The Unabridged Lloyds List Series on EEDI and CO2 Reduction

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1 Introduction

This is a slightly expanded version of the original text of a three part series on EEDI and reducing ship-borne CO2 emissions which was written for Lloyds List. Lloyds List required and published a much shorter two part version, which necessarily had to omit some important points.

2 Part I. EEDI cannot be fixed

Ever since EEDI was first proposed naval architects have been pointing out problems and strange biases associated with the regulation. This has led to a never-ending series of "fixes" resulting in a formula which is a typesetter's nightmare, and a set of correction factors that take seven dense pages to explain. Recently Krüger identified the mother of all biases: ***for tankers, bulk carriers, and LNG ships, the maximum allowable speed under EEDI decreases with increasing size.***[?]. Table 1 shows the numbers for tankers.[**?**]

Dead-weight	Baseline kts	Phase 1 EEDI down 10% kts	Phase 2 EEDI down 25% kts	Phase 3 EEDI down 35% kts
100000	16.73	15.87	14.49	13.49
150000	16.07	15.24	13.91	12.95
200000	15.61	14.81	13.52	12.58
250000	15.26	14.48	13.22	12.31
300000	14.99	14.22	12.98	12.08

Table 1: Maximum allowable design speed for tankers under EEDI

This turns ship design upside down. Basic physics decrees that the economic speed of a larger ship is higher than that for a smaller ship of the same type. Currently, the calm water design speed of a 300,000 dwt VLCC is about 16 knots. For a 100,000 ton Aframax, it's about 14.5 knots. EEDI will reverse this difference. And if the ship is small enough, EEDI is a non-event. This nonsensical result will push owners to smaller ships. Yet increasing ship size is one of the best things a designer can do for CO2 emissions. If he can replace two ships with a single ship with twice the capacity, he obtains

1. A lower Froude number and less wave-making resistance.
2. A 40% saving in wetted surface and frictional resistance.
3. A bigger, slower turning engine with a better specific fuel consumption and a more efficient propeller.
4. A single larger engine room to which he can economically apply more energy saving devices.

For RoRo and RoPax ships, the results are even crazier. Krüger shows that not only allowable speed but allowable power decreases with increasing size. According to Figure 1, a 5,000 ton RoRo can have 17,000 kW; a 25,000 ton RoRo 7,000 kW. Absolutely nuts.

In the past, the response to such nonsensical results has been: amputation or a band-aid. In the case of RoRo ships, we push them under the table as if they no longer produced any CO2. In other cases, we introduce yet another correction factor. But nobody has come up with a correction factor for the speed absurdity. Greece tried by changing the base line regression to get rid of the speed dependence and ended up with an even stranger result: big ships would be outlawed.[**?**]

So since we can't come up correction factor, we come up with promise of a correction factor. Sure EEDI has crippling problems we don't know how to solve; but enact it anyway and we will fix them later. This is a proposition that no one in her right mind would accept.

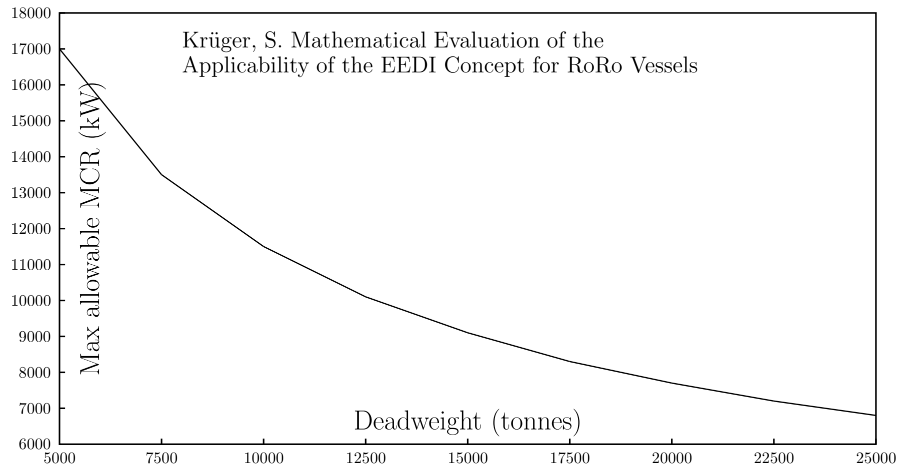

Figure 1: Allowable MCR for RoRo Ships under EEDI

And it gets worse. The sad fact is that EEDI cannot be fixed. Even if we could somehow eliminate the debilitating biases and inefficiencies of EEDI, we would still face two major problems.

EEDI is unsafe. No one knows how unsafe. At least for big ships, EEDI will result in a drastic reduction in installed power. Phase 3 EEDI will require VLCC's with half the installed power of current ships. This will result in badly degraded maneuverability and heavy weather performance. It will mean 30% more ships on the water. It implies these smaller engines will be pushed much harder. Yet despite this there has been no study of the implications of this dramatic reduction in installed power for reliability and safety (or CO2 emissions). This contravenes IMO's own rules which require a Formal Safety Assessment of any regulation which could affect safety or pollution.

EEDI is ineffective. EEDI will result in little of no reduction in CO2 emissions in those sectors where slow-steaming is practiced, which include tankers, bulk carriers, and big containerships.

1. EEDI effectively limits installed power. But at current and expected BFO prices, a ship owner in these sectors uses all his installed power only in a full boom. So for the great bulk of her life, a non-EEDI ship uses little or no more power than an EEDI-compliant ship.
2. In limiting installed power, EEDI induces owners to use smaller bore, higher RPM engines. These engines have higher Specific Fuel Consumption and more importantly require a smaller, less efficient propeller. This means the EEDI-compliant ship consumes more fuel when the market is not in boom, which is 90% of the time.

EEDI does not encourage slow-steaming. EEDI only puts a limit on how fast the ships can go in a boom, which is precisely the time we want them to go fast if we are to avoid wastefully building ships just to handle a boom. When you work out the numbers for VLCC's, you find that over a market cycle, a 35% reduction in EEDI results in a 1 or 2% ***increase*** in CO2 emissions over no regulation at all.[**?**] The whole idea that a x% reduction in EEDI will result in an x% reduction in CO2 is nonsense. But that's how EEDI is being sold.

But we must do something you cry! Yes, we must. The second part of this article will advance some ideas on what we should do. But let's take the time to do it right. Meanwhile the $400 increase in bunkers over the last 5 years will do far more to reduce CO2 than anything that the IMO is contemplating. In the course of my career, bunkers went from $50 to $250 per ton. Over that 30 year period, fuel consumption halved. The first ships I operated were 390,000 tonners built in the late 70's. They burned 210 tons per day at 16 knots. These ships were at least twice as efficient as the smaller tankers they replaced. The last ships I operated were 440,000 tonners built in 2002. They burn 121 tons per day at 16 knots. Today's owners are responding in a similiar fashion. The massive jump in bunker prices has given us some time.

There is no need for irrational, unsafe, or ineffective regulation. EEDI is irrational, unsafe and ineffective.

3 Part II. Taxing CO2 Emissions, Theory, Practice, and Problem

An earlier article in this series argued that EEDI is irrational. A regulation aimed at reducing CO2 turns out to be a deadweight dependent limit on design speed. For most ship types, this restriction is upside-down, ***the bigger the ship the lower the design speed.*** Fiat regulation almost always ends up being wasteful and prone to unintended consequences. EEDI is a spectacular example of both. So what should we do?

3.1 The Theory

When it comes to regulating ship-borne CO2 emissions, it all comes down to:

1. The atmosphere is a public good. It belongs to all of us.
2. As far as ships are concerned, we are giving away this public good. We are charging ships zero for the use of our atmosphere.
3. Unless we want to waste the planet's limited resources, we must cut back efficiently, that is, in the least costly way possible.
4. We need to balance the cost of pollution versus the cost of reducing pollution.

Economics 101 teaches us that, if we charge each polluter the social cost of his pollution, then we will end up with the optimal amount of pollution and do it in the least costly way possible. The obvious way to put a price on carbon emissions is to tax them. It is just that simple.

There are a number of implications of these elementary principles:

The current level of pollution is irrelevent.

The fact that ocean transportation has much lower CO2 emissions per ton-mile than trucks or planes is irrelevant. What counts is what's the cost of cutting back? If it's cheaper to cut back on the ship side than the land side, then that's where the cut back should take place.

There is no requirement to cut back evenly.

The fact that the current level of pollution is irrelevent cuts both ways. There is no need to give a big polluter a break just because he is a big polluter. This is the philosophy of regulatory schemes that work from baselines based on the pre-regulation amount of pollution.

EEDI is such a scheme, proposing the same percentage reduction in EEDI (not CO2 emissions) over all ship types and sizes. Currently, IMO is discussing a 30% reduction by 2023. Under EEDI, the main way this will be accomplished is to build ships with lower speed capability. To meet the 30% requirement instead of building a 24 knot capable containership, the owner will have to build a 20 knot capable ship, a speed reduction of about 18%. For a 14 knot bulk carrier, the required speed reduction is also 4 knots, a 30% reduction, ending up with a ship that can only do 10 knots in calm water. This rewarding the big polluter may not be unethical, but it sure is wasteful.

Cariou finds that when bunker prices skyrocketed in 2008 and box rates plummeted in 2009, containerships on the Asia to Europe route slowed down much more than containerships on the South America to Europe route. The reason was obvious. There is almost no perishable cargo going from Asia to Europe and little reefer cargo. 30% of the cargo from South America to Europe is perishable and another 30% is reefer. The cost to society of slow-steaming South America to Europe is much higher than the cost to society of slow-steaming Asia to Europe. What happened is exactly what should have happened, except neither trade was being charged for its use of the atmosphere.

The social cost of cutting back can vary not only by trade but also with time. The tanker and dry bulk markets offer dramatic examples. These markets cycle between boom and bust. In boom, when ships are scarce the value of a marginal ton-mile to society is an order of magnitude or more higher than in slumps when ships are in surplus, and this is reflected in the spot rate. To efficiently reduce emissions, ships should reduce speed far more in a slump than in a boom.

There is a requirement to price evenly.

In the case of CO2 pollution, it is appropriate to assume that the social cost of each unit of CO2 is the same.[1] In such a case, each polluter must be charged the same price for his pollution. The obvious way to do this is with a tax. This eliminates the need for some regulator to guess how costly it is for each polluter to cut back. Those polluters for whom it is cheaper to cut back than pay the tax will cut back and those for whom it is cheaper to pay the tax than cut back will pay the tax.

[1] This is not necessarily true of all emissions. For example, the social cost of SO2 and NOx emissions depends on location, and in the case of NOx on local weather.

Eventually, everybody gets to the point where the cost of cutting back one more unit is equal to the tax. At that point we will have reached the optimal level of pollution, and we will have done so efficiently.

3.2 The Practice

How would tax reduce CO2 in ocean transporation? For shipping, there are essentially only two means of reducing CO2 emissions:

1. In the short-run, slow-steaming.
2. In the long run, building a fleet which produces less CO2 for a given transport capacity.

Consider how a tax, which for now we can think of as a carbon content bunkers tax, handles these two aspects of the problem.

Slow-steaming The cost of reducing emissions varies not only from polluter to polluter, but with time. In a cold winter or a period of high economic activity the cost of reducing emissions is higher than in a mild winter or slack times. Bulk transport offers an extreme example of this.

In the short run, by far the single most important emissions reduction measure in shipping is *slow-steaming*. Fuel consumption goes as something more than the cube of speed. Amount transported per period is roughly linear in speed. Thus, by reducing speed ship owners can reduce emissions per ton delivered. The question is: what is the efficient level of slow-steaming?

The answer is: it depends on the market. When ships are scarce, the cost to society of reducing steaming speed is much higher than when ships are in surplus. This shows up most dramatically in the bulk markets. The tanker and dry bulk markets are examples of nearly textbook competition. These markets cycle between boom and bust. In boom, when ships are scarce the value of a marginal ton-mile to society is an order of magnitude or more higher than in slumps when ships are in surplus. This is reflected in the spot rate. To be efficient, tanker and bulk carrier owners and charterers should reduce speed far more in a slump than in a boom. The same thing is true, a little less dramatically, for container ships. With a tax, this will happen automatically.

The CTX has done a study of how VLCC's owners and charterers would react to a bunkers tax.[**?**] This analysis indicated that over a market cycle, a $50 per ton CO2 tax would induce a 6% reduction in VLCC emissions. A $100 per ton CO2 tax would result in an 8% reduction in CO2 due to the additional slow-steaming. A carbon tax will increase the cost of bunkers to owners which will have the over-all effect of slowing them down ***on average.*** However, with a tax, we will see much more slow down in slumps than in booms, which is the efficient inter-temporal response.

In doing so, tankers and bulk carriers will steam at speeds as low as 9 knots in a slump and as high as 16 knots in a boom.[2] Big containerships wil steam at speeds as low as 15 knots and as high as 25 knots depending on the market. They will spend almost zero time at the speed corresponding to 75% MCR. One of the fundamental fallacies of EEDI is to assume that a ship will spend all its time at a single speed and that that speed is linked to MCR. This foundation of EEDI is simply false.

Newbuildings Overall, a tax will slow the fleet down. This slow down will increase spot rates. In the bulk markets, this increase can be quite dramatic.[**?**]. These higher rates in turn will engender newbuilding. With a bunkers tax, the owners of these newbuildings know that they will be facing higher bunker prices. Thus, they will optimize their ships against a higher fuel price. It will pay them to install those fuel saving devices that are economic at the higher price, and not install those that are not. In some cases, such as LNG carriers, it may pay them to switch to a less carbon intensive fuel. In all cases, it will pay them to run their engines closer to the minimum Specific Fuel Consumption (SFC) point, which is about 70% of the Maximum Continuous Rating.[3] To do this, they will have to ***increase*** installed power for a given design speed, ***exactly the opposite of the EEDI mandate***. The design speed will drop with increase in fuel cost, but the installed power will increase for a given design speed.

Table 2 shows an actual example based on an 82,000 dwt bulkcarrier. The bigger engine can turn a larger propeller at lower RPM which improves propeller efficiency. That's the reason the ship on the right requires less power to do 14.5 knots than the ship on the left. EEDI assues a low powered ship is an efficient ship. In fact, the oposite is true.

[2] Such a ship will have a decent amount of power to handle heavy weather.

[3] A important by-product of operating closer to the minimum SFC point will be an improvement in main engine reliability. Todays engines are very aggressively rated. At Max Continuous Rating (MCR), all the design margins have been pared down to the minimum. As a result, the failure rate is high. CTX estimates that the tanker fleet above 10,000 dwt is experiencing at least 10 complete losses of power per day. Operating at lower piston pressures and slightly lower temperatures should increase the Mean Time Between Failures markedly.

Table 2: High powered vs Low powered Kamsarmax Bulk Carrier

	Low powered ship	High Powered ship
Main Engine	MAN 6S50 ME	MAN 6S60 MC
Installed power	10,680 KW @ 117 RPM	14,280 @ 105 RPM
Power at 14.5 kts	9,610 KW @ 113 RPM	9,050 @ 88 RPM
Full load speed	14.5 knots	14.5 knots
Consumption	38.4 TPD	35.0 TPD

In the long run, the fleet will operate at a lower ***average*** speed due to the increased bunker costs, which means a larger fleet overall than without the tax. All this happens automatically and at the efficient level with a tax.

Finally, a tax is easy to sync with CO2 regulation elsewhere, at least in theory. Simply set the tax so the price of CO2 emission is the same for everybody. A tax filters through the system automatically sending the right signals at every level. Recently, the Japanese shipyards attempted to argue that very lightly built ships were an environmental good since they carried more cargo than a robust ship and thus less CO2 would be produced for the same amount of cargo moved. Supporters of robust ships had to counter with a complicated analysis of the CO2 generated by repair intensive, shorter lived versus longer lived ships.[**?**] This analysis tried to go back to the CO2 produced not only by the newbuilding yard, but the steel mill as well. At this point, they stopped. They did not include CO2 produced by the mining process, nor indirectly in any of these activities (eg CO2 produced by yard workers commuting to work). If a tax, roughly representative of the societal cost of CO2 emissions, had been in place, all such analyses become unnecessary.

3.3 The Problem

All this sounds good in theory. In fact few knowledgable in resource allocation would dispute any of this. The real problem is implementation: how do you impose and administer an extra-national tax in a world built around national sovereignty. Aye, there's the rub. We will tackle this difficult issue in the next article in this series. But to do so, we must be prepared to think outside the box.

4 Part III: Direct Taxation of Stack Emissions

Earlier articles in this series have contended that the only effective, efficient, and safe alternative for reducing CO2 emissions from ocean shipping is a tax on CO2 emissions. In particular I have argued that EEDI is just about the worst of all possible regulatory alternatives, irrationally wasteful, unsafe, and in the sectors where slow-steaming is practiced totally ineffective. But it is not enough to say that a tax is the way to go. It is incumbent on any tax proposal to lay out exactly what the regulation will look like, and how it wll be implemented and enforced.

Up to now, all the proposals for taxing CO2 emissions do not tax CO2 directly. They are a tax on the CO2 content of bunkers. This focus on fuel is based on two assumptions:

1. A carbon content based bunkers tax is a near-perfect proxy for CO2 emissions, since removing and sequestering carbon on-board is next to impossible.
2. A tax on fuel will be much easier to implement and enforce than a tax on the actual emissions.

Assuming tanker owners don't turn cargo into fuel, (1) is almost true. But it turns out that (2) is just flat wrong.

Current BFO tax proposals envision collecting the tax either at the ship level or the bunker supplier level. Either way we end up being dependent on the Delivery Ticket, the paperwork that documents the transfer of bunkers from the bunker supplier to the ship. Under either system, both buyer and seller have a huge incentive to produce paperwork that under-states the amount of bunkers transferred. Assuming a $50 per CO2 ton bunkers tax, the tax bill on a single 5000 ton VLCC bunkering, will be about $750,000. The opportunity for collusion is inescapable. To prevent this would require incorruptible, fearless third party inspectors at every bunkering. And their bosses and bosses' bosses would have to be equally incorruptible and fearless. This saintly army would have to have the strong support of the local legal system despite the fact that the bunkering country has less than nothing to gain from collecting the tax. If a bunkering country made such strenuous and valiant efforts to prevent collusion that it were successful, its bunkering business would move to a less vigilant nation. The amounts of money at stake are so large that the corruption will extend to the highest levels in all but the wealthiest countries. The IMO estimates that international shipping emitted 870 million tons of CO2 in 2007. A $50 per ton CO2 tax represents over 40 billion dollars a year of economic rent, just waiting to be pounced on. Given the ability of bunkering to move to the most "attractive" jurisdiction, ***enforcing a bunker tax on international shipping is simply not feasible.*** This is the reason international bunkers are currently tax exempt.

What to do? Regulators have assumed that monitoring ship stack CO2 emissions is not feasible, or at least not economically feasible. In fact, CO2 stack emissions can be monitored to an accuracy of better than +/-2% in a reliable, tamper-proof, difficult to spoof manner for about $60,000 per ship. And as a bonus, we can throw in a direct, encrypted transfer of the data via satellite to a central processing entity.

Stack gas flows and composition are being measured all over the world. For example, the USA EPA requires 4,674 American installations to continuously monitor CO2 emissions. There are several technologies for doing this including:

1. Measure volumetric flow by ultra-sonic pulses. This works by measuring the difference in travel time of sound pulses sent downstream and upstream in the stack.
2. Measure CO2 concentration via absorption spectroscopy. This system uses a laser to project a beam across the stack. The frequency of the beam is tuned to an absorption line of the gas of interest. One analysis box can support multiple beams (typically four). Sulfur and NOx control regimes could piggyback on the CO2 system by simply adding two more modules to the analyzer.
3. The data would be collected in a sealed computer, and periodically transmitted directly to a central processing entity, presumably IMO, via satellite.

There are several points to be made about such a system:

Difficult to by-pass By-passing an engine fuel flow meter or a bunkers transfer gage is child's play. But a VLCC generates up to 300,000 m3/h of stack gas. By-passing even a modest portion of this flow will require major modifications of the ship's exhaust system. The modifications would require the connivance of a large part of the crew, exposing the owner to whistle-blower risks.

No paperwork The data goes direct to the IMO. There is no dependence on the ship or the bunker supplier or any third party inspector or a contra-motivated bunkering nation. There will be no forgery, for there is no paper to forge.

Nearly tamper-proof Once the data is collected it is nearly impossible for the ship to change it. The data would not only be in a sealed black-box, but it would be immediately check-summed and encrypted. If someone were able to break into the emissions computer, no one other than the software designers would know how to take advantage of the break-in.

Difficult to spoof There are no moving parts, no sample extraction system whose tubes might be "re-directed". Whatever the would be spoofer attempts to do, it has to be done in the middle of a hot stack. The probes themselves would be sealed to the stack, both physically and electronically. Any attempt to remove them would set up off alarms, and result in broken seals.

The cost of enforcement is almost in the noise. Assuming a $50 per ton CO2 tax, a $60,000 package would be paid for with 400 tons of fuel burn, four full-power steaming days for a VLCC. If a system stopped reading or the readings are anomalous, the ship would be charged an amount that is a generous upper bound on what she could have emitted during the period the system is down or malfunctioning, as the US Acid Rain Program does now. Thus, the owner will be strongly motivated to keep the system well maintained. In short, ***monitoring of ship-based CO2 emissions is not only feasible, it is cheap.***

Under such a system, once a month, the shipowner would be sent a bill for his emissions. This raises a number of issues:

Price What should the level of the tax be? Economic theory tells us that the price of a ton of CO2 injected into the atmosphere should be the marginal social cost of that ton of CO2. Unfortunately, no one knows what that is. Current prices range from about $15 per ton (EU ETS permit price) to about $150 per ton (Swedish carbon tax). IMO will have to make a guess. What's important in my view is that, whatever the tax is, it be fixed for at least 4 years. This is required to give the owners the certainty they need to make long-term investments in CO2 reducing technology. Every 4 years IMO would meet to adjust the price. Ideally, over time the international shipping tax would follow similar CO2 taxes/prices in other sectors.

Getting Paid Sending out an invoice is not the same as collecting the tax. Very large sums will be at stake. Owners have the ability to magically disappear and re-appear in another corporate guise; and IMO has no police power. To control this the tax must be levied on the ship. In the event of non-payment, IMO would send out an alert to the flag state and the port states who are party to the Convention. If the money is not forthcoming in a reasonable amount of time, the port states would be empowered to detain the ship, until the monies are paid. Failing such payments, the ship would be auctioned off. As long as the bulk of the major port states detained ships for non-payment, any non-paying owner would either lose his ship or be forced off all the world's major trade routes.

Term Charters When a ship is term chartered, the term charterer becomes the effective owner. He has control over what bunkers are purchased, where the ship goes and how fast, in other words, how much CO2 the ship produces. For the system to work, the term charterer, not the owner, must end up being charged the cost of his pollution. This will require reasonably minor changes in the charter party forms. All that is needed is a charter party clause that makes the term charterer explicitly responsible for the ship's CO2 emissions as billed by IMO during the duration of the charter.[4] And the enabling legislation must make explicit the owner's right to require repayment of the CO2 tax from a term charterer. IMO will still bill the ship, but the owner becomes a pass-through. It's little different than requiring a landlord to collect a property tax from a tenant.

This system could be made to work. It has a strong foundation in economic theory. Therefore, it would be safe and efficient and free of unintended consequences. It makes good use of technology to attack otherwise insuperable enforcement issues. Let's get to work on it. The obvious first step is a pilot project which would put together a monitoring package and demonstrate it at sea.

[4] Net of any penalties due to system malfunction.