Transitioning to Low Carbon Shipping Module

Sustainable Sea Transport Solutions for SIDS: Pacific Island Countries Case Studies

3. The Potential for Renewable Energy for Sea Transport for SIDS

http://unctadsftportal.org/sftftoolkit/transitioningtolowcarbonshippingmodule/chapter3/

Summary

In this chapter we summarise the options that are currently being explored around the globe for the use of renewable energy for shipping and discuss the potential application for SIDS.

Key Themes: Retrofitting – Renewable Energy – Wind – Solar – Biofuel

There is a growing tide of research supporting renewable energy use for shipping. Renewable energy, including wind, sun, wave and biofuel/gas, has been identified in most studies as contributing to sustainable sea transport in the future. However, research and deployment for renewable energy in shipping lags significantly behind other energy use sectors. Near future efficiencies from renewable energy are most likely to be seen at the smaller ship scale travelling at slower speeds. With minimal investment, this is the sector that might provide the quickest results from renewable energy uptake, making these advancements of particular interest to SIDS. New technologies are making headway in the creation of vessels powered to varying degrees by renewable energies, however the characteristics of SIDS fleets means that the focus should be on retrofitting existing vessels with renewable energy capabilities.

3. The Potential for Renewable Energy for Sea Transport for SIDS

"The maritime history of the Pacific peoples is recognised as part of the shaping of Pacific societies but is also a basis for comparison in making changes for the future. Not least is the possibility of a renaissance of commercial sail under changing economic relationships between distance, rising cost of fuel, environmental concerns, and the always available Pacific wind systems for assistance in ship propulsion."

Prof Alastair Couper (2009) *Sailors and Traders: A Maritime History of the Pacific*

"No longer an abstract 'pie-in-the-sky' technology, wind assist propulsion could well be a game-changer in the 'Carbon Wars'."
Barry Parker, 4Q (2014) www.maritimeprofessional.com

3.1 Context and Discussion

Renewable energy (RE), including wind, sun, wave and biofuel/gas, has been identified in most studies as contributing to sustainable sea transport in the future. Potential applications include primary propulsion, hybrid propulsion (either combining different RE technologies or partnering RE with non-RE), auxiliary propulsion, and on-board and shore-side ancillary power substitution. RE has varying potential across the global fleet and at all scales, including international and domestic transport of goods, people and services, and for fishing, tourism, research and security/defence. There are numerous RE designs developed to advanced concept stage and increasing numbers of "proof of concept" vessels in operational use.

In this chapter we summarise the options that are currently being explored around the globe for the use of RE for shipping and discuss the potential application for Small Island Developing States (SIDS). On the available science the potential for significant fuel savings and additional performance benefits to vessel operations and secondary socio-economic benefit is high. Industry innovators claim there is no longer a technological barrier to selected RE applications for shipping capable of significant fuel savings using existing mature technologies. Such savings can be substantially more when coupled with other efficiency methods, such as slow-steaming, voyage routing and design changes (see chapter 4).

Research and deployment for RE in shipping lags significantly behind other energy use sectors. Electricity generation in particular has seen RE technology develop at pace and in 2014 was reported to be worth more than USD 270 billion p.a. globally. According to the REN21 Renewables 2015 Global Status Report *"Renewable energy provided an estimated 19.1% of global final energy consumption in 2013, and growth in capacity and generation continued to expand in 2014."* Renewables such as wind, solar and biomass generated an estimated 9.1% of the

The following images are selected from "Appendix D: Chapter 3."

Please refer to this appendix for full size images and sources.

IRENA: "Renewable Energy Options for Shipping," January 2015.

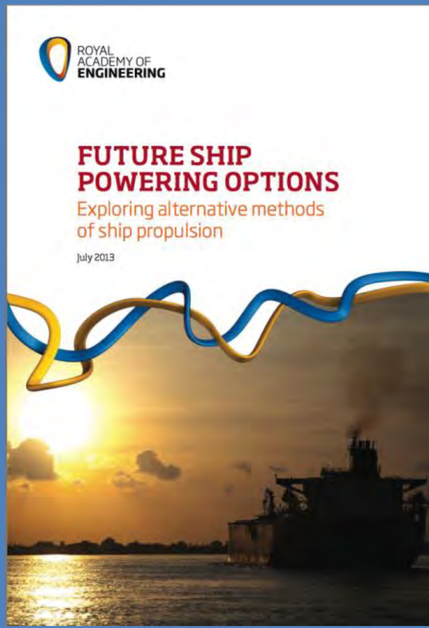
Lloyd's Register: "Wind-powered shipping."

world's electricity in 2014, up from 8.5% in 2013. These sources made up the majority of new power capacity in Europe and are planned to soon power entire cities in the U.S. Major advances are being made in RE for land transport, reflecting the fact that at a global level road transport accounts for 81.4% of transportation energy use, compared to 8% for air transport, and 4.5% for water. Such technological development in these sectors has strong lessons for applications in the shipping industry. But RE development for sea transport has been not accorded the priority of its electricity and land transportation counterparts. Despite the apparent logic and the demonstrated proof from historical evidence, the reasons and barriers to this are complex (see chapter 5).

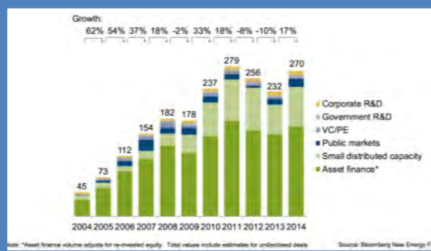
Current industry analyses consider RE playing a minor role in overall shipping industry energy savings, even under optimistic scenarios. There is promising rhetoric from industry leaders for exploring this field but this has yet to be matched by sufficient commitment of investment in research and development (R&D). For example, Scandinavian shipping leader Wallenius Wilhelmsen Logistics (WWL) believes that "*the future of the shipping industry lies in the utilisation of the energy sources already available at sea: the energy from the sun, from the wind and from the waves.*" They also concede that achieving 100% emissions-free shipping for most applications requires further technology advances. Near future efficiencies from RE are most likely to be seen at the smaller ship scale travelling at slower speeds and market leaders of large-scale shipping are increasingly monitoring small ship developments for RE technology innovation.

This should be good news for SIDS in particular, if there was willingness and commitment to invest at this scale of the industry. Larger and newer ships are inherently far more efficient fuel users than small, old ones per tonne/km of cargo moved. It has been estimated that ships under 10,000 tonnes deadweight (dwt) transport less than 4% of world cargo but contribute about 25% of all shipping emissions. However, most innovation effort is targeted at large scale and new asset shipping. The needs of small ships, the most prevalent size servicing the world's most vulnerable in the developing world, and SIDS in particular, is not receiving adequate, if any, priority. Yet with minimal investment, this is the sector that might provide the quickest results from RE uptake. There is potential for smaller fleets of new build RE powered or assisted vessels replacing single, larger, aged assets in developing world, especially SIDS, scenarios allowing greater servicing of currently uneconomic routes to scattered or remote communities.

Despite the highly limited investment in R&D there is a growing tide of research supporting RE use for shipping. The field is still relatively immature but growing fast. Wind, solar and biofuels have greatest initial potential. The enormous variety in global shipping vessel types, usages and routes means different



Royal Academy of Engineering: "Future Ship Powering Options," July 2013.



Global investment in renewable energy technology of USD 270 billion in 2014.

applications will favour use of differing energy sources and technologies. Innovation effort is coming primarily from developed world shipping strongholds in Europe and Japan with advocates arguing for new, and often high-tech, solutions as drivers for national industry reinvigoration in the face of increasing competition from the developing world.

While there are still only a limited number of designs securing the necessary backing to advance to proof of concept stage, these are producing encouraging results in real world deployment. For example, Enercon reported in 2013 that their prototype *E-Ship 1* fitted with Flettner rotors was averaging 25% savings after 170,000 sea miles and OCIUS Technology is reporting 5-100% savings with wind and photovoltaics on fast harbour ferries **(see Fact Sheet – Appendix E)**, dependent on application, with numerous prototypes proving commercially viable over several years in multiple locations. The role and extent of RE technology adoption by the industry will vary greatly depending on the scale, function and operating location of a particular vessel. Costings of leading designs also appear attractive. Innovators B9 Shipping and Fair Transport's *BV Ecoliner* are predicting an additional build and maintenance cost of around 10-15% of total asset cost for projected 60% savings in fuel, significant reductions in main engine and propeller wear, cleaner fuel compliance and possible future emission trading levies.

Energy saving projections vary from close to 100% fuel savings for designs such as *Greenheart* **(see Fact Sheet – Appendix E)** down to the 0.05% main energy and 1% ancillary energy savings of NYK's solar array retrofitted car carrier *Auriga Leader*. University of Tokyo is projecting that fuel costs could be reduced by as much as one-third with the 60,000gt *UT Wind Challenger*. Assuming a conservative 25% fuel saving based on modelling of actual routes, the return on investment (ROI) of each USD 2.5 million sail is projected at 5-10 years. EFFship Project (www.effship.com) modelling of actual routes suggests savings of a similar magnitude with ROI determined by the cost of fuel and emissions compliance.

OCIUS Technology contends that without altering the primary propulsion system of a modern tanker or bulker and retrofitting opening wing sails to "motor-sail," ship operators can expect 20-25% fuel savings on cross-equator shipping routes and 30-40% on same-hemisphere shipping routes with ROI at today's fuel price estimated at 1 to 2 years. In the case of rotor technology, the amount of fuel savings decreases as the ship size increases but savings of 60% for small vessels have been proven historically and up to 19% on Very Large Crude Carriers (VLCCs) are being modelled from multiple sources. In 1984 the USD 40,000 invested in retrofitting soft sails on 300gt cargo/pax vessels proved fuel savings of 23-30% at a ROI of 127% on the most favourable routes and an average ROI of 35% across all Fiji routes **(see Fact Sheet – Appendix E)**.

3.2 Retrofit or New Build Pathways; Primary Propulsion, Auxiliary Propulsion, Ancillary Power?

There are two basic ways for introducing RE: as retrofits to existing fleets or incorporation in new build designs. Most new design work considers RE options for hybrid auxiliary and ancillary use and a smaller number are looking at l00% RE or zero-emissions technology as primary propulsion (e.g. *B9, Ecoliner, Greenheart, Neoline, Orcelle*). Most applications envisage RE as part of an integrated package of efficiency measures. RE also has potential for shore-side infrastructure, primarily for electricity generation.

Most current designs and trials for RE use in shipping envisage new build options. However, for application in SIDS, where ship asset tends to be older, retained in service for longer and much of the replacement stock is second hand, equal effort needs to be focused on retrofit of existing vessels. As seen in chapter 2b, soft sails were successfully trialled in Fiji as retrofits in the 1980s. Rotor technology also has strong retrofit potential where existing deck configuration allows.

RE can also be divided into primary propulsion orientated (e.g. *Greenheart, B9,* OCIUS Technology, Noeline), auxiliary propulsion (e.g. *UT Wind Challenger, E Ship 1, SkySails*) or ancillary power substitution (e.g. *Auriga Leader* and shore-side electricity).

When considering the energy efficiency of the industry it is important that a “whole of operations” approach is taken that fully calculates the energy footprint of the technology from cradle to cradle over a vessel’s lifetime and also considers the primary source of energy used for all aspects of the vessel lifetime – construction, operational life and breaking. For example, there are various concepts and prototypes of electric and hydrogen fuel-cell powered vessels. The “renewable” aspect of these needs to consider the primary source of the energy being used. Where the electricity being used is coming from renewable sources such as hydro, wind or solar then these can be considered RE. But for many SIDS, especially Pacific Island Countries (PICs), where diesel is still the dominant electricity generation source and shore-side generation from hydro or geo-thermal is not an option, great care will be needed not to equate electricity use for shipping with RE approaches. This is particularly the case for “cold ironing,” the practice of using shore-side electricity sources to power ship-board ancillary power systems while in port being now adopted in many major centres to reduce vessel fuel use.

3.3 Current Renewable Energy Foci – Wind, Sun, Biofuels, Wave

The primary candidates for near future RE maritime use are wind, solar, biofuel/gas and wave. The use of RE requires an operational paradigm shift as weather and seasonal routing to maximise exposure to the primary energy source (sun, wind, wave) is essential for efficient performance and new operational processes and systems will need to be acquired

3.3.1 Wind

Wind energy is the primary RE source being pursued for shipping. Prior to the advent of the steam engine, sail monopolised the high seas propelling relatively small ships, by today's standards, and with large crew compliments. Wind is a readily available, if fluctuating, renewable energy that is well understood. The major disadvantages are variations in wind force and difficulty in harnessing propulsion potential when sailing into or close to the wind. Current initiatives include adoption of a number of different types of RE technology targeting a range of ship types from small village-scale ships to large cargo carriers both as primary and auxiliary propulsion.

Wind-assisted propulsion is one of the few approaches offering potential double-digit fuel savings today. Although wind cannot be considered a primary means of propulsion for the majority of the merchant fleet, it presents a realistic option for introducing RE power into shipping by reducing the overall required propulsion power. Advances in materials, automation and control systems, weather routing, and fluid dynamics and wind tunnel testing mean that the industry is better placed to overcome some of the challenges faced in the past. There are strong commercial, societal and environmental drivers favouring adoption of wind-assisted propulsion.

Wind-assisted propulsion works in one of two ways:

1. It maintains the same ship speed for reduced engine power. This means reduced fuel consumption, costs and CO_2 emissions.
2. It increases ship speed for the same engine power. This means reduced voyage times and, potentially, increased ship profitability.

Wind propulsion can be categorised under soft-sail, fixed-sail, rotor, kite and turbine technologies.

3.3.1.1 Soft-sails

Conventional soft-sails attached to yards and masts offer a proven mature technology capable of directly harnessing the propulsive force of wind. Technological advances in the super yacht and yacht racing industries are beginning to be incorporated into industrial use. Sails can be deployed as either primary or auxiliary propulsion and can be either retrofitted to some existing assets or incorporated into new build design.

Current design market leaders include Greenheart's 220gt freighter **(see Fact Sheet – Appendix E)**, Noeline's 5000gt containerised Ro-Ro, B9 Shipping's 3,000dwt bulker, and Dykstra/Fair Transport's 7,000dwt *Ecoliner*. The latter two designs feature versions of Dyna-Rig systems (proven on the super yacht


Dkystra - Ecoliner .


B9 Ship.


Neoliner.

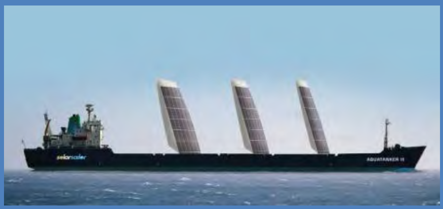

GreenHeart.

Cargo Proa.

Maltese Falcon) that are operated automatically from the bridge, enabling wind to be harnessed more easily, keeping crew sizes comparable with fossil-fuel powered ships and allowing easy access to hatches for loading and discharging cargoes. Greenheart's freighter will deploy a more conventional jib and mainsail combination **(see Fact Sheet – Appendix E).** Italian innovators Seagate have patented folding delta wing sails for retrofitting to existing ships including Ro-Ro, containerships and car carriers, modelling fuel savings of 9-19% with a payback period of 3 to 4 years.

Various rig configurations can be used on small-scale freighters and catamarans for local use, especially in SIDS, or as auxiliary power to a wide range of existing small-scale conventionally-powered craft. *SV Kwai* provides a working model of a 200 tonne sail assisted freighter serving Kiribati and the Cook Islands, saving an average 30% of fuel **(see Fact Sheet – Appendix E)**.

Tokyo Wind Challenger.



OCIUS Wind Solar.

3.3.1.2 Fixed-sails

Fixed-sails are essentially rigid wings on a rotating mast. Current proposals include *UT Wind Challenger* and EFFship's project using rigid sails capable of reefing down on telescoping masts for heavy weather or in-port situations. Various forms of fixed wings have been proposed since the Japanese experiments in the 1980s **(see Fact Sheet – Appendix E)**. These include the Walker Wingsail, fitted to the 6,500dwt *Ashington,* in 1986. Trials then did not demonstrate substantive savings and some technological barriers are still to be overcome. UK company Oceanfoil has revisited the wingsail and is offering a new patent design from 2015 modelling 20% fuel savings with a payback period of 15 to 18 months.

E Ship 1.

Promising new commercial designs adapted from the racing yacht sector are being developed by Propelwind. Australian leader OCIUS Technology use fixed wings combined with solar panels to successfully power fast harbour ferries **(see Fact Sheet – Appendix E)**. OCIUS Technology has recently patented a unique form of fixed sail capable of folding down to complement differing wind conditions and predicts the technology will be usable on all sizes of modern vessels. WindShip is claiming their new designs for a motor sailing system with modern fixed wings will cut 30% of fuel bills.

Alcyone.

One of the advantages for SIDS is that fixed sails can be built simply and cheaply and do not necessarily require high-tech application. Such sails could be fitted to landing craft and motorised barges moving large loads where speed of delivery is not a priority requirement.

3.3.1.3 Rotors

Flettner Rotors harness the "Magnus Effect" created when wind passes over an already revolving cylinder, for propulsion. It was first proven in the 1920s on a number of ships, including the 3000dwt *Barbara*. The technology was largely forgotten until the last oil crisis. In 1985 US company Windship Corporation released findings from a detailed analysis of 75 wind-powered rigs backed by extensive practical trials, concluding the rotor to have by far the greatest potential of any wind powered system. Flettner rotors have been described as 'storm proof' in that the stronger the wind the greater the stability provided to the vessel by the rig.

The oceanographer Cousteau introduced the "TurboSail," a non-rotating fan-driven design, on his research vessel *Alcyone* in the 1980s. CRAIN Technologies in France are now revisiting this concept with a Suction Wing, modelling its use for VLCCs. However, it would work as well, arguably more effectively, at small ship scale and could be retro-fitted.

In 2010 Enercon began trials of the 12,800dwt *E-Ship-1* with four Flettner rotors powered initially by the exhaust gas from the main conventional turbine motor. After 170,000 sea miles the Enercon technology (including rotors and improved hull, rudder and heat waste recovery designs) saved an overall 25% of fuel for this vessel. Retrofitting Flettner rotors to bulkers and tankers is being considered by numerous innovators although the use of deck space is a key consideration. Modern concepts show Flettner style rotors included in numerous applications including the Wärtsillä 1800-pax ship (scheduled for operation in 2018).

Rotors must be considered to have very high potential for SIDS, potentially a "game breaker" for both new ship and retrofit applications, given their proven savings and capacity to be built and fitted cheaply and locally. In the case of rotor technology, the amount of fuel savings decreases as the ship size increases; savings of 60% for small ships have already been demonstrated while savings of up to 19% on VLCCs are being modelled. German-led work on the Coastal Hybrid Coaster **(see Fact Sheet – Appendix E)** offers a design that would revolutionise island shipping at inter-country and archipelago levels.

3.3.1.4 Kite sails

Kite sails attached to the bow of the vessel operate at altitude to maximise wind speeds. A small number of innovative companies have been advocating this technology for more than a decade. In 2008 *MS Beluga Skysails* was the world's first commercial container cargo ship partially powered by a 160m^2 kite and saved 10-15% of fuel on selected passages. However annual savings in consumption on most routes is in the order of 5.5%, as determined by the EU-funded Life project WINTECC. Propulsive savings are only made with wind coming from the beam to dead aft of the ship.

This technology is thought to have a higher maintenance and servicing cost to other wind technologies. Most modelling has shown return on investment to be uneconomic until fuel cost increases further. Recent studies under the EFFship programme have modelled savings using fixed wing, rotor and kite auxiliaries for a Panamax and Tyndall Centre has recently modelled fuel savings comparisons for rotor and kite fitted ships on transatlantic runs. Although kite sails have been extensively promoted, their


Wind Hybrid Coaster.

SkySails.


KiteShip of Martinez.

high tech nature, high set up costs, predicted high maintenance costs and the so far unresolved safety issues means they are unlikely to have great application for SIDS in the near future.

3.3.1.5 Wind turbines

Wind turbines, large blades harnessing energy either to convert to electricity or to a mechanical drive train, have been mooted over many years. To date there are no successful prototypes reflecting systemic issues with ultimate stability and vibration and the inherent inefficiency in energy conversion relative to other technologies. The advantage of the turbine is that it can continue to harness power even when the craft is sailing directly into the wind. There is a case to be made for wind turbines as a producer of ancillary power for ships and as a replacement for shore-side electricity generated from non-renewable sources. Given the enormous advances made in wind turbine technology for land-based electricity generation it is highly likely there are important lessons to be transferred now to the maritime sector.

3.3.2 Solar – Photovoltaics

Solar RE applications under consideration use electricity generated by photovoltaic cells (PV). All advances in this fast-evolving technology for electricity and land transport applications, are available for maritime transport use. The primary limiter is the available deployment area for the PV and how to store such power which generally involves a battery array of some description. Battery technology is developing rapidly, offering some potential for propulsion. However, full ship propulsion requires further technical development and is likely to be confined to relatively small scale and short range ships. The Greenheart design for a 220gt freighter proposes using solar-charged lead-acid batteries to provide auxiliary propulsion for its primary sail rig. Battery-based propulsion would be beneficial due to producing no CO_2, NOx, SOx, VOC (volatile organic compounds) or particulate emissions in operation. Batteries may offer a potential hybrid solution in conjunction with other modes of propulsion for some small to medium-sized ships provided that their recharging does not increase the production of other harmful emissions.

OCIUS Technology's designs of hybrid fixed sails in tandem with PV arrays, both sail and deck mounted, have now resulted in commercially competitive harbour ferries in Australia, Hong Kong and Shanghai and show strong promise for deployment on larger ships **(see Fact Sheet – Appendix E)**. Japan-based Eco Marine Power is developing a large solar-sail Aquarius MRE system for tankers and bulkers and WWL's proposed *Orcelle* zero-emissions car carrier is proposing a similar set-up with solar panels incorporated into large fixed wing sails that can harness power in sail mode or when deployed horizontally on deck. The *Auriga Leader* project in 2008/09 saw 328 solar panels fitted to a 60,000 grt car carrier providing 40 kilowatts, about 10% of the ship's

OCIUS Technologies' SolarSailor.

CRAIN Technology.

ECO Marine Power.

power while sitting in dock. It was also the first ship to direct the solar power into the ship's main electrical grid. The solar panels produced 1.4 times more energy on the ship at sea than in port in Tokyo but overall contributions to propulsive power were minimal.

Solar has potential when used to charge shore battery systems supporting rechargeable electric propulsion units for smaller scale car ferries but this is only applicable for extremely short run shipping. It also has application in augmenting other electric supplies for most shore side infrastructure. For most benefit to be accrued, this type of use needs to be coupled with other low carbon and other power saving technologies. Solar (along with wave energy and wind turbines) may have a future role to play in providing initial energy for hydrogen separation from seawater for hydrogen fuel cell technology.

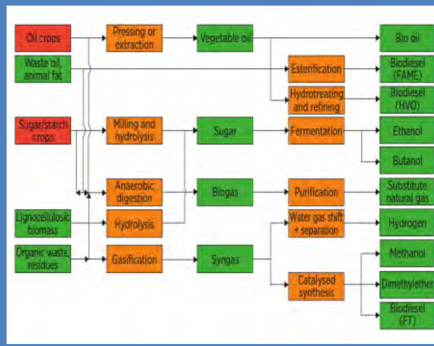
For SIDS, solar technologies offer a number of different potentials. As propulsive power, until battery technology improves and becomes more affordable, the main applications appear associated with use in small to medium scale short range vessels, especially associated with the tourist industry – often a major income and employment generator in island localities. There is also strong potential as a substitute or more likely, in the immediate future, a supplement for ancillary power, for example in maintaining refrigeration of containers and freezers, lighting, communication equipment, etc while vessels are in port or loading/unloading and thus reducing the need for fuel powered ancillary generators.

3.3.3 Bio-gas/biofuel

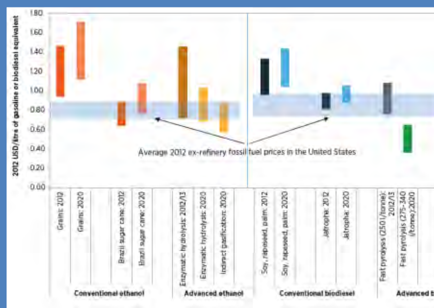
The shipping sector is still in the early stages of orientation towards biofuel, with almost all biofuels currently being used by the road transport sector. There is a long list of available biofuels, but there are currently few examples of commercial vessels that are using these and much of the R&D has been conducted by private initiatives that have closely held the results. Biofuels evolution is now in its third generation of fuel types.

Type	Process	Product Examples
1st generation	From oil extracted from agricultural crops or sugar or starch containing agricultural crops	bio-diesel, Straight Vegetable Oil (SVO), bio-ethanol
3rd generation	Algae-based fuels produced in reactors and closed systems	

Table 1: Biofuel by Generation



Aspect	Biofuel			
	Biomass to liquid (advanced biofuels – e.g. via Fischer-Tropsch process)	HVO/ SVO/ FAME	Dimethyl ether (DME)	Liquid biomethan (LBM)
Engine and fuels system cost	Drop-in	Drop-in	Storage	Dual fuel cryotanks
Projected fuel cost	Refining	Land use	Infrastructure	Infrastructure
Emissions abatement cost				
Safety-related cost			Ventilation	Pressure / Temperatur
Indirect cost		Water energy, land and food nexus	Cargo space	Cargo spac



Bio-gas/biofuel (3).

3.3.3.1 Liquid Biofuels

Liquid biofuels can be combusted in a diesel engine and are potentially applicable to all vessel types, with only small modifications of the main engine required. Early trials in 2006 to 2007 demonstrated commercial feasibility of use. Royal Caribbean Cruises tested biodiesel on selected cruise ships, including the 293m *Jewel of the Seas*, starting out with 5% blends and eventually with 100% biodiesel. The Canadian Bioship project ran the 17,850dwt freighter *Anna Desgagnes* on a B20 blend of rendered animal fats and cooking oil biodiesel. These were followed by Maersk and Lloyd's biofuel feasibility tests in 2010-11 using batches of biofuels on the 88,669dwt *Maersk Kalmar* container ship. The biodiesel FAME (fatty acid methyl esters) results were promising but inconclusive.

In 2012, the *Meri*, a 105m 4359dwt multipurpose vessel, made the world's first commercial voyage using 100% biofuel derived from wood pulp waste in Finland, powered by three Wärtsilä generators that can use MDO as a backup fuel. Tests of algal biofuels have also been progressing. The U.S. Navy ran tests in 2011-12 as part of their Great Green Fleet initiative aiming to cut fossil oil use 50% by 2020. In 2012, Maersk envisaged 10% of the world's shipping fleet could be powered by biofuels by 2030.

3.3.3.2 Bio-gas – Bio-methane

Liquid bio-methane (LBM) is derived from food or green waste and can, when cleaned, be injected directly in to the liquefied natural gas (LNG) grid. LNG is favoured by the shipping sector as a transitional fuel to a low carbon/low emission future and a suitable bunkering network is fast evolving on established transport routes. The case for shipping to adopt LBM as a renewable fuel of choice is strong. Combining LBM with other proven RE solutions such as wind, as is proposed by B9 Shipping, enables 100% renewable energy ships to be operational in the short term. The Rolls-Royce Bergen K gas engine has been certified to power the world's first major car and passenger ferries running on LNG and is now used in over 20 vessels. The increased development of LNG storage facilities at ports will help facilitate the use of this technology and bio-methane.

Bio-diesel Blends >20%	Most Viable	Best compatibility with current engines and existing supply chain, though very limited supply.
SVO 100%		
Bio-ethanol in diesel engines	Viable	Investments to supply chain seem manageable, though less favourable than biodiesel/SVO
DME, Bio-LNG	Upcoming Technology	Limited by biomass feedstock available. More investment needed to supply chain to introduce fuels. New build vessels are more promising.

Table 2: Current Viability for Shipping of Selected Biofuels (Florentinus et al, 2012)

There are issues over the actual carbon savings from biofuels generally that must be considered when assessing the real savings from this fuel type. However, for remote island locations where there is excess easily harvestable biomass or the cost of substitute organic oil can be justified against imported fuel prices, for example from coconut oils, then it is likely that there is considerable potential for SIDS. Greater economic analysis is required than currently exists.

3.3.4 New Horizon Technologies

There are many developments in RE and in ship design that promise to add new perspectives and expand the field in the future such as the *Vindskip*, a hybrid merchant vessel with an aerodynamic hull that functions as a giant sail coupled with a LNG engine. Seimen's *Zerocat* is a 150 car ferry operating a 20 minute route powered by a lithium ion battery charged onshore from hydro-generated electricity due to come into service in 2015. There are currently two short-run super-capacitor ferries operational in Scotland.

OCIUS Technology has patented a range RE-powered unmanned vessels for ocean surveillance and research which could potentially be responsible for significant fuel savings if they can replace large-crewed research and security vessels at any scale. Application of these types of new horizon technologies is unlikely to have Immediate or near future practical contribution for SIDS, although there is no reason why island locations cannot be used as testing and development grounds for such.

3.3.4.1 Wave

Current wave power plant designs suggest an entirely new design concept will be needed. The small number of developers in this field are attempting to use bio-mimicry of dolphins and pelagic fish. WWL's ambitious *Orcelle* car carrier proposes using a series of underwater flaps copying dolphin tail fin movements to create propulsion and generate electricity and hydraulic power for propulsion and ship's systems. Wave power is actively being pursued in the field of marine drones. If proven viable this technology could have high application for use in marine research, and surveillance deployment for fisheries, marine protected areas and national border control for many SIDS.

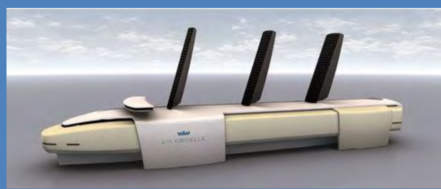
3.3.4.2 Hydrogen

Hydrogen was much vaunted in the mid-2000s as the fuel for the future in shipping and is still hoped to provide a long-term solution. Fuel cell technology development has seen significant advances and attracted significant interest, especially from the offshore supply vessel, passenger and cruise ship markets.

In 2008, the Zemships project developed the *Alsterwasser,* a 100-pax fuel cell powered passenger vessel for inland waterways and a number of other small ferries and river boats have followed suit. In 2012 as part of the FellowSHIP project, a 330kW fuel cell was

Super-capacitor driven ferry.

Fuel cell hybrid offshore support ship.



Orcelle Project.

successfully tested on board the offshore supply vessel *Viking Lady*, operating for more than 7000 hours. This was the first fuel cell unit to operate on a merchant ship, with the electric efficiency estimated to be 44.5% (when internal consumption was taken into account), and no NOx, SOx and PM (particulate matter) emissions detectable. When heat recovery was enabled, the overall fuel efficiency was increased to 55% with room for improvement. In 2012, Germanischer Lloyd set out concepts for a zero-emission 1500-pax Scandlines ferry and a 1,000 TEU container feeder vessel with a 15 knot service speed using liquid hydrogen as fuel to generate power with a combined fuel cell and battery system.

The sustainability of hydrogen production is a critical issue, with almost all current commercial production coming from fossil fuels. Potential for RE hydrogen production will come from the electrolysis of seawater using energy sources such as excess offshore wind-farm energy, other land-based RE energy supplies or generators aboard wind powered vessels. Reliable, low-pressure storage of hydrogen remains a challenge to development. The high tech nature of the technology means it is unlikely to have real benefits for most SIDS.

3.3.4.3 Renewable Energy Shipping Applications and SIDS

Experiments in the last oil crisis clearly demonstrated strong potential for RE use for SIDS sea transport in a variety of settings. The potential today has only increased. It is hard to escape the logic that wind offers for auxiliary propulsion, especially for islands situated within the trade wind belts. Solar for short reach shipping, especially within reef systems and where associated with tourism hubs, has a variety of near future application. Biofuels for remote islands must also rank highly on any research agenda.

Most SIDS lack the internal R&D capacity necessary for market development of this type of initiative. Therefore, partnering with research centres of excellence in the developed world is a likely priority. Proof of concept prototypes backed by strong economic analysis is needed before existing private sector interests will change from established patterns. As discussed in depth in chapter 5, entrenched barriers in policy (within national, regional and donor spaces), financing and perception necessitate a shift in paradigm.

Island applications need to be cognisant of the need of technologies to be both affordable and appropriate to their settings and field of operations. A “low technology – high application” mentality is required. The ability to service emerging technologies requiring sophisticated engineering support are not likely to be of great benefit. Retrofit solutions for existing shipping is necessary if immediate benefit is to be achieved, the capacity to purchase new build assets is beyond the financial reach of most operators. Given that many SIDS acquire essential sea transport services as donations from development partners and bilateral donors, understanding and leadership is required from the same.

Disclaimer

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Chapter 3

The Potential for Renewable Energy for Sea Transport for SIDS

The maritime history of the Pacific peoples is recognised as part of the shaping of Pacific societies but is also a basis for comparison in making changes for the future. Not least is the possibility of a renaissance of commercial sail under changing economic relationships between distance, rising cost of fuel, environmental concerns, and the always available Pacific wind systems for assistance in ship propulsion.

Prof Alastair Couper (2009)

No longer an abstract 'pie-in-the-sky' technology, wind assist propulsion could well be a game-changer in the 'Carbon Wars'.

Barry Parker, (2014)

Recent Studies on RE for International Shipping

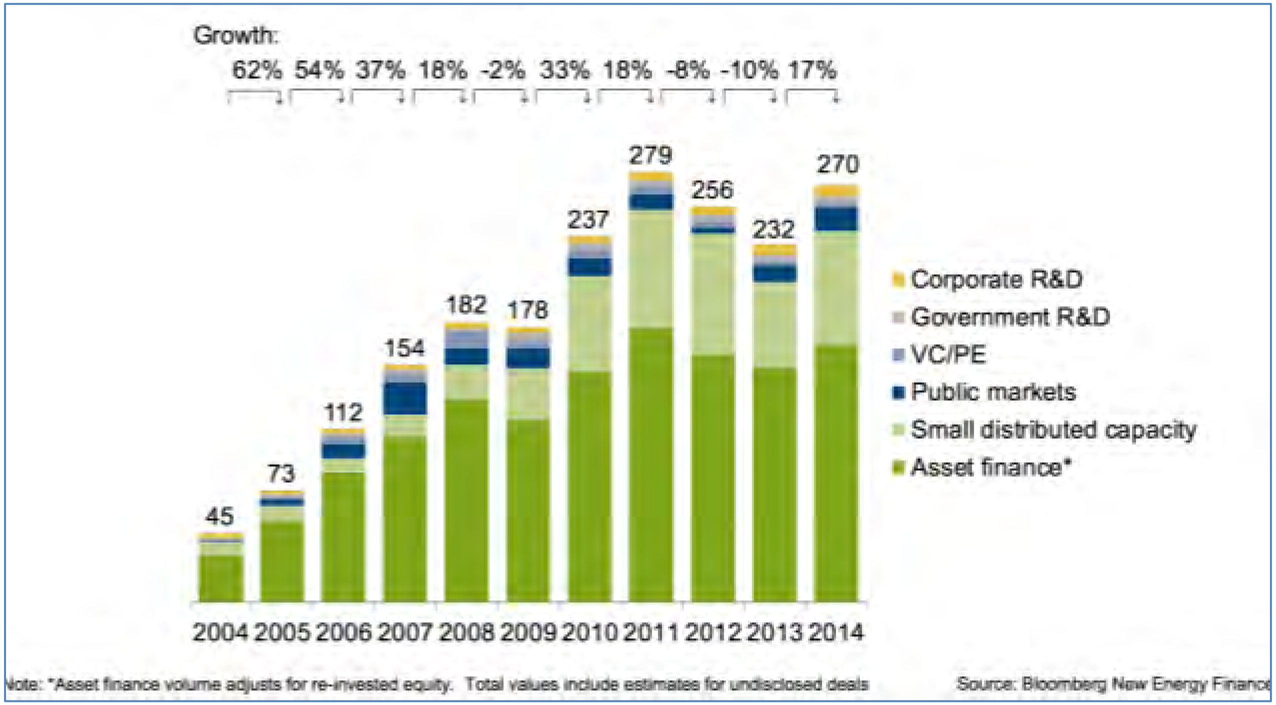
Recent Studies on RE for International Shipping

- Renewable energy (RE) options identified, including wind, sun, wave and biofuel/gas.
- Applications include primary propulsion, hybrid propulsion (either combining different RE technologies or partnering RE with non-RE), auxiliary propulsion, and on-board and shore-side ancillary power substitution.
- RE has varying potential across the global fleet and at all scales, including international and domestic transport of goods, people and services, and for fishing, tourism, research and security/defence.
- Greatest potential for savings and application is at the small ship scale, the shipping type most prevalent servicing island countries and communities.
- At this scale there is high potential for significant fuel savings and additional performance benefits to vessel operations and secondary socio-economic benefit.

Recent Studies on RE for International Shipping

- There are numerous RE designs developed to advanced concept stage and increasing numbers of ‘proof of concept’ vessels in operational use.
- Industry innovators claim no technological barrier to selected RE applications for shipping capable of significant fuel savings using mature technologies.
- Savings can be substantially more when coupled with other efficiency methods, such as slow-steaming, voyage routing and design changes.
- Near future efficiencies from RE are most likely to be seen at the smaller ship scale travelling at slower speeds.
- RE applications can be either built into new ship design or as retrofits to existing vessels.

Investment in RE shipping trails other energy use sectors

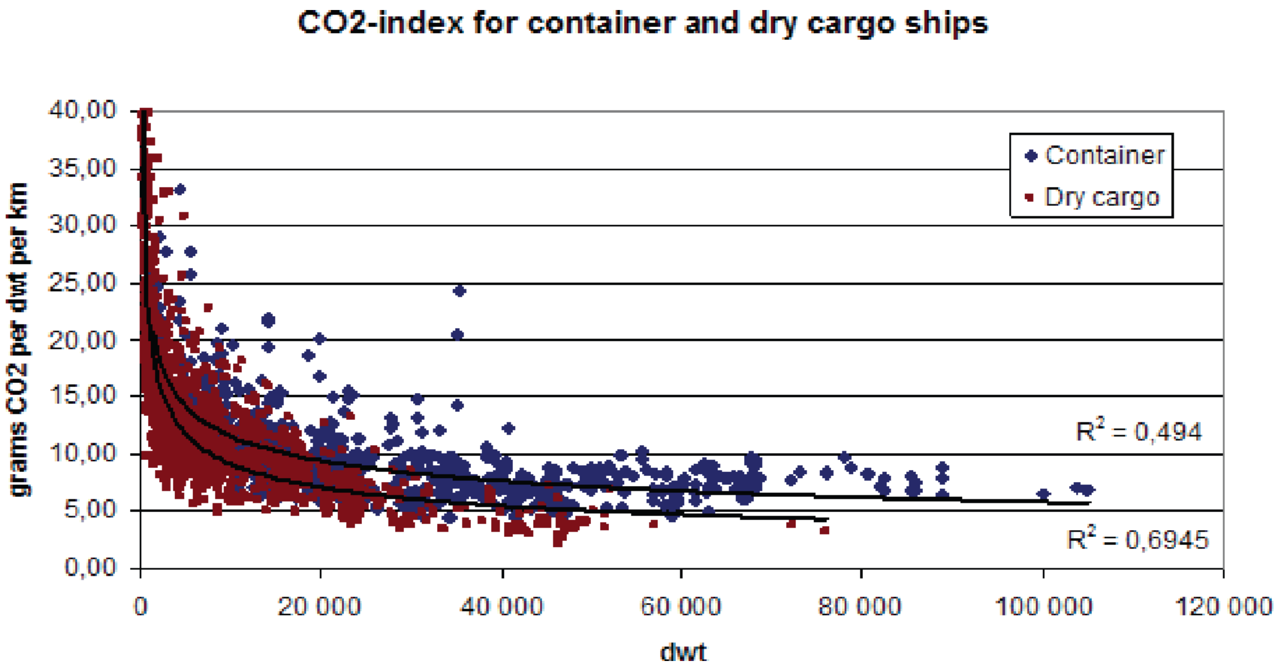


Global investment in renewable energy technology of $270 billion in 2014

- RE development for sea transport has been not accorded the priority of its electricity and land transportation counterparts.
- Renewables such as wind, solar and biomass generated an estimated 9.1% of the world's electricity in 2014.

Source: UNEP, 2015

Small Ships move Least Cargo but create Highest Emissions



- Most energy efficiency innovation effort is targeted at large scale and new asset shipping.
- Ships under 10,000 dwt transport less than 4% of world cargo but contribute ~25% of all shipping emissions. The needs of small ships are not receiving adequate priority.
- With minimal investment, this is the sector that might provide the quickest results from RE uptake.

Source: Buhaug et al, 2009

Renewable Energy Shipping Options - Wind

- Wind power has the most immediate potential for RE deployment.
- Wind power was the dominant energy used for shipping before fossil fuels.
- Most options being considered today are for wind assistance to primary propulsion.
- Options include soft sails, fixed sails, rotors and kites.
- Wind options are available for new build and retrofit and for all sizes of shipping.
- Most easily proven savings are likely at small ship scale.
- Rotor technology is a potential game changer.
- Potential to learn from massive advances in sail technology in sport/ocean racing .

Wind Energy – Soft Sails

Dkystra - Ecoliner

Source: http://fairtransport.eu

B9 Ship

Source: www.b9energy.com

Neoliner

Source: www.neolinetransport.com

GreenHeart

Source:www.greenheartproject.org

Cargo Proa

Source: www.fairwindstradingcompany.org

Cargo Catamaran

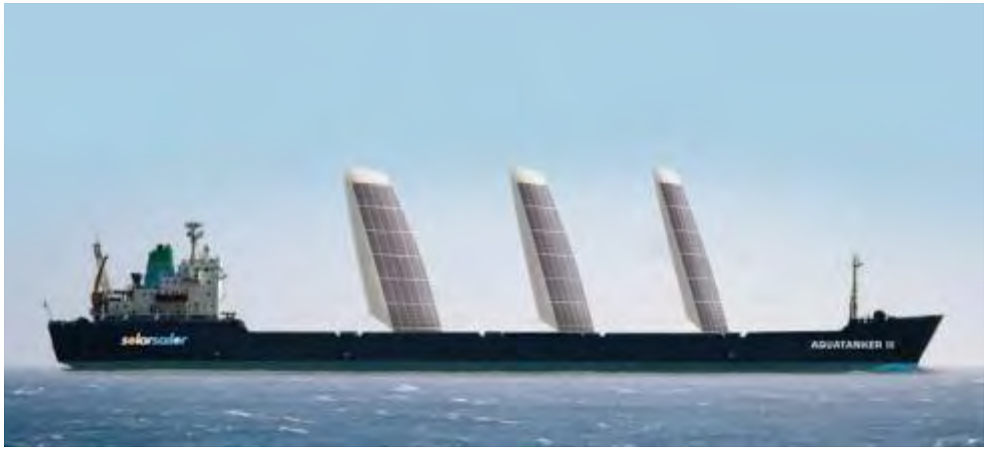
Source: www.wharram.com

Wind Energy – Fixed Sails

Tokyo Wind Challenger
Source: http://wind.k.u-tokyo.ac.jp

Shin Aitoku Maru
Source: https://seaspout.wordpress.com

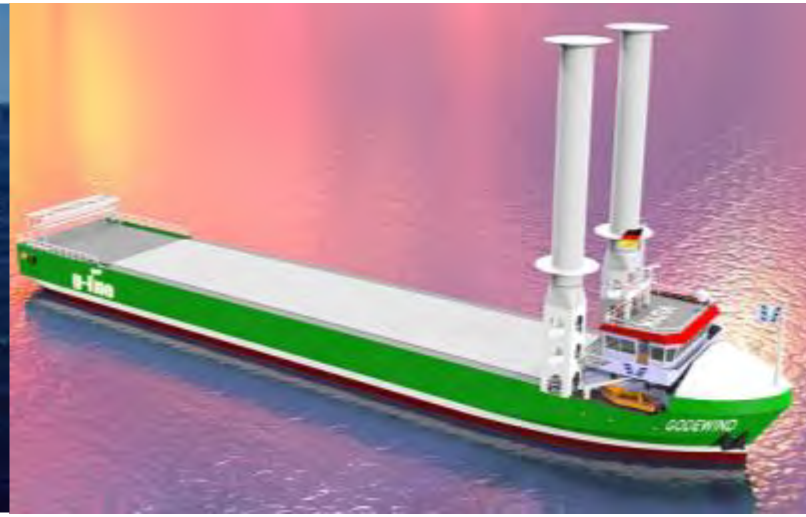
Windship
Source: www.windshiptechnology.com



OCIUS Wind Solar
Source: http://ocius.com.au

Wind Energy – Rotors

Alcyone
Source: https://escales.wordpress.com



Wind Hybrid Coaster
Source: http://www.maritim-de-nl.eu

Flensburg UniCat
Source: https://commons.wikimedia.org

Baden Baden

Source: https://en.wikipedia.org

Barbara

Source: http://www.sdtb.de

E Ship 1

Source: http://www.enercon.de

Wind Energy – Kite Sails

SkySails GmbH

KiteShip of Martinez

Source: http://www.skysails.info

Solar Energy

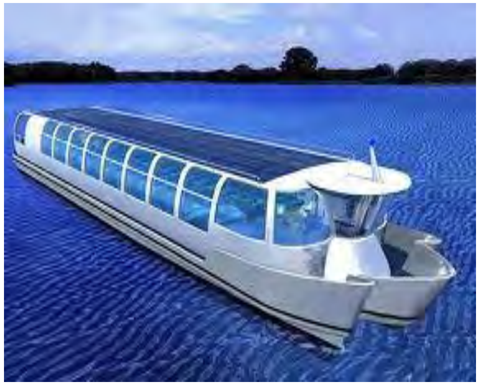
- Major advances in electricity land-based use and electric motor technology.
- Potential for short range transport especially passenger and tourism – OCIUS = commercial proof of concept.
- Potential for auxiliary propulsion to wind-powered propulsion – battery storage major limiter.
- Potential for ancillary onboard power – especially freezers and in port power for small scale ships.

OCIUS Technology SolarSailor

Source: http://ocius.com.au/

OCIUS Technology SolarSailor

Source: http://ocius.com.au/



ECO Marine Power

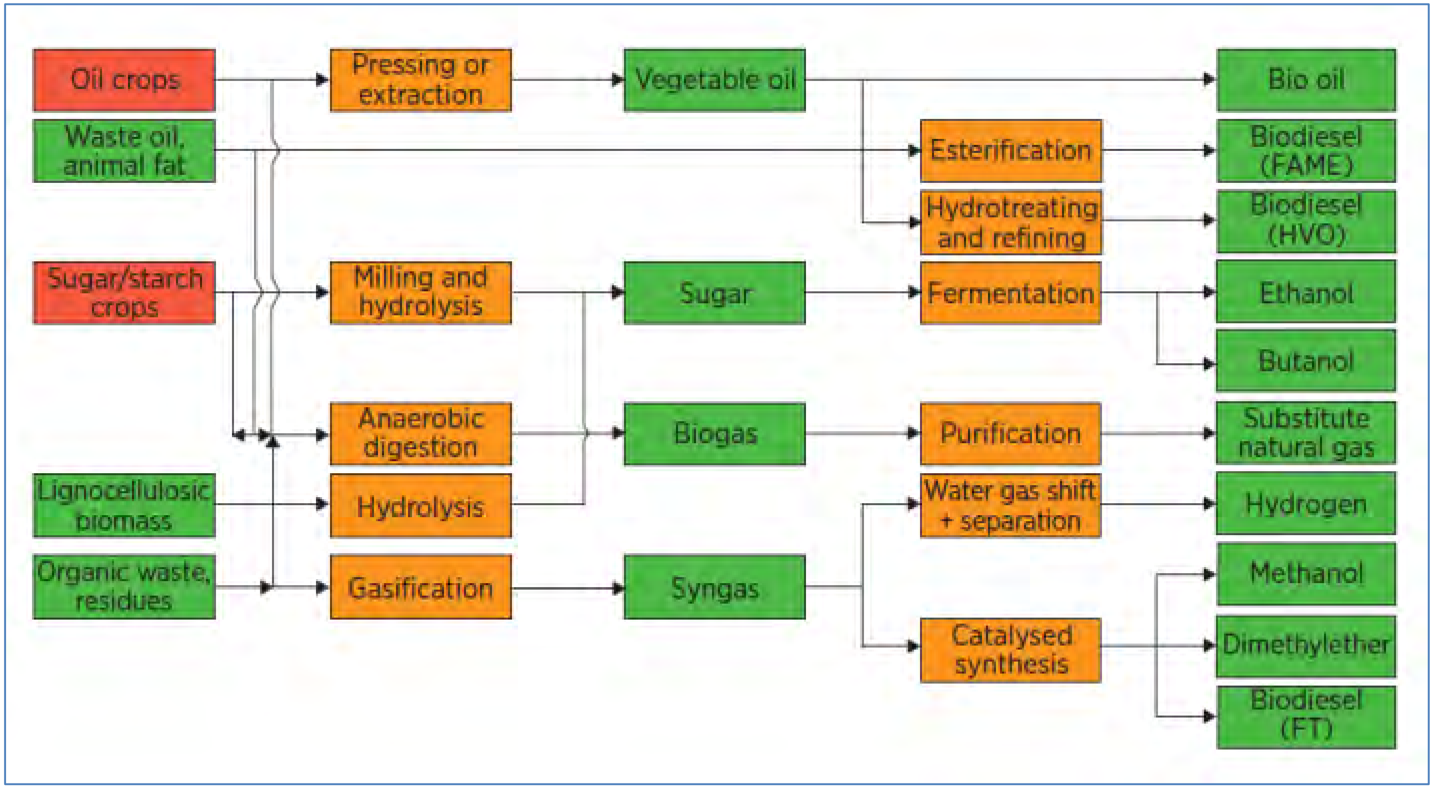
Source: http://www.ecomarinepower.com

CRAIN Technology

Source: http://site.craintechnologies.com

Biofuels

Summary of pathways for conventional & advanced biofuels production



Source: Mofor, L., Nuttall P. and A. Newell, 2015

Biofuels

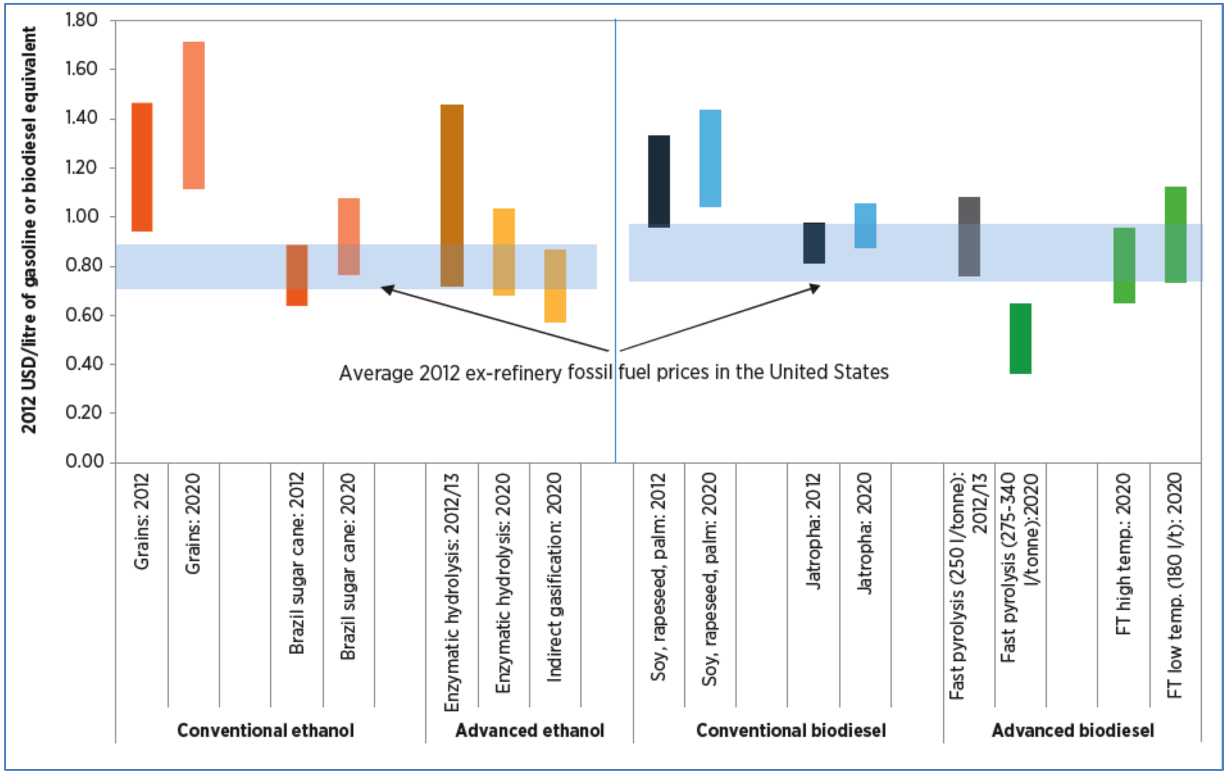
Summary of applications and issues for biofuels in shipping

Aspect	Biofuel			
	Biomass to liquid (advanced biofuels – e.g. via Fischer-Tropsch process)	HVO/ SVO/ FAME	Dimethyl ether (DME)	Liquid biomethane (LBM)
Engine and fuels system cost	Drop-in	Drop-in	Storage	Dual fuel cryotanks
Projected fuel cost	Refining	Land use	Infrastructure	Infrastructure
Emissions abatement cost				
Safety-related cost			Ventilation	Pressure / Temperature
Indirect cost		Water, energy, land and food nexus	Cargo space	Cargo space

Source: Mofor, L., Nuttall P. and A. Newell, 2015. Adapted from IEA-AMF, 2013

Biofuels

Production costs for conventional and advanced biofuels, 2012 and 2020



Source: Mofor, L., Nuttall P. and A. Newell, 2015. Adapted from IEA-AMF, 2013

Current Viability of Selected Biofuels for the Shipping Sector

	Engine Applications	
	Drop-in fuel	**Comment**
Diesel cycle	Biodiesel (FAME)	• High availability and variety of feedstock • Land use and food nexus issues for conventional biodiesel production • Standard well-understood specifications • Bio-fouling potential • Requires anti-corrosion seals and components in engine • Suitable for low to medium speed propulsion (e.g. small carriers and cargo ships)
	Straight vegetable oil (SVO)	• Up to 100% replacement possible • Cheap and readily available • High viscosity requires pre-heating • Can be used in dual engines • Suitable for low-speed propulsion of all vessel sizes
	Hydro-treated vegetable oil (HVO)	• Very high quality for shipping • High energy content • Land use and food nexus issues depending on feedstock used • Suitable for medium-speed propulsion of all vessel sizes
	Dimethyl ether (DME)	• High potential • Challenges with stability and storage • Limited availability, but can be produced from ethanol using on-board alcohol to ether (OBATE) technology • Requires fuelling infrastructure and anti-corrosion seals and components in engine • Takes up cargo space • Suitable for low-speed propulsion of all types of vessels
	Biomass-based Fischer-Tropsch diesel	• Can use residues for feedstock • Limited availability, depends largely on gasification • Not yet commercially viable • Can be used for medium-speed propulsion of all vessel sizes
	Pyrolysis oil	• Low cost and high availability potential • Corrosive • Low heating value and high viscosity • Difficult to store • Suitable for low-speed propulsion of all types of vessels

Source: Mofor, L., Nuttall P. and A. Newell, 2015

New Horizon Technologies

Ar Vag Tredan super-capacitor driven ferry

Source: http://articles.maritimepropulsion.com/

Eidesvik offshore support ship *Viking Lady* first commercial fuel cell hybrid propulsion

Source: http://www.motorship.com/news101/ships-and-shipyards/viking-lady-commercial-ship-debut-for-fuel-cell-technology

Source: http://www.wilhelmsenasa.com/media/multimedia/Pages/Orcelle.aspx

Orcelle Project – wave, hydrogen, sail and solar hybrid car carrier

Renewable Energy Shipping for SIDS

- Near future efficiencies from RE are most likely to be seen at the smaller ship scale travelling at slower speeds, and market leaders of large-scale shipping are increasingly monitoring small ship developments for RE technology innovation.
- This should be good news for SIDS in particular, if there was willingness and commitment to invest at this scale of the industry. The needs of small ships, the most prevalent size servicing the world's most vulnerable in the developing world, and SIDS in particular, are not receiving adequate, if any, priority.
- With minimal investment, this is the sector that might provide the quickest results from RE uptake.
- There is potential for smaller fleets of new build RE powered or assisted vessels replacing single, larger, aged assets in developing world, especially SIDS, scenarios allowing greater servicing of currently uneconomic routes to scattered or remote communities.
- Island applications need to be cognisant of the need of technologies to be both affordable and appropriate to their settings and field of operations. A 'low technology – high application' mentality is required. The ability to service emerging technologies requiring sophisticated engineering support are not likely to be of great benefit.

Renewable Energy Shipping for SIDS

- Trials in the last oil crisis clearly demonstrated strong potential for RE use for SIDS sea transport in a variety of settings. The potential today has increased.
- It is hard to escape the logic that wind offers for auxiliary propulsion, especially for islands within the trade wind belts. Solar for short reach shipping, especially within reef systems and where associated with tourism hubs, has a variety of near future application. Biofuels for remote islands must also rank highly on any research agenda.
- Most SIDS lack the internal R&D capacity necessary. Partnering with research centres of excellence in the developed world is a likely priority. Proof of concept prototypes backed by strong economic analysis is needed before existing private sector interests will change from established patterns.
- Currently entrenched barriers in policy (within national, regional and donor spaces), financing and perception necessitate a shift in paradigm.
- Retrofit solutions for existing shipping are necessary if immediate benefit is to be achieved, the capacity to purchase new build assets is beyond the financial reach of most operators. Given that many SIDS acquire sea transport services as donations from development partners and bilateral donors, understanding and leadership is required from the same.

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Vessel: *Solar Sailor*

LOA: 21.5m

Built: 1999

Capacity: 100 passengers

Type: Passenger ferry

Designed: OCIUS Technology Ltd

www.ocius.com.au

New Build Wind Solar PV Hybrid Operating Commercially

This is an example of one of the range of solar PV hybrid powered vessels designed and built by OCIUS Technology in Australia. There are several other designs operating commercially in Hong Kong, Singapore and Australia. The sails are made of solar PV panels which can be used to utilise wind and solar energy. This vessel has been operating commercially for over ten years in Australia. This type of vessel has high potential for short distance routes, particularly for the tourism and commuter markets operating in sheltered waters.

Key Features:

- Hybrid propulsion – with 8 solar sails (160 x 100W panels)
- 2 x 40 kW electric motors, 1 x 80 kW generator running on LPG and 80 x 70ah lead acid batteries
- Speed of up to 10 knots, 6 knots under sail alone
- Low noise, low pollution, low cost

OCIUS has also designed a 24m commuter solar sail ferry, three of which are operating in Hong Kong, which can travel up to 18 knots and carry 100 passengers; and a smaller ferry which can travel up to 24 knots with 76 passengers which is also operating in Hong Kong. They also have designs for vessels for specific functions such as whale watching as well as smaller ferries (30 pax) and larger ferries (149 and 250 pax).

OCIUS has also patented a revolutionary "rigid opening sail" design for use on bulk carriers of 1000 dwt and above, which are *"flat, hinged & collapsible steel sails affixed to the deck between the main hatches*, *powered by simple, affordable hydraulic motors*". The predicted return on investment is 1 – 2 years, no additional crew are required, and modelling shows potential fuel savings of ~200-1000 tonnes/voyage depending on the route and weather conditions.

OCIUS has also recently begun trialling their designs of "unmanned surface vessels", which use wind, solar and wave energy to power *"self-propelled, self-deployable and retrievable"* drones which can be used for a variety of ocean research and surveillance applications.

Vessel: *Greenheart*

GRT: 220 LWL: 32.5m

Total sail area: $300m^2$

Type: Interisland pax/cargo

Designed by: Greenheart Project

www.greenheartproject.org

100% Renewable Energy Freighter Design Concept

This vessel was designed with LDCs and SIDS in mind. Using soft sails for primary propulsion with auxiliary motors powered by a $125m^2$ solar PV array and lead acid battery storage, the Greenheart has been designed as a 'zero emissions' vessel.

Key Features:

- In cargo configuration designed to carry 75 tonnes of cargo in 3 TEUs plus 10 - 12 passengers and crew of 5 - 6
- Primary propulsion from sails with auxiliary solar PV powered two DC motors of 150 kW
- Auxiliary motoring range of 55 miles without recharge
- Capable of beach landing – no requirement for shore-side infrastructure
- Operational speed of 7 – 8 knots
- Cargo access is via Roll On/Roll Off port in transom, main hatch, and aft hatch, with the rig being used to load/unload the containers

The vessel has been designed by a Non-for Profit organisation, and the design process has been open-source, using volunteer input, including from leading naval innovators from Germany and Japan. Crowd funding was tried to secure funding for the build of a prototype in 2014 but was unsuccessful in raising the funds required to commence build. Until a prototype has been trialled, the effectiveness of the design concept is unproven, but could have significant potential for SIDS and LDCs. The vessel could also be used with conventional motors if required or used to trial biofuels as an alternative to the solar PV driven motors originally proposed by the Greenheart Project design team.

Potential Benefits:

- Could be built and maintained in SIDS with shipyards with training
- With no fossil fuels required, this vessel could provide a solution for trade routes which are uneconomic because of high fossil fuel costs and low cargo/passenger volumes or lack of shore-side infrastructure (jetties, wharves)
- Could be used for disaster relief where shore-side infrastructure has been damaged/destroyed which limits conventional vessel operations

Renewable energy type		Retrofit (RF) New Build (NB)	Vessel category, application, examples and potential							
			< 400 tonnes **e.g., recreation, artisanal/small fishery, tourism, passenger, break, landing craft, barges, research, coastal patrol and security**		**400 – <10 000 tonnes** **e.g., large landing craft, small-medium fishery, domestic Ro-Ro, break bulk, bulk, container, tanker, tramp**		**10 000 – <50 000 tonnes** **e.g., Ro-Ro, deep sea fishery, bulk, container, tanker, car carrier, cruise liner**		**>50 000 tonnes** **e.g., Very Large Crude Carrier, Panamax, Aframax, large container ships**	
Wind	Soft sails	RF	√√√	*Na Mataisau*, *Kwai*, Avel Vor	√√√	Seagate deltasail	√√√	Seagate deltasail	√√	Seagate deltasail (up to 100 000 tonne)
		NB	√√√	*Greenheart*	√√√	*B9*, *Rainbow Warrior 3*, *Maltese Falcon* (Dynarig), *Maruta Jaya* (Indosail), *Atlantic Clipper*	√√√	*Ecoliner*, *B9*	√√	*Bulker-1*
	Fixed wings	RF	√√		√√	*Shin Aitoku Maru*, *Ashington*, Oceanfoil wingsail	√√	*Usuki Pioneer*, Oceanfoil wingsail	√	Oceanfoil wingsail
		NB	√√	OCIUS – short run passenger	√√√	Propelwind	√√√	*UT Challenger*, OCIUS, *Orcelle Ecomarine*	√√	*UT Challenger*, OCIUS, *Ecomarine*
	Rotors	RF	√√	*Tracker*	√√	*Bacau*	√√	Numerous applications	√√	
		NB	√√√	*UniKat*	√√√	*Barbara*	√√√	*E-Ship 1*	√√	Magnuss (telescopic)
	Kites	RF/NB	√√	Beyond the Sea	√√	SkySails, Beyond the Sea, *Beluga*	√√	SkySails, Beyond the Sea	√	Beyond the Sea
	Turbines	RF/NB	√	Ancillary power only	√	Ancillary power only	√	Ancillary power only	√	Ancillary power only
Solar photovoltaics	Main	RF	**N/A**	Small outboard/inboard, short run	**N/A**					
		NB	√	Lagoon, tourism	**N/A**	Theoretical only	**N/A**		**N/A**	
	Auxiliary	RF	√√		**N/A**		√	*Auriga Leader*	**N/A**	
		NB	√√	OCIUS – short run passenger	**N/A**		√		**N/A**	
	Ancillary	RF/NB	√√		**N/A**		√	*Auriga Leader*	**N/A**	
Biofuels	1st Generation	RF	√√	High technological feasibility. Cost effectiveness unproven. Environmental sustainability of feedstock issues	√√	High technological feasibility. Cost effectiveness unproven. Environmental sustainability of feedstock issues	√√	*Jewel of the Sea*, *Anna Desgagnes.* Cost effectiveness unproven. Environmental sustainability of feedstock issues	√	High technological feasibility. Cost effectiveness unproven. Environmental sustainability of feedstock issues
		NB	√√	As above	√√	*Meri*. As above	√√	As above	√	As above
	2nd Generation	RF	**N/A**		**N/A**		**N/A**		**N/A**	
		NB	√√√	High technological feasibility	√√√	*B9*. High technological feasibility	√√√	High technological feasibility	√√	High technological feasibility
	3rd Generation	RF	**N/A**		**N/A**		**N/A**		**N/A**	
		NB	√√√	Upcoming technology	√√√	Upcoming technology	√√√	Upcoming technology	√√	Upcoming technology
Wave	Main	NB	√	Unmanned research RCVs	**N/A**		√	*Orcelle*	**N/A**	
	Auxiliary	NB	√	Theoretical concept only	**N/A**		v	*Orcelle*	**N/A**	
Electric	Super-capacitor	NB	√	Short run – limited geographical range	√	Short run – limited geographical range	**N/A**		**N/A**	

Keys:

Current Application

This provides a measure of the market status of each renewable energy technology

(yellow)	In commercial use
(green)	Proven
(light green)	Proof of concept
(blue)	Design
(cyan)	Concept
(white)	Unknown

Potential Application

This provides a crude assessment of overall potential benefits of each technology in terms of economics (e.g. does it offer improved economic performance for the end user? Is it easy to adopt?), environmental (what CO_2 savings are likely? How is embedded CO_2 managed?) and social (is the technology suitable for cultural/societal development? Does it support development or create community resilience?).

√√√	High potential (scores well on all 3 metrics)
√√	Medium potential (scores well on 1 or 2 metrics)
√	Low potential (does not score well on any metric)
N/A	Unknown