A new ship on the horizon?

Using technology to plot a course to a lower carbon future for international shipping

A Tyndall Centre report on a shipping technology roadmapping workshop, held at the UK Chamber of Shipping
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Tyndall°Centre for Climate Change Research

Research Councils UK Energy For a Low Carbon Future

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Introduction

The origins of international maritime trade can be traced as far back as the first Phoenician galley ships carrying cedar wood, purple dye, gold and fine linen. Those first ships set sail in search of new markets in Greece and north Africa as early as 1000 BC.

Over three thousand years later, despite the development of a variety of alternative transport methods in the interim, shipping remains the most common method of moving goods from one country to another.

Today, it facilitates over 90 per cent of all global trade, according to the International Maritime Organization (IMO).

With such heritage and scale comes great responsibility. Accordingly, the IMO has stated its commitment to ensuring that the shipping industry "will make its fair and proportionate contribution" to tackling what is widely regarded as the greatest threat this planet has ever faced: climate change.

Yet the significant and alarming growth in global CO_2 emissions across all sectors appears to be unchecked by the repeated pledges of the international organisations responsible for developing meaningful emission reduction policies.

The pressure on all governments and industry sectors to take decisive action to prevent calamitous climate change grows by the day. In an effort to articulate how technology could enable the shipping sector to make a proportionate contribution to the climate change challenge, a participatory workshop was held on 15th January 2013 at the UK Chamber of Shipping.

This report describes the outputs from a 'technology roadmapping' workshop, organised and facilitated by the School of Mechanical Aerospace and Civil Engineering and the Tyndall Centre for Climate Change Research

The workshop brought together stakeholders from a variety of technical, research, policy and industry backgrounds to explore potential options and timelines for achieving a significant reduction in CO_2 emissions from the global shipping fleet with a focus on technological developments.

The workshop was the last in a series of engagement activities run as part of the University of Manchester's High Seas project funded by the Engineering and Physical Sciences Research Council (EPSRC) that began in April 2010 and ends in December 2013.

The aim of "High Seas" is to assess the technical and operational potential of a rapid and significant carbon emission reduction by international shipping. This report is not designed to be a fully comprehensive collection of all the points raised at that workshop (they are available online), nor an exhaustive academic exploration of all the technologies potentially available.

What it should do, however, is offer a concise and readable summary of the key points discussed, set within the context of the challenge faced by shipping, and every other sector, to cut CO_2 emissions.

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A fair and proportionate contribution: The challenge for international shipping

Shipping faces an enormous challenge: to secure its future as the primary channel for international trade, while simultaneously overseeing a dramatic and rapid reduction in its global CO_2 emissions.

Both the UN regulatory agency responsible for shipping and ship operators (the IMO) and the International Chamber of Shipping (ICS) have made clear their support for globally agreed action to reduce emissions.

At the international climate change summit in Durban in 2011, the IMO stated that the sector it represents would "make its fair and proportionate contribution towards realising the objectives… that the global community pursue".

The ICS went a step further in its response to the Durban conference and suggested that any emission reductions achieved by the shipping industry "should be at least as ambitious as the CO_2 emissions reduction agreed under any new UNFCCC".

The challenge faced by both the IMO and the ICS in keeping to their stated commitments lies in implementing regulations in the face of the sometimes conflicting positions of member states, or coalitions of member states. There appears, therefore, to be a discrepancy between the stated commitments of the industry to ensure a leading role for international shipping in keeping a lid on potentially dangerous levels of CO_2 emissions and the policies it currently advocates to support those commitments.

Over the last 20 years, annual CO_2 emissions from international shipping have doubled to levels around 900 metric tonnes (Mt) and continue to grow, in contrast to many other industrial sectors, particularly within industrialised nations. If the shipping industry is to make a truly "fair and proportionate contribution" to the reduction of global emissions in line with the stated goal of the international community, research conducted by the High Seas project team suggests it would need to reduce emissions urgently, by as much as 40 per cent (from 2010 levels) by 2030 (Anderson and Bows, 2012).

In reality, despite the recent implementation of emission reduction policies by the IMO, the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), international shipping appears to be on course an increase - not a cut - in CO_2 emissions of over 100 per cent from current levels by 2050.

In recognition of this situation, the IMO is also exploring complementary market-based measures to control overall greenhouse gas emissions from shipping, but the longer this takes to materialise, the greater the challenge becomes to limit cumulative CO_2 to within the target range.

The shipping industry is far from being alone in facing this unfortunate dilemma. A range of international summits, accords and protocols over the last 20 years have all agreed that action must be taken to restrict CO_2 emissions and avoid a subsequent global temperature rise of more than 2°C that scientists agree is likely to lead to "dangerous climate change".

Yet global emissions have continued to grow and concentration levels of CO_2 in the atmosphere are at a record high. At this rate, the planet is headed for a temperature well above the 2°C of the international consensus.

Indeed, the International Energy Agency (IEA) believes that the current trend suggests a 6°C increase is more likely, which it says would have "devastating consequences", far beyond those caused by a 2°C rise. According to Efthimios E Mitropoulos, Secretary General of the IMO for eight years until December 2011, the shipping industry, like the rest of us, has some very tough decisions to make.

"Faced with facts we cannot argue against, we need to consider our priorities and accept that we have to make certain sacrifices; we need to start putting 'life' ahead of 'lifestyle'," he said on World Maritime Day in 2009.

Acknowledging these words, the High Seas project team recognises the challenge facing international shipping in their paper *Executing a Scharnow turn: reconciling shipping emissions with international commitments on climate change* (Anderson & Bows 2012) and concludes that "fundamental change" is essential.

Concluding his introduction to the technology roadmapping workshop at the UK Chamber of Shipping, one of the authors of that paper, Kevin Anderson, told the participants that international shipping would need to go far beyond the approach taken through the EEDI and SEEMP. In particular, he told the assembled delegates that the industry should commit to achieving a 40 per cent reduction in emissions by 2030 and as much as a 90 per cent reduction by 2050.

To achieve these challenging targets, international shipping will need to think and act differently, throw off the shackles of the status quo and see this issue as a unique opportunity to create a resilient industry for the next 3,000 years, rather than an insurmountable threat.

The benefits of innovation also have the potential to extend more widely than reducing CO_2 alone. Making new use of some technologies, such as sails or batteries for power, could help to reduce emissions of other pollutants. For those companies looking to improve the environmental performance of their supply chains, the most carbon efficient ships could prove the most attractive.

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Mapping the potential of technology in a decarbonised future

So just how can international shipping achieve a dramatic and rapid reduction in its CO_2 emissions, without losing any of its vibrancy and influence as a global industry?

The shipping sector provides a service to other sectors, facilitating the movement of trade, and will therefore be affected by changes in demand for goods.

If a country, like the UK, was to reduce its dependence on coal, oil and gas, for example, the number of large ships required to carry that cargo would probably fall in line with a fall in demand for fossil imports (Mander et al, 2012).

Operational changes, such as more efficient scheduling of shipping routes may also deliver reductions in emissions, but these are unlikely to do more than scratch the surface of the reductions required by 2030 and 2050.

There are some technologies, on the other hand, that have the potential to deliver significant, rapid and long-lasting change, albeit once a number of gaps and barriers are identified and overcome.

The workshop at the UK Chamber of Shipping challenged participants to develop technology roadmaps for three ship types:

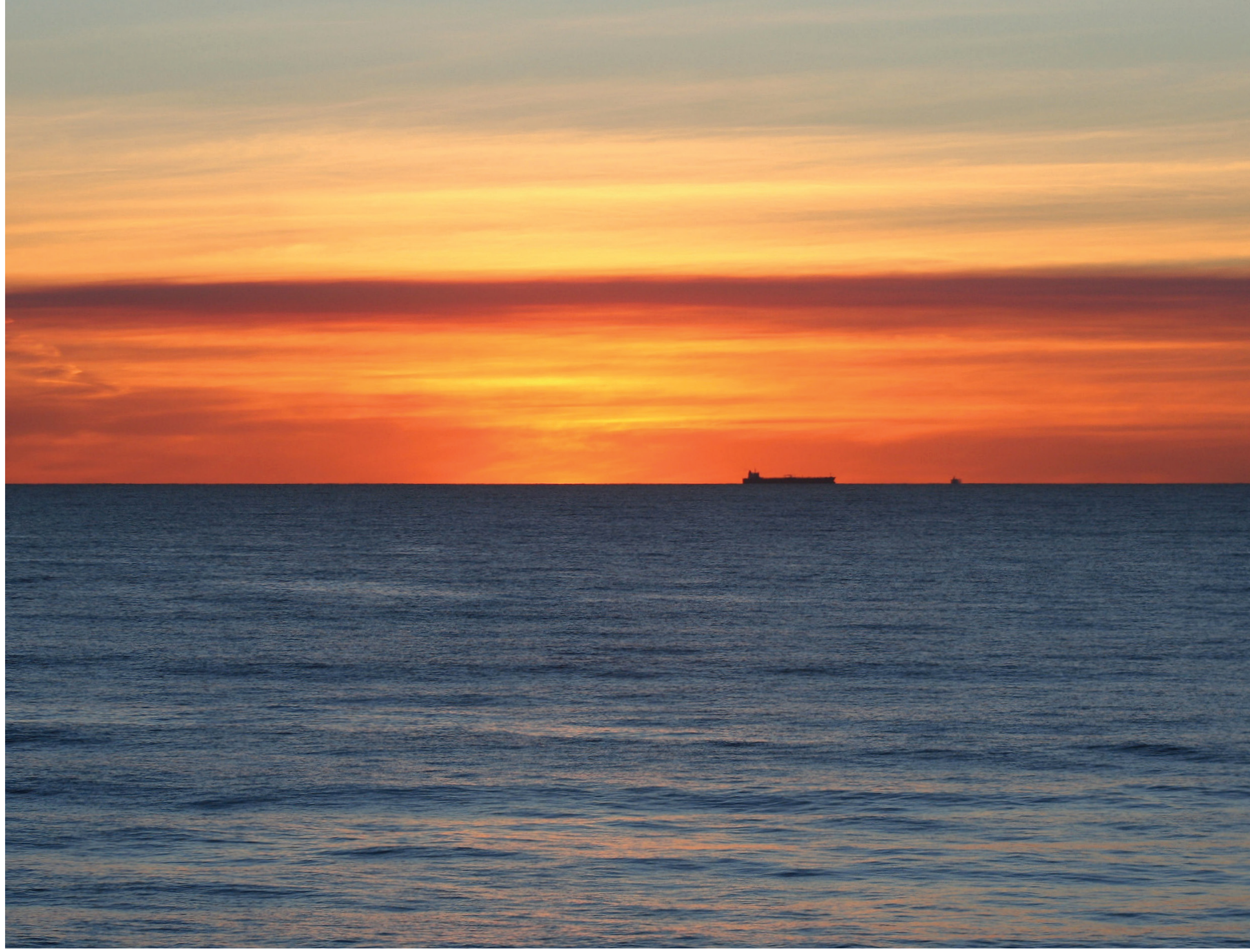
- Bulk carriers and tankers (>100,000dwt);
- containers (>50,000dwt);
- and smaller ships (ferries, coastal freighters).

This differentiation was made as ships in each of these categories have different superstructures, hull designs and power requirements, serve different types of market, and therefore different technologies have greater or lesser applicability.

A roadmap is a strategic plan that describes the steps required to reach a defined goal. Roadmaps support decision-making by helping to anticipate future obstacles, mapping out the most efficient way to reach an objective and communicating the route as clearly as possible. Typically, it takes a three-step approach and this was adopted by the workshop, as follows:

Choose your destination

Workshop participants were asked to envision a series of vessel concepts for new-build zero emissions ships capable of achieving significant penetration by 2050 and to consider how retrofitting technology could contribute to significantly reducing the emissions from the existing fleet between now and 2050.



Survey different paths

For each ship type, participants were asked to create a vision of what these ships would look like in terms of hull design, materials, fuel and propulsion systems.

Plot the course

The three groups were then asked to develop the roadmap for their ship type, outlining the stages of technology development, the likely timescale and the gaps and the barriers that would have to be overcome. A roadmap is intended to be a visual means of communicating how a particular goal can be reached, in this case how the visions of the different ship types can be achieved.

Small ships: A low carbon vision for the future

According to figures published by the United Nations Conference on Trade and Development for their 2012 Review of Maritime Transport, the global fleet was made up of a total of 104,305 commercial seafaring ships in service.

Of these, 20 per cent were classified as "general cargo" ships, with an average size of 5,182 deadweight tons (dwt).

According to UNCTAD's classification, this category of ships would include refrigerated and specialised as well as general cargo ships.

A further 55 per cent were classified as "other ships", with an average size of 1,726 dwt.

This category includes chemical tankers, liquefied gas carriers, passenger ferries, fishing boats and offshore supply vessels.

By way of comparison, the global distribution of the different ship types and associated size bands results in a global mean ship size of 14,700 dwt.

For the purpose of the High Seas workshop, both categories were included within the discussion of potential technology roadmaps for smaller vessels.

Numerous technology options were proposed to reduce the carbon impact of small ships.

One important starting point would be reducing hull friction through the use of microbubbles - tiny air bubbles injected into the outer layer of the hull that have been shown in small-scale tests to reduce drag and therefore enable the ship to use less power.

In terms of the source of that power, the following energy sources for new build ships with zero CO_2 emissions were suggested: wind, liquid biomethane, solar and nuclear.

Fuels cells or other energy storage devices would be required to convert or store the energy from these new fuel sources.

The example of B9 Energy Group's ship design illustrates how wind is already a viable option for cargo ships up to a size of 3,000dwt.

Certainly, no other method of propulsion can boast the same depth of development.

5,000 years of building and sailing ships of all shapes and sizes suggests that wind will always be an effective way of powering vessels at sea.

It was agreed that with further development, wind would be capable of powering ships of up to 10,000dwt by 2030.

The main barriers to widespread penetration across the fleet were identified as being logistical rather than technical, most particularly ensuring that either ports and bridges around the world are capable of accommodating ships with tall masts or Flettner rotors or that the masts can be lowered.

The unpredictability of wind, particularly over short sea routes, would likely necessitate a back-up or complementary power source in new build smaller ships. Biomethane, generated from the anaerobic digestion of, for example food waste, was proposed as a viable fuel to supplement wind power and could potentially be available widely within the next five years.

While ships using biomethane would not be emission-free, it was agreed that they would carry "zero global warming potential" as the biogenic CO_2 would essentially be sequestered from the atmosphere rather than created directly from burning fossil fuels. The use of fuel cells was also considered for new build small ships, most likely using methanol rather than hydrogen.

The challenge here moving forward will be scaling up the power output of the fuel cells while ensuring that they remain small enough in size to use on a ship.

Currently there are high-temperature fuel cells producing power of 1MW on land.

The consensus from this group, at least, was that it would take until at least 2030 to create a fuel cell capable of generating 10MW that was suitable to power a 10,000 dwt ship.

Emissions generated from using non-bio-derived methanol would also require some form of carbon capture and storage to be built into the design, which could further delay deployment.

Energy storage, although not a form of power generation in itself, was also expected to play an important role in a decarbonised short sea shipping fleet.

With significant research into energy storage being funded by a variety of industries, if not shipping itself to any great degree, it was felt likely that by 2025, there would be an efficient and cost effective means of energy storage.

Potential energy storage technologies include supercapacitors, fly wheels, superconducting magnetic energy storage (SMES), redox and liquid batteries.

With effective energy storage onboard, there is also the possibility of using cold ironing when in dock or solar panels during the voyage, although this latter option would require a significant fall in the relative price of photovoltaic technology.

Nuclear was briefly discussed as a potential power for new build ships in this segment, although there was considerable concern that there would be major political and regulatory barriers to overcome first, pushing any small-scale implementation out until 2040 at the earliest.

Class approval is now risk based and the burden of evidence would be on the designer to prove the safety of any technology. Most new technologies take 5-10 years to gain approval, nuclear would require a minimum of 25 years.

In terms of adapting the existing fleet with the aim of emissions reduction, slower ship speeds (14 knots or less), greater engine and propeller efficiencies and a smoother flow of water over the hull were recommended as the first steps to take. While microbubbles may not be a practical retrofit option, blasting or using coatings could help create a smoother and friction-reduced hull.

Propeller inefficiency, meanwhile, may be improved by the introduction of contra-rotating propellers, an idea that has been around for a long time.

With significant investment now being made, notably in Japan, within 10 years they may become commercially viable, offering as much as a (one-off) 5-10 per cent benefit, especially in combination with podded drives. Improved propeller designs such as rim-driven propellers offer further hope for efficiency savings.

It was proposed that power for existing small ships could be generated from retrofitted kites or Flettner rotors where deck space allowed, or through the fitting of methanol-fuelled high-temperature fuel cells. The cost of redesigning or retro-fitting vessels was deemed to be particularly high for small ships compared to the cost of building a new vessel.

Thus, scrappage schemes were suggested as a means of encouraging shipowners to invest in the latest, most up-to-date ships.

Vision for a 2050 SMALL ship:
Low friction hull made from recycled steel with lightweight, composite materials; optimised propeller; sail propulsion combined with high temperature methanol fuel cells and batteries

KEY:

- Superstructure
- Energy Storage/Fuel cells
- Propulsion
- Fuel

	BARRIERS	2013	2020	2030	2040	2050	ENABLING MECHANISMS
HULL		Importance of hull friction recognised	Hulls designed to reduce friction			Low friction hull	Reducing hull friction to improve energy efficiency
STEEL		Design for recycling	Auto industry best practice / ISO standard	Easily removed coatings		Recycling in regulated facilities	Economic model that values materials - extra value for vessel
FIBRE GLASS	Scale/applicability of materials; classification;	Fibre glass accommodation blocks	Composite propeller, fibre glass mast and superstructure			Build modernisation	Standard and training to design and build with new materials
WIND PROPULSION	Infrastructure barriers e.g. bridges and ports, or design to be lowered	Demonstration - 3000dwt		10000 - 30000dwt			Route optimisation; infrastructure barriers e.g. bridges and ports, or design to be lowered; business models that recognise higher upfront but lower operating costs
PROPELLERS		Hub-driven Rim-driven		Light weight for ships/ Electrical unit with good propulsive effiency		Counter rotating propeller/Electric drive	
FUEL CELLS	No fuel (H2 or methanol) infrstructure; costs of fuels cells are high	High temp (1MW)		High temp - 10MW (5000dwt @ 14 knots)			
ENERGY STORAGE	Scale, life, charge rate, discharge rate; requires low carbon electricity grid	Range of possible tech		Reliable			
BIOFUEL	Competition with other sectors and lack of re-fuelling infrastructure	Niche		Widespread refuelling infrastructure			

Container ships: A low carbon vision for the future

Container trade has increased steadily over the past 30 years, although growth rates have dipped slightly in recent years in line with the global economic slowdown.

Despite being responsible for the transport of over a billion tonnes of dry cargo every year, container ships only represent 5 per cent of the global shipping fleet, according to UNCTAD's 2012 Maritime Transport Review. The average size of ship in this category, according to this Review, was 39,505dwt, although the size of container vessels these days is more commonly expressed in twenty-foot equivalent units (TEU). The largest container ships in the fleet today are around 18,000 TEU.

Looking to the future and a targeted reduction in emissions to the levels stated earlier in this report, a variety of technologies and energy efficiency ideas could be considered for container ships.

In terms of energy efficiencies, three main ideas were explored:

- Travelling at slower speeds, or slow steaming, would use less fuel and therefore generate fewer emissions; an operational speed of 5 knots was proposed, which would create a significant reduction in the propulsion power demand;
- Counter-rotating and/ or tractor propellers could increase the efficiency of the ship's propulsion, again reducing the requirement for fuel;
- At slower speeds, hull friction in the water becomes increasingly important, so hull shape and coatings need to be considered.

From a new-build perspective, a two-tier vision was proposed, comprising a big (20,000 TEU) and a small (3,000 TEU) container ship type.

The small ship would be designed to be compatible with most ports, including the smallest ones, and therefore provide operational flexibility.

Its smaller size, meanwhile, would also allow it to be powered, principally by wind, most likely in the form of air foils.

Fuel cells would provide auxiliary power and increased speed reliability.

With a power demand of 30MW, compared to a suggested power demand for smaller ships of 5MW, wind could never be the primary energy source for the larger ship without a complete rethink in design, but could provide a proportion of propulsive power in combination with biofuels (that were carbon neutral over their lifecycle) and fuel cells.

Both ships would be designed to run at a maximum speed of 10 knots, with an operational speed of 5 knots – the reserve for manoeuvring and bad weather.

For a power demand of 30MW, a fuel cell of 10MW and a large-scale wind installation of at least 2-3MW could be combined with biofuels.

For these ships to achieve significant penetration of the global fleet, a timeline for development might look something like this:

- By 2015 - Hydrogen and biomass production is increased significantly, as well as continued research into fuel cell development
- By 2020 - Significant regulatory change, with carbon reductions made mandatory, leading to an increased uptake in biomass by ship operators.
- By 2030 - Fuel cells are capable of producing up to 10MW of power, there is a reliable infrastructure in place for biofuel and hydrogen production and 5,000m2 kites are feasible. A staggered approach to rolling out fuel cell infrastructure is taken, initially set up on the major routes (eg China/Singapore/Northern Europe).

Financing of take-up of low carbon technology could be done through a rebate mechanism from funds gathered from a carbon tax or other market-based mechanisms within the industry. This could also help with technology transfer to non-Annex 1 countries where these funds are used to compensate the original IP holders.

Turning to the existing container fleet, a ship size of around 10,000 TEU was thought to be most suitable for retrofitting alternative technologies.

The following measures and their potential savings were identified:

- Install counter rotating/tractor propellers (potential 5 per cent CO_2 reduction)
- Adapt engines to run at reduced speeds (potential 35 per cent CO_2 reduction)
- Adopt bulbous bow (potential 5 per cent CO_2 reduction)
- Optimise voyage planning to enable operation at more constant speeds. Constant ship speeds are not a problem on the high seas but access and entry to canals and ports require speed to be slowed. By 2030, it is possible that a global virtual docking system would be widely in use to enable this change
- Switch to LNG as a bridge technology, shifting to biofuels after 2030 (potential 10 per cent CO_2 reduction)
- Use kites (potential for between 10 and 20 per cent CO_2 reduction). These are more straightforward to retro-fit than sails or Flettner rotors due to necessary structural changes to the ships. It was suggested that the systems to enable the use of real-time (and accurate) global weather forecast data would be available by 2030, to allow operators to decide when and where they make the best use of the kites.

Together, these retrofitting measures could potentially provide a 55 per cent reduction in CO_2 emissions from adapted container ships.

CO_2 scrubbing was considered as a potential means of reducing footprints further, but due to uncertainty over the technology's current effectivectiveness, it was not considered likely to be a viable option until after 2020.

Visions for a 2050 CONTAINER ship:
3000 TEU, principally powered by wind (air foils) with fuel cells for auxiliary power or 20000 TEU, powered by a 10MW fuel cell, a kite installation of 2-3MW and biofuels

KEY:

- Superstructure
- Propulsion
- Energy Storage/Fuel Cell
- Fuel

	BARRIERS	2013	2020	2030	2040	2050	ENABLING MECHANISMS
DESIGN SPEED			Optimised ship design to operate at 5 knots, with 10 knots maximum speed	Global virtual docking system in place			Designs optimised to facilitate travelling at slow speed
HULL			Low friction hull				
WIND PRO-PULSION		Kites and airfoils emerging		5000m^2 area sails feasible			Weather data systems maximise use of wind propulsion
PROPELLERS			Optimised propeller shape and set-up				Propeller design optimised to maximise efficiency over operating profile
FUEL CELLS		1MW		10 MW fuel cell			
BIO FUEL		Upscale production	Increased use	Refuelling infrastructure widespread			
HYDROGEN		H2 in niche onshore applications		Refuelling infrastructure widespread			
LNG			Infrastructure in place	LNG is used as a bridging fuel in short term and phased out as H2 and biofuels penetrate the market		LNG use ends	

Bulkers and Tankers: A low carbon vision for the future

By number of ships, bulk carriers and tankers make up over 20 per cent of the global shipping fleet, according to UNCTAD's data.

By size of ship, they represent over 70 per cent of the fleet, with an average tanker size of 45,251dwt and an average bulker size of 63,420dwt.

In terms of potential carbon-reducing measures for these giants of the sea, both for new-build and adaptations to the current fleet, there are two main considerations: energy saving measures due to ship speed, ballast and hull design, and alternative means of propulsion.

From an energy saving perspective, the following measures would be appropriate:

- Slow steaming - as with the smaller ships and containers, slower speeds open up the potential for the use of wind power
- Ballast - a zero ballast ship could deliver enormous savings but safety assurances would also have to be built into the design
- Design improvements to both the hull and the structure of the ship, including minimizing the accommodation onboard

Workshop participants came to the view that, together, these measures have the potential to reduce the energy consumption of each ship by between 10 and 40 per cent.

In terms of propulsion, the following methods were prioritised:

- Nuclear
- Fuel cells (either as the main source of propulsion post 2030 or as auxiliary power)
- Algae fuel generated and loaded at sea or other biofuels
- Flettner rotors (more applicable to bulkers than to containers)
- Other wind and renewable sources (including solar)

All these elements were considered in creating a vision of new build ships that might penetrate the global fleet by 2050.

These ships would be optimised for slow steaming at around 5-6 knots, but would have a wider range to enable them to navigate through difficult weather conditions. They would have improved hull design, zero ballast, minimised accommodation and benefit from more efficient and effective global logistics agreements and trade route planning.

Propulsion in these bulkers of the future would be provided not by a single technology, but by a combination of Flettner rotors and kites, nuclear, fuel cells or biofuels, like algae fuel. Micro-algae is low in sulphur and nitrogen and has the potential to be produced at sea while the ship is en route, but there are concerns currently over securing sufficient quantities to make this a viable proposition in the long-term.

These ships could also potentially store supercritical steam that is then put through a turbine for steam propulsion.

A variety of measures were proposed for reducing the emissions of existing bulkers and tankers.

It was proposed that a co-generation system could be retrofitted, which would recover excess heat energy and store it for auxillary energy use when needed.

Savings could also be made by tuning the engine, reducing the amount of hotel capacity required onboard, making adjustments to the propellers or using hull coatings as also suggested for smaller and container ships.

When combined, these efficiency improvements could potentially help reduce emissions by as much as 10-15 per cent.

Cold ironing, or shore power, was also suggested as a means of reducing emissions while the ships were in port, particularly if the energy generated on shore was from a renewable source.

In terms of energy to power these ships on the high seas, nuclear, hydrogen, biofuels and wind were the main technologies discussed.A nuclear retrofit was thought to potentially be viable. The main barrier identified was concern over gaining political and regulatory approval and the length of time required to achieve this.

Hydrogen could also potentially be used in existing ship designs, but as well as sharing some of the same issues as nuclear over approval timelines, there were also practical concerns over designing ships capable of storing sufficient hydrogen safely, effectively waiting for a step-change in storage and transport technology.

A less disruptive transition to a lower carbon bulker fleet might be made through the use of biofuels, although these would not strictly be zero-emission ships. Currently, biofuels are used to power small boats but nothing close to the size of a tanker or bulker.

Fuel cells were discussed but were thought currently to be unable to generate sufficient amounts of power as a primary propulsion source.

Hydrogen fuel cells are in use in various land-based applications but not yet at sea.Batteries were thought to be a good idea for auxiliary energy use, while wind through Flettner rotors or kites could provide additional or supplementary sources of power.

“In terms of potential carbon reducing measures for these giants of the sea, both for new-build and adaptations to the current fleet, there are two main considerations: energy saving measures due to ship speed, ballast and hull design, and alternative means of propulsion.”

Kites have already been developed for use on bulkers but have experienced some teething trouble in their implementation. It was agreed that carbon capture and storage devices or the use of “CO_2 scrubbers” would be needed to reduce the impact of emissions between now and 2050, as low-carbon technologies gradually penetrated the fleet.

Looking ahead to the potential decarbonisation of the bulker fleet as a whole, the following milestones were imagined:

2015

- Biofuels tested in ships in dual fuel engines
- Zero ballast ships designed
- More widespread use of kites and better route planning
- Flettner rotors and sails retrofitted on some ships

2020

- The engineering concept for modular nuclear reactors is developed and demonstrators create 100-300MW of power. There are still few licensed ports for maintenance and refueling however
- Enough feedstock is sourced for third generation biofuels, there is some penetration but they still need to prove their viability
- Significant research into hydrogen storage

2025

- The first zero ballast ships set sail

2030

- There is significant penetration of biofuels
- The first thorium nuclear power designs for bulkers and tankers emerge
- The first small modular reactors start being retrofitted to ships
- Research and testing

2040

- The production of algae fuel at sea for refuelling tankers and bulkers begins
- Hydrogen is produced at sea on refuelling platforms and begins to be used in fuel cells and in engines of bulkers and tankers
- The first ships appear with wind turbines to produce hydrogen to refuel while at sea; this overcomes the issue of pipeline materials becoming brittle due to exposure to hydrogen

Vision for a 2050 BULK ship:

Fuelled by nuclear, H_2 and biofuels; kites to provide additional propulsion; design optmsed for slow steaming; CO_2 scrubbing for emissions reduction prior to 2013

KEY:

- Superstructure
- Propulsion
- Energy Storage/Fuel Cells
- Fuel

	BARRIERS	2013	2020	2030	2040	2050	ENABLING MECHANISMS
HULL		Zero ballast ship designed	Deployment of zero ballast ship. Optimised accommodation block design				Hull and accommodation block design optimised to improve fuel efficiency
WIND PROPULSION		Demonstration use of kites		Big penetration of sails and kites			Route planning to facilitate use of wind propulsion
BIOFUEL	Mixing and blending standards	Some use on small boats	Biofuels tested in duel fuel engines 3rd generation biofuels	Significant penetration	Production of biofuels at sea for re-fuelling		Superstructure design optimised for energy efficiency
HYDROGEN	Political and social perception; regulatory approval; knowledge of new technology; capital investment	H2 not used for ships	Effective H2 storage New, less brittle materials		H_2 produced from wind on offshore fueling platforms		
NUCLEAR	Political and social perception; de-commissioning costs; availability of uranium; regulatory approval ;economic model	Niche uses	Engineering feasibility for modular reactors demonstrated	Modular reactors retro-fitted to ships First designs for thorium reactors	All bulk ships		

Overcoming barriers: turning visions into reality

So it's clear that there are lots of ways for ships of all sizes to start reducing their CO_2 emissions, both from new build ships and across the current fleet.

Turning the various visions discussed at the UK Chamber of Shipping workshop into reality will not be without some significant challenges, some of which appear to have potential resolutions at hand and others that do not.

These were the main "gaps and barriers" identified at the workshop:

Carbon capture and storage.

With CCS still uncommercialised, onboard removal of CO_2 is largely dependent on the progress of that technology deployment away from shipping

Political barriers.

Both to nuclear and to major changes to the shipping fleet in general. Is there the political will for nuclear when there are potentially other options available? If some countries or representative organisations like the IMO are stalled on significant climate change prevention measures, why should that stop ship operators or 'port states' from going ahead with mitigation policies?

Costs.

In order to achieve a significant take-up of these technologies, they need to be proven to be cost-effective and preferably cheaper to run than any existing technologies. The more evidence there is of these technologies in action, the more likely ship operators are to take an interest, particularly if supported by independently-produced information on payback periods. Funding support for particular technologies from government may also help to incentivise developments.

Regulatory (CLASS) approval.

Many of these low and zero carbon technologies are ready to be installed today, but when even something as seemingly simple as installing a fire alarm can take months to be approved, there is a concern over how long it would take to introduce something as significant as a new engine, set of Flettner rotors or new propeller.

Slow steaming.

Despite the evidence that shows slower speeds save fuel and reduce emissions, the just-in-time market dynamic is still very much the dominant force for bulkers and containers. Making the most of the opportunity offered by slow steaming requires highly reliable logistics networks.

Uncertainty and risk

Everyone, from governments, the IMO to ship operators themselves need to understand the technologies in front of them. They need assurance of performance, timescales and costs from people they can trust, for example Lloyds, classification societies, Oil Companies International Marine Forum (OCMIF), Baltic and International Marine Council (BIMCO) and the ICS.

Are alternative fuels just a pipe dream?

Until significant upscaling is achieved and demonstrated, hydrogen, renewables, fuel cells and biofuels will not be considered as serious energy sources for the global shipping fleet. Currently there is also a lack of infrastructure for large-scale production of methanol, hydrogen and nuclear.

Effective communication and co-ordination.

Without this, widespread and rapid take-up of new technologies will be impossible. Transparency and publicly available data and information are essential elements of this.

Competition.

Many of the fuels identified within the workshop will also be in demand from other industries and sectors as the pressure grows to find their own lower carbon roadmaps. Competing demand for very low supplies of low carbon fuels like biomethanol derived from food waste or biofuel will continue to be a real challenge for every industry and sector.

Shipping market conditions.

At present, there is overcapacity in the shipping market and an absence of a market for new ships that could hamper those looking to fund investment in new technologies.

Contractual arrangements.

The shipping sector, with its many different markets and complex contractual arrangements, clouds the design of economic incentives to promote investment in low carbon technologies.

Next steps

Undoubtedly, one of the most difficult barriers to overcome will be the lack of political will. In the absence of a carbon cap and/or price that reflects the 2°C target, regional and national governments need to devise regulatory regimes which offer economic incentives to the traditionally conservative shipping businesses for the adoption of new technologies.

To change the propulsion technology of a significant section of the global shipping fleet to a fuel such as hydrogen or nuclear would require national governments to play a central role. Similarly, tough regulation to force shipowners to seek low or zero CO_2 emitting technology pathways would require institutions like the European Union and the IMO to take a line that would be unpopular with some member states.

This represents a particular challenge for the IMO as it would require the participation of member states that do not support the development of climate change mitigation regulations if they are considered to pose a national disadvantage.

On the whole, policy makers have, to date, been unable to implement regulations with real teeth, preferring instead to opt for more flexible guidelines, indexes or plans.

But as the High Seas project team and their wider research show, significant change is urgently required.

So if tough new regulation or a state-sponsored nuclear fleet refit is unlikely, how can international shipping begin plotting a course to a future with radically fewer CO_2 emissions, along the lines of some of the technology routes identified in this report?

The consensus appears to be that if political pressure won't do the job, then economic pressure offers the only other realistic alternative.

The form that this economic pressure should take is, however, unclear, though such a mechanism will undoubtedly have to be innovative.

For example, reduced port charges and preferential treatment for greener ships could persuade more shipowners to risk retrofitting their fleets with wind or substituting conventional fuel for biofuel or even investing in a radical new build design.

Further incentive to change may also come down through the supply chain if large corporations like supermarkets are keen to demonstrate to their customers and the public how seriously they take their environmental commitments.

Many of the big supermarket chains have talked in recent months about the need to reduce the footprint of their supply operation as well as their own direct operations.

Conclusion

As this report makes clear at the outset, climate change is an issue that challenges all of us, not just shipowners, operators and their representative organisations.

The planet is warming at an unprecedented rate due to a similarly unprecedented rise in man-made CO_2 emissions.

Decisive action must be taken sooner rather than later if we are to avoid the catastrophic 6°C global temperature rise that the IEA think we are currently headed towards. Technology is not a panacea.

Successful reduction of global CO_2 emissions will require an unheralded mix of social, political and commercial innovation, academic rigour and endeavour, collaboration and determination.

Technology will clearly play a hugely significant role within that mix.

As this report outlines, there are a range of options for ships of all sizes to reduce emissions from new-builds and the existing fleet, albeit options that face significant if not insurmountable barriers to implementation and widespread use.

For more than 3,000 years, shipping has opened our horizons, geographically, commercially and metaphorically.

Now it has the opportunity to play a leading role in securing our future for the next 3,000 years. New ships headed towards a new horizon.

As the words of former IMO Secretary General Efthimios E Mitropoulos from his stirring 2009 address remind us: "This cannot, and should not, go on. We need to make some tough decisions and we need to make them now."

> "For more than 3,000 years, shipping has opened our horizons, geographically, commercially and metaphorically."

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