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Controlling GHGs: For love or money?

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Good morning and thank you for inviting me to talk about the technical solutions that ships can use to reduce greenhouse gas emissions.

My comments this morning will not all be new to some of you, but I hope that by bringing this brief summary to your attention I can give you a taste of what has been done in the past, what is being done now and what might be possible in the future.

First of all, as you can see from my CV, I trained as a naval architect and worked at a ship model experiment tank. Our task was simple: to measure a design's performance and improve it to reduce fuel consumption.

And reducing fuel consumption is at the heart of reducing greenhouse gasses, so this is what ship designers have been doing since we first started using fossil fuels. Hitherto, the driving force has been economics. Only more recently have greenhouse gasses come into the equation although, as I'll discuss later and as the title of my presentation suggests, the real motivation has hardly changed.

Before we get into the meat of my presentation, I would like to make an aside about the size of the problem. The secretariat's briefing note (Table 1, p4) listed a number of studies that estimated the fuel consumption and CO2 production from world shipping. As it notes, they have different underlying assumptions, but I was surprised at the range of figures offered. Using the figures to calculate tonnes of CO2 per tonne of fuel produces figures ranging from 2.29 to 3.20 tonnes per tonne – a variation of about 40%.

	Base Year	**CO_2 million tons**	**Fuel million tons**	**tons CO_2/ tons fuel**
IMO Updated Study (2008)	2007	843	277	3.04
IMO/Group of Experts (2007)	2007	1,120	369	3.04
IMO GHG Study (2000)	1996	419.3	138	3.04
IEA (2005)	2005	543	214	2.54
TRT Transporti e Territorio	2006	1,003	NA	
Endressen et al., 2007	2002	634	200	3.17
Eide et al., 2007	2004	704	220	3.20
Eide et al., 2007	2006	800	350	2.29
Corbett et al., 2003	2001	912	289	3.16

It seems to me that there should be a more definite figure than this, based on the fuel's chemistry. I mentioned this to the Norwegian consultant Professor Tor Wergeland, who has done some valuable work in this area, and he referred me to a paper prepared last May by the National Technical University of Athens on behalf of the Hellenic Chamber of Shipping (1). Although that paper was itself an analysis of other work, its conclusion was that a factor of 3.17 tonnes of CO2 per tonne of fuel was the best estimate and was independent of fuel type. Professor Wergeland tells me that he has "come to trust" this figure but it would be interesting to hear from a chemist what the theoretical figure is. Unless there is an accepted figure for this, then estimates of the scale of the problem will continue to vary wildly, and I commend this Athens figure of 3.17 to you.

I will also digress slightly from my brief to mention that Lloyd's Register-Fairplay Research, which is a subsidiary company to Lloyd's Register-Fairplay and based in Gothenburg, has developed a model for analysing ship emissions based on movement information derived from AIS records and engine emissions estimated from our database of ships and engines. This can produce a detailed report on emissions in a specific area over a specific period and I mention it as an example of the sort of analysis that is available to help assess the scope of the problem of ship emissions, including GHGs.

Now to business. And I shall say at this point that I refer to a number of companies in my remarks, but this should not be seen as my endorsing these organisations over any other that offers similar technologies.

Engines

Improving engine efficiency obviously offers the greatest potential for reducing fuel consumption and thus GHGs and this has been a constant quest for engine designers. This graph, which appears on the Wärtsilä website, shows how much progress has been made in the past 40 years, as engine efficiency has risen from around 41% to 50%. It was initially driven by the first oil price shock in the early 1970s, which raised fuel efficiency up the agenda. Improvements have slowed somewhat in recent years and I have never met an engine designer who will say what limit will eventually be reached, but it would appear as though it will take more than another 40 years to raise it by another nine percentage points.

Ironically, Wärtsilä's website notes that "the pace of improvement in efficiency has fallen off somewhat in recent years owing to the increasing restrictions placed on nitrogen oxide emissions." So there are two sides to every coin.

In the text accompanying this graph, Wärtsilä explains how these improvements have been achieved, listing such things as increasing the cylinder pressure, raising the compression ratio, reducing the fuel injection period, optimizing the valve timing, and improving the combustion process and notes that its most important priorities include raising efficiency and reducing emissions.

And so, of course, are the other engine designers; the need to increase efficiency is as much driven by commercial competitivity as anything else. And there's nothing wrong with that.

But the fact remains that only about half of the energy bunkered goes into propulsive power. That is not to say that the other half all goes to waste: according to figures from MAN B&W, about 25% is wasted with the rest powering various items of auxiliary equipment.

Where the energy goes

Engine: MAN B&W 12K98ME/MC Standard engine version
SMCR : 68,640 kW at 94.0 rev/min
ISO ambient reference conditions

	Standard Engine	With TES
Shaft power output:	49.3%	49.3%
Exhaust gas:	25.5%	22.9%
Air cooler:	16.5%	14.2%
Jacket water cooler:	5.2%	5.2%
Electrical Power from TES		4.9%
Lubricating oil cooler:	2.9%	2.9%
Heat radiation:	0.6%	0.6%

Source: MAN B&W

Much has been done over the years to recover energy from this exhaust. Exhaust gas boilers can be used to produce steam that can be passed through a steam turbine to produce electricity and increase the system's efficiency to about 55%. For engines used for power generation on land, then a combined heat and power system that distributes the recovered heat to the local area can raise the total efficiency to 75-90%, according to Wärtsilä, so there is still plenty of value to be gained from further exploring on-board waste heat recovery.

One option is to review those other auxiliary items, as MAN B&W has done with its Thermo Efficiency System (TES), in which changes in the engine timing and exhaust system make the exhaust gas more suitable for generating steam to produce electricity – although it may slightly reduce the efficiency of the engine itself – gaining a few percent in overall efficiency.

Before we move on from engines, two obvious areas for improving overall efficiency are turbochargers – which improve what's going into the engine – and waste heat recovery systems, which make better use of what comes out.

Turbochargers have been around for more than 100 years and first went to sea in 1926. Their job is to pressurise the charge air, providing more oxygen for combustion and significantly increasing an engine's power. One of the leading turbocharger manufacturers, ABB, has introduced multi-stage compressors delivering higher boost pressures and greater efficiencies, and thus reducing emissions of all kinds.

MAN Diesel has developed what it calls its VTA (Variable Turbine Area) turbocharger. This arrangement is designed to feed in turbocharger air in variable quantities. It has adjustable blades to optimise the turbocharger's performance to different engine conditions and thus reduce fuel consumption and emissions. I don’t have figures for the overall efficiency improvements that these systems bring, but I mention them as examples of the work that is being done at that end of the engine.

At the other end, I have already referred to MAN B&W’s Thermo Efficiency System, but there are other systems available that achieve similar aims. Siemens, for example, offers what it calls its SISHIP Waste Heat Recovery System, which uses not only steam generated from a waste heat boiler to generate electricity but also takes energy from the exhaust gas flow itself to drive a turbo generator. Some of the exhaust flow energy, of course, is driving the turbocharger, but not all and this system benefits from that.

Propellers

Now let’s move outside the ship and look briefly at propellers.

Propellers have been refined over the years and it might be thought that there is little more that can be done to improve them. Yet German propeller maker MMG believes that, for some ships – VLCCs and bulk carriers – three blades are better than four, and quotes a gain of 3.5% gain in power.

Others claim even more: Ferry operator Stena changed the four-bladed propellers on its ferry *Stena Germanica* in 2005 for three-bladed replacements supplied by Rolls-Royce and reported 10% less fuel consumption. It immediately repeated the exercise on two more ferries, *Stena Scaninavica* and *Stena Nordic* and saw savings of 12% and 17% respectively, according to the Royal Institution of Naval Architects magazine The Naval Architect (3)

Or look at this unusual system from Voith Turbo: The Vector Prop. This challenges the conventional wisdom that propellers have to be submerged. This surface-piercing controllable pitch propeller is made from compound plastics and is intended for shallow water vessels, where it allows for larger and slower propellers to be fitted. Its manufacturer claims that in tests, both on models and at full scale, it has shown efficiency improvements of an astonishing 20-40% - which would translate to equivalent fuel savings.

As far as I am aware, this proposal has not gained any significant references, but it is another indication that propeller manufacturers are looking for improvements with some imaginative thinking.

Other propeller systems that have been tried in recent years include the various podded systems that have been fitted to cruise ships and other types of vessel. Then there are devices intended to recover energy lost in the wake, such as contra rotating propellers and freewheeling vanes behind the propeller itself, which have seen varying degrees of success.

These can claim significant savings – one estimate says that contra rotating propellers will save about 15% of energy – but they are complex and expensive devices. Nonetheless, Japanese shipbuilder IHI has fitted a number of contra rotating propeller arrangements of its own design.

Here's something rather simpler: back in the late 1980s, Mitsui OSK Lines developed Propeller Boss Cap Fins, which are small fins fitted to a propeller's boss cap. These are intended to reduce the energy lost into the hub vortex and have proved very popular. More than 1,000 ships have been fitted with these and MOL reports 4-5% power saving – and thus fuel and GHG savings – as a result.

Or there is this stern arrangement, launched by Wärtsilä at last September's SMM exhibition in Hamburg. It is by no means the only, or indeed the first, system that operates in this way and Wärtsilä itself has produced similar arrangements in recent years.

It is called Energopac and works by filling the gap between the propeller and the rudder so as to smooth the flow and improve the interaction between propeller and rudder. As you can see, a bulb is incorporated into the rudder, which is made by Becker, that extends forward nearly to the propeller itself, which has a suitably shaped cap to fair n with the bulb. What is not obvious from this picture is that the rudder itself has a twisted leading edge to align it better with the propeller's slipstream, which reduces drag and is said to reduce vibration. This design also has a flap at the trailing edge of the rudder, which is intended to reduce the angle of rudder needed to steer and thus reduce drag and fuel consumption.

Model tests are said to have shown as much as 8% improvements in efficiency by changing a conventional propeller and semi-spade rudder to this arrangement. If that is borne out in reality, there are obviously significant fuel savings and thus GHG reductions to be won from this sort of arrangement. We shall soon know, as Finnlines has specified this arrangement for six newbuildings due for delivery this year.

<u>Appendages</u>

Just as the Energopac rudder is shaped to match the flow leaving the propeller, other options aim to improve the flow into a propeller. You might think that a symmetrical stern shape is optimum, but with a rotating propeller, of course, on one side the blades are going up while on the other side they are going down. So the water flow off a symmetrical stern strikes the blades differently on either side of the ship and designers have been experimenting with hull shapes and appendages to improve the flow around the propeller for more than 20 years.

I don't have time to detail all the many and varied shapes and sizes of twisted sterns and hull appendages, but here is a pictures from the website of an American company, Ship Propulsion Solutions, which works with the Marine Design & Research Institute in Shanghai to design energy saving devices, for which it then sub-contracts the manufacture, supply and delivery. It says it has so far supplied installations for around 200 ships.

You'll see here that it has fitted fins to the propeller boss cap and what it calls a Simplified Compensative Nozzle ahead of the screw to improve the flow into it. And these pictures, also courtesy of Ship Propulsion Solutions, show the difference that the fins can make on a propeller's vortex.

The company says that estimates that each of its various devices delivers between 2-5% gains and recommends using them in combination, to get 7-10% but it acknowledges that measuring the improvements at full scale requires long-term assessment, but estimates that payback times for even modest improvements can be less than two years.

Here's a different approach to the same solution, from Japan's Tsuneishi Shipbuilding. Its FAST-MT device uses fins ahead of the propeller to improve flow and reduce losses. It predicts fuel savings of 4% and plans, by next year, to include this device as a standard installation on most of the ships it builds.

I won't say much on hull design itself, save to say that, over the years, improved computational fluid dynamics programs have made it much quicker to design an efficient hull than when I was in the business in the late 1970s.

But I will mention bow shape. Over the past 50 years or so, most large ships have been fitted with a bulbous bow. This is there to modify the water flow by setting up a wave system that partially cancels out the ship's own bow wave pattern. And it is very effective at doing its job. Now, some are daring to question its universal application.

And for fast craft: we know what sort of bow shape they have – sleek and swept back. Not like this [Axebow picture]. These are a pair of ships built by the Dutch shipbuilder Damen in 2006 as fast crew supply ships and are called Axebow 101 and Axebow 102, in honour of the bow design, called an Axe Bow. In a paper in 2006 (2) Damen's product director for High Speed & Naval Craft, Jaap Gelling, explained that it had emerged from a project to improve seakeeping and provide a more comfortable ride in waves. Three different hull concepts were considered, including a conventional crew boat hull, and the Axe Bow gave the best seakeeping performance. But, at speeds of up to 35kts, it also showed 5% better resistance than the other alternative form considered which was itself "significantly" better than the conventional hull.

<u>Coatings</u>

Of course, hull shape can only affect part of a ship's total resistance. By far the largest part comes from friction, and if this can be reduced, then significant power and fuel savings are to be found.

The main source of friction is fouling, so antifouling coatings are crucial. Since TBT paint was banned, the replacement coatings have improved considerably in terms of their durability and there is now talk of ‘once-in-a-lifetime’ coatings being possible, which would just need cleaning during the ship’s routine drydocking.

First, however, it would be useful to have an understanding of the performance of anti-fouling coatings and their effect on overall ship performance in service. So the UK’s Newcastle University has carried out a three-year research project, sponsored by International Paint, the Iranian ship operator IRISL and tanker operator OSG to obtain some data that identifies the effect of the coatings, independent of such things as environmental and operational factors.

The findings of this project have not yet been made public, as far as I am aware, but they will be valuable in helping to design coatings that control the most important factors affecting ship resistance.

International Paint was a runner-up in last year’s Seatrade Awards in the Protection of the Marine and Atmospheric Environment category, for its product Intersleek 900. One of the issues surrounding foul release coatings is that they do need a reasonable ship speed to work. International say that its coating will work at speeds as low as 10 knots and produced fuel savings of 6% - a 2 percentage points improvement on its previous best silicone-based performer.

This picture shows the MSC Poesia, which was finished last year at the Aker St Nazaire yard in France and coated with Intersleek 900.

Future prospects

Now let’s look ahead to developments that are in the pipeline.

First, inside the ship, fuel cells will have a role to play. These can use hydrogen as fuel and the cell breaks this down to obtain the electrons needed to create an electric current. The by-product is water, so no GHGs are produced.

They can also use carbon-containing fuels such as natural gas, in which case the exhaust will contain CO_2, but this is said to be up to 50% less than that from a comparable compared diesel engine running on marine bunker fuel.

This Proton Motor Fuel Cell is made by Germany’s Proton Power Systems and generates 48kW of power. Two of these are used to power what is called the *FCS Alsterwasser* (FCS: Fuel Cell Ship) as part of the ZemShip – zero emissions ship – project. The ship was named last August and is the first fuel-cell powered marine passenger craft in the world. It has been developed with EU funding worth €2.4M to keep the vessel operating on the Alster until 2010.

On larger ships, fuel cells are unlikely to replace propulsion units, but could provide alternatives to diesel-powered generator sets.

Class society DNV has been leading a joint industry fuel cell project running since 2003. It is called the FellowSHIP project and DNV tells me that in late spring or early summer this year it will start shore tests on a fuel cell power unit with sea trails starting in the autumn. This will be the first merchant ship to use a fuel cell to provide some of its auxiliary power and it will use LNG as fuel, which will also be the main fuel used in the ship. DNV has not told me the name of the ship.

I mentioned the importance of coatings in reducing friction, but there are researchers who are looking at using bubbles. Denmark's DK Group has patented its Air Cavity System, which it says will yield up to 15% fuel savings on ships such as tankers and bulk carriers – less on more streamlined hull shapes with less flat bottom area. This is in return for about 0.5-1% of engine power to work the air pumps and the company promises a return on investment of between two and five years.

Its proposal pushes air under the hull towards the bow and allows it to vent at the stern. Model tests and trials on the Oslo Fjord have been carried out and the company is looking for business on large ships of at least 275m length.

And finally, wind power. Commercial sail obviously became unsustainable once engines were developed, but in the past 30 years, wind power has attracted growing interest as an auxiliary power source. Interest has fluctuated largely in line with fuel prices, so at present wind power must be taken seriously.

Back in the 1980s, a few Japanese ships were fitted with large metal sails, such as *Usuki Pioneer*. One German ship, the container ship Bold Eagle, rigged two huge spinnakers on its deck cranes for added power. Some of you may remember Walker Wingsails, which used a computer-controlled vertical aerofoil assembly to produce thrust. One commercial installation was made in 1986 on the 6,500dwt cargo ship *Ashington* but oil prices fell and the company struggled for several years, eventually being wound up in 1998.

More recently, however, wind power is becoming more visible again and Walker Wingsail has effectively been reborn as the UK company Shadotec. Last May, Shadotec started working with Norwegian companies Wilhelmsen Marine Consultants and Petroleum Geo-Services on a joint project backed by funding from the Norwegian National Research Council to look at wind assistance for a Ramform seismic exploration vessel owned by Petroleum Geo-Services.

Investigations by consultants CFDnorway suggested that 5% of the vessel's fuel could be saved. Wilhelmsen's corporate magazine WW World noted that kites would also be investigated as another alternative.

It's worth noting that wingsails feature in another imaginative concept called 'Orcelle' that Wallenius Wilhelmsen Logistics developed after Toyota approached it to develop a zero emissions ship for EXPO 2005 in Japan.

If it were ever built, this ship would use no fossil fuels, relying instead on fuel cells, sun, wind and wave power. I haven't touched on wave propulsion, in this paper, but that is another interesting potential source of propulsion, which has attracted interest on and off since the early 1980s.

Wallenius Wilhelmsen Logistics accepts that a vessel like this is just a concept at present but it hopes to see some of the elements in future generation of vessels. And this is not a small ship: It is being seen as a future car carrier, able to carry up to 10,000 cars on eight cargo decks.

The most promising wind propulsion option at the moment seems to be kite power, and the best known and most successful so far is Germany's SkySails. It claims that, "depending on the prevailing wind conditions, a ship's average annual fuel costs can be reduced by 10 to 35% by using the SkySails System. Under optimal wind conditions, fuel consumption can temporarily be cut by up to 50%. "

The kite flies at about 200m, where the wind is stronger than sails can use at ground level, and it has the attraction of packing away when not in use and so not getting in the way of cargo operations.

And the system is getting noticed. Last year, the World Economic Forum named SkySails as on of 39 Technology Pioneers. In January last year, the first newbuilding to be fitted with the system, Beluga Skysails, went into commercial service and the first retrofit was announced. And in October, the Norwegian owner Wilson ASA ordered a SkySail for its 3,700dwt vessel *Wilson Grip*.

Skysails says that it will supply a 160m² sail that it says will generate 8 tonnes of thrust in good wind conditions. This compares with 11 tonnes of thrust needed for this ship to reach its cruising speed of 11kts.

While wind can be used for propulsion, it is usually a source of resistance. High-sided ships such as car carriers and box ships are especially susceptible and Japan's MOL has been addressing this for a number of years. In 2003, it introduced the *Courageous Ace*, which is shaped to reduce wind resistance and incorporated what MOL calls wind channels along the sides at the top of the garage deck. I don't have a figure for how much fuel this saved, but the ship was named "Ship of the Year" in 2003 by the Society of Naval Architects of Japan.

Further improvements led to the *Utopia Ace* a year later, which has what MOL says is a "hyper-slim energy-saving design under the waterline", which it says reduces resistance by 8% compared to a conventionally designed vessel. It also made further refinements to its aerodynamic features but, again, I have no figures for that further saving. *Utopia Ace* received the 'Ship of the Year Award' in 2005 from Lloyd's Register.

Box ships, too, have been receiving attention. Class society Germanisher Lloyd has recently done some wind tunnel tests in cooperation with Hamburg University to measure the effect of gaps between containers on the air resistance around the stow. They have found that, by covering the stow with a tarpaulin, the air resistance can be reduced by as much as 66%, depending on the wind direction and stowage arrangement.

I asked GL what proportion of a ship's resistance is due to air resistance and got this reply: "The additional resistance affected a Panamax containership resulting from wind (at Beaufort 5) is about 11% of the calm water resistance." So a 66% reduction of that would represent about 7% of total ship power and fuel consumption. Of course, you would have to balance this benefit against the cost of the tarpaulin, its fixing arrangements and the extra time and labour needed to handle it.

That was a brief summary of just a few of the options available now that could become more important in the future. But the fact is that we don't know what technologies are around the corner that might offer more significant GHG reductions. And I haven't mentioned nuclear power, which may be the elephant in the room, being able to meet all our emission goals but which we feel unable to support politically.

Conclusion: Love or money?

While there is no doubt that shipowners are spending money on systems to reduce greenhouse gas emissions, let's not pretend this is down to their innate altruism. I called this paper 'For love or money' because those are the two sides of this coin.

Yes, shipowners love the environment we all live in, but it is money that motivates them. And if the money doesn't add up, it is the environment that pays the bill.

Take the liner operator CMA CGM, for example, which experimented last month by rerouting a couple of sailings round the Cape of Good Hope instead of going through the Suez Canal. The economics were compelling: it saved an estimated $600,000 per canal transit at a cost of around $250,000 in extra fuel for the additional 3,400 miles. It is now said to be considering diverting all appropriate sailings on a permanent basis, saving it tens of millions of dollars per year. Meanwhile, each extra 3,400 tonnes of fuel will put more than 10,000 tonnes of CO_2 into the atmosphere.

Maersk sent six sailings of its new E-class ships round the Cape for a couple of weeks last month, which will have put rather more than 10,000 tonnes of CO_2 into the atmosphere but will have saved it hundreds of thousands in Canal tolls. And these ships have been hailed as environment-friendly vessels, with many fuel-saving and energy recovery features incorporated into them, but it will take a long time for its energy-saving details to compensate for this extra fuel burnt for economic reasons. It is continuing this policy and earlier this month asked for significant reductions in Suez Canal tolls to make that route competitive again, but it conceded that the reductions will have to be substantial.

That does not detract from the quest for more efficient ships, and thus fewer GHG emissions. Indeed, if you are in London next week you can attend a free-of-charge two day seminar about energy-efficient ship technologies organised by the Japan Ship Centre, but my point is this: whatever comes out of the discussions here this week, shipping is driven by trade and economics. As you formulate your conclusions in the following days, keep in mind that balance between love and money. And, as the musical Cabaret reminds us, money makes the world go round.

References:
(1) Ship Emissions Study, National Technical University of Athens – Laboratory for Maritime Transport – for the Hellenic Chamber of Shipping, May 2008

(2) The Axe Bow, the Shape of Ships to come, by Jaap Gelling, Product Director High Speed & Naval Craft, Damen Shipyards. 19th International HISWA Symposium on Yacht Design and Yacht Construction, 13-14 November, 2006.

(3) Driving Efficient Propulsion, Patrik Wheater, *The Naval Architect*, July-August 2008, p47-55