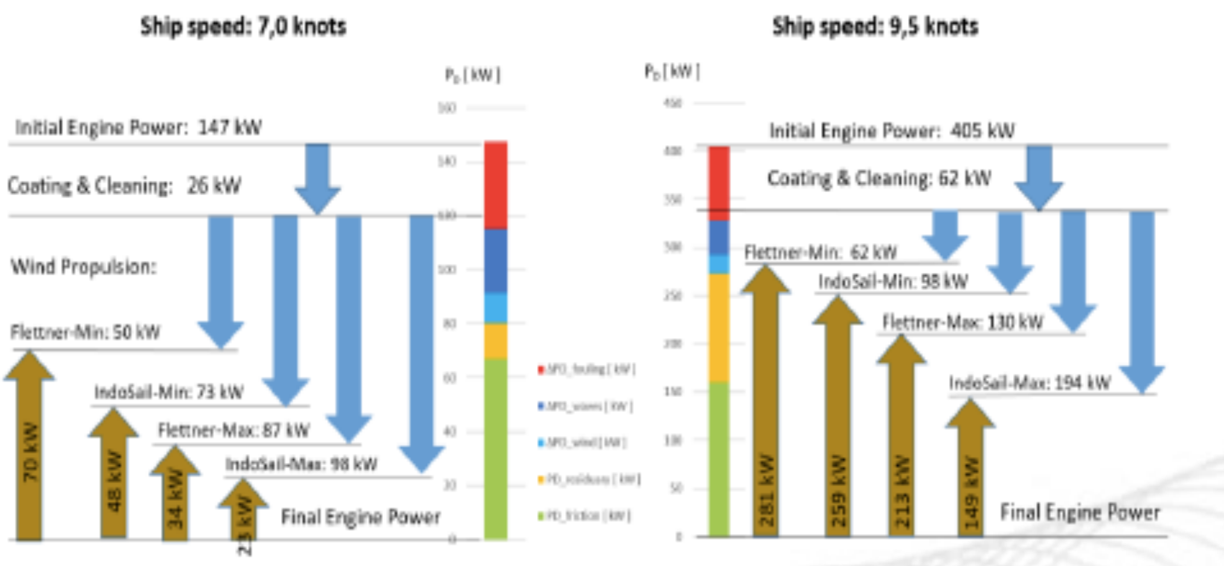
All Domestic Commercial Shipping Fuel Consumption & CO_2 Emissions

The following captures the key learnings from this new body of knowledge. It is noted that this work is focussed on retrofit options for existing assets. The HEL study is focussed on options for reduction within the current RMI government fleet. The assessment found that the combination of operational measures to raise the ship's efficiency and the use of renewable energy has the potential to reach the short and mid-term NDC. The project should demonstrate the potential of fuel and emissions savings of 50% for one or more ships of the LSC fleet on the base of retrofitting. The following measures were considered:

Summary of Options structured in groups

Operational measures	Technical measures	WASP Retrofit	Auxiliary energy	Newbuilding examples
Slow steaming	Hull cleaning	Flettner rotor	Efficiency improvements	Kwai-similar
Voyage and route optimization	Drive train adaption	IndoSail System	Photovoltaics	Greenheart-Project /
Navigation	Engine efficiency improvements	Traditional rig Kwai-like tripod rig	Wind turbines	Maruta Jaya (IndoSail project) similar
Cargo hold efficiency	Diesel-electric (ready for hybrid)		Increased battery capacity	Fast multihull

Summary of potential emissions savings including slow steaming options



Key observations:

- The potential savings from operational improvement identified (-17 to -27%)[ix] requires a reduction in government shipping capacity to achieve and is significantly smaller than the NDC targets initially set by RMI (32% reduction by 2025) and the more recently revised NDC (45% by 2030).
- Wind/sail technology has by far the highest potential for reducing ship propulsion fuel use/emissions– there is currently no other option scenario that meets the requirements for zero-emission maritime transport. Overall wind conditions in the Marshall Islands create high efficiency for wind propulsion and are described as 'close to ideal'.
- Wind and solar technologies are both suitable for the supply of electricity to auxiliary systems and demonstrate strong potential savings.
- Other near future options that would complement wind propulsion, include electric-hybrid drives, biofuels, and fuel cells (hydrogen or similar).
- Speed reduction on the modelled vessels of 26%, in combination with other measures can achieve savings of ~50% using existing asset. New build options, including lighter and better optimised hull designs and custom layout of wind hybrid arrangements combined with other measures could improve substantially on this projection.

Analyses of the Marshall Islands government vessel *MV Kwajalein* in detail show various options and combinations of wind assist technologies that have power saving potential including:

Average power savings for refit with two Flettner-rotors

Ship Speed (knots)	Average Power reduction (kW)	Fuel/Emission savings per nautical mile (%)
7.00	~ 105 kW (excess power: 18 kW)	~ 45%
9.50	~ 130 kW	~ 31%

Power savings for refit with 3-mast IndoSail

Ship Speed (knots)	Average Power reduction (kW)	Fuel/Emission savings per nautical mile (%)
7.00	~ 97 kW (excess power: 67 kW)	~ 50%
9.50	~ 195 kW (excess power: 11 kW)	~ 46%

The following is taken from the ADB report[ix].

Key observations:

- Potential savings from operational improvement (-17 to -27%) sell MISC vessel, slow steaming and just-in-time operations, hull cleaning and propeller polishing, engine tuning, – 700 tonnes CO_2 US$400,000 per annum
- Slow steaming and just-in-time arrival could reduce fuel costs by US$100,000 and GHG emissions by 400 tonnes CO_2 annually across the fleet

Alternative Operating Practices to Consider

Measure	Fuel saving	CO_2 reduction (t CO_2)	Cost Saving (US$pa)	Comment
Majuro Turn Round	3.8%	103 t	$232k	May allow disposal of one ship
Slow steaming	5%-15%	300 - 500 t	$100k	Possibly already being practiced
Hull & Prop cleaning	7%	200 t	$50k	
Engine Tuning	1%	25t	$6k	
Low-emission fuels	-	135- 200 t	-	10% blend with diesel
Total		**~900t**	**$400k**	

[i] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf and https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf

[ii] https://www.gov.uk/government/publications/clean-maritime-plan-maritime-2050-environment-route-map

[iii] https://publications.parliament.uk/pa/cm201011/cmselect/cmsctech/619/61913.htm

[iv] Frontier Economics, E4tech and UMAS (2019) *Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution: Economic Opportunities from Low and Zero Emission Shipping*.

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