Zero Emission Vessels, what needs to be done?

Report prepared for Sustainable Shipping Initiative

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The Sustainable Shipping Initiative

The Sustainable Shipping Initiative (SSI) is an independent charity, comprised of ambitious leaders spanning the whole shipping value chain from charterers and ship owners, to class societies and technology companies.

The SSI's objective is to drive the whole shipping industry value chain towards greater resilience by defining, tracking and accelerating industry progress towards sustainability. The SSI works to ensure shipping fulfills its vital role in the global economy during this time of extraordinary change.

The vision for SSI is for a shipping industry where social, environmental and economic sustainability equates to commercial success. We work with our members and other shipping stakeholders to create a more environmentally responsible, socially conscious, safer, accountable, and more economically profitable industry. One that is truly sustainable by 2040, as outlined in the SSI Roadmap.

The SSI was founded by global sustainability non-profit organisation Forum for the Future in conjunction with WWF, the global conservation NGO, and a number of leading shipping industry companies.

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1. Background

MEPC 72 in April 2018 achieved the first milestone in the IMO GHG roadmap. The industry agreed to the overarching objective of reducing Greenhouse gas (GHG) emissions by at least 50% by 2050, while at the same time pursuing efforts to phase them out entirely. The IMO agreed a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals. For this to be possible, zero-emission vessels (ZEVs) must begin to enter global fleets from the year 2030 and form a significant proportion of new builds from this point onwards.

To the present day, shipping, along with many other industries, is reliant upon fossil fuels to provide the energy source needed for propelled motion. The convenience of a fuel with very high relative energy density, simple storage requirements, ease of combustion and advanced enabling infrastructure is one that has made the transition away from fossil fuels daunting to some stakeholders. The nature of climate change mitigation, which must be tackled by limiting cumulative emissions over a period of time, means that beginning the technology transition from fossil fuels earlier can ease the rate at which changes must occur and keep disruption to the industry minimal.

The pioneers of the shipping industry looking towards the inevitable decarbonisation of the industry are now supported by regulatory policy that advances the development of alternative technology and fuels. There must also be a clear understanding of the route to achieve the goal of removing reliance of convenient fossil fuels, and detailed insights into what the enabling technology and policy may look like. This report aims to assess the current viability of zero-emission vessels entering trans-oceanic fleets from 2030, and understand the key drivers that would need to be worked on in order to achieve this outcome.

1.1 Objectives

- Understand technology options that represent viable routes towards zero-emission vessels for SSI members
- Understand the economic implications of adopting ZEV enabling technologies for SSI members
- Explore modelling sensitivities with SSI members
- Identify and support the enabling drivers toward ZEVs.

2. Survey to identify routes for ZEV transitions

A survey was undertaken with members of SSI to explore the parameters under consideration as part of the scope of this work, and to reflect the views and opinions of their members with regards to these parameters.

2.1 Requirement for ZEVs

Amongst the survey respondents, the consensus was that a transition towards low-carbon alternatives for shipping is gathering momentum and is now at a stage that warrants consideration in the decision making process of freight selection. This has come about through a combination of growing pressure from customers and incoming regulations such as the global sulphur cap.

Specifically, when considering exactly how shipping can realise this transition and be in line with the objectives of the Paris Accord, ZEVs were identified as a requirement, both for trans-oceanic shipping which cause most of the emissions, as well as smaller vessels. This is due to the fact that ships in service and under construction now will continue to emit high levels of CO_2 for the next 20 to 30 years, thus meaning that ZEVs will be required to make significant changes to the industry's profile in the same time frame.

2.2 Technological maturity

The particular technology options being considered in this study were explored with SSI members. Biofuels and Hydrogen are typically considered as feasible zero-emission replacements for fossil fuels, although concerns regarding land-use and fuel cell maturity respectively are apparent. Battery technologies, with fully electric vessels, have recognised advantages, such as the technological maturity and uptake in other industries. At the same time, however, concerns arise over how suitable batteries are to long-distance shipping. These concerns are further explored in the scoping and conduction of this study.

2.3 Carbon pricing

SSI members were asked whether a suitable approach to enabling ZEVs would be through a carbon pricing regulation. While a price of $50/tonne CO_2 was established as a likely threshold to encourage change, concerns were raised over whether carbon pricing regulation does address the root polluter and whether a too high price would create excessive resistance.

2.4 Upstream emissions

Increasing use of biofuels raises concerns over land usage, such as competition between food or fuel crop, or advancing deforestation. Sustainability concerns need to be taken into account before biofuels can be considered as net-zero carbon emitters. For other fuels under consideration, the upstream concerns must also be considered. Most members agreed that simply moving the emissions upstream into the fuel production process was not aligned with the overarching aim of decarbonisation, and so emissions must be evaluated from "Well to Wake".

3. Viable candidates and methodology

3.1 Technology groups

Enabling ZEVs is dependent on their ability to match the capabilities of today's conventional ships. Reflecting this wide range of operational requirements, and the fact that no single, dominant technology has yet emerged as suitable for all ship types, or voyage lengths, three potential options for ZEV main propulsion systems have been considered. These are set out in Figure 1.

These candidates have been selected on the basis that they can feasibly replace a conventional ship with limited impacts to voyage times, routes or cargo-carrying arrangements that are of a magnitude which can be accounted for within operational requirements and limitations. They can also be considered as genuine ZEVs, since they all produce only trace GHG emissions under continuous operation.

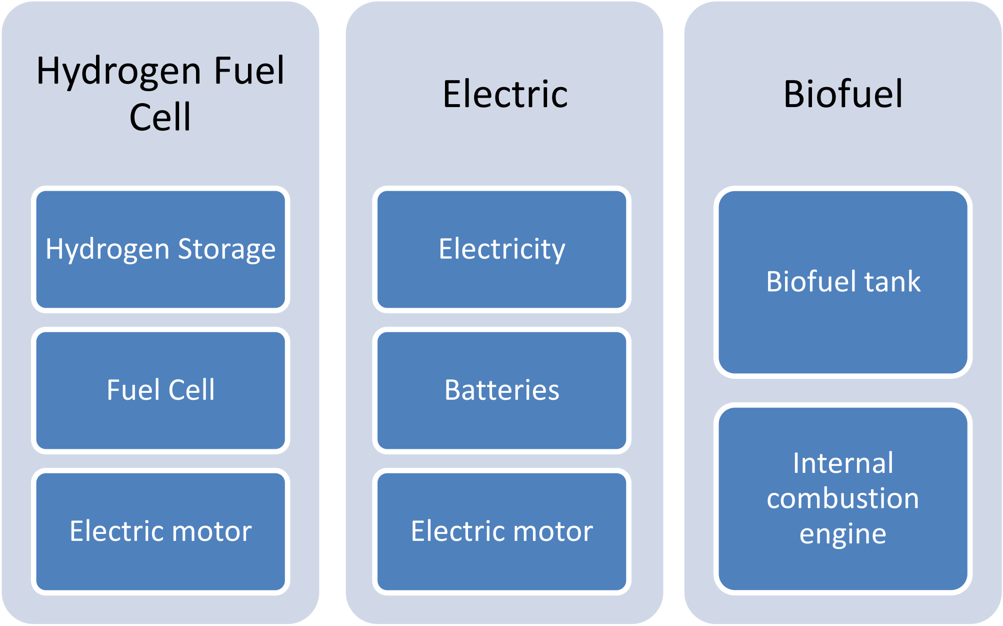

Figure 1: ZEV Technology groups under consideration

Certain existing technologies have been excluded from this study even though, in some cases, the industry has been examining them for many years. Nuclear power, for example, still faces significant barriers to global acceptability; wind power and other technologies that contribute to increased efficiency of conventional systems are unsuitable as the only propulsion options for a ZEV so would still need an additional propulsion system – albeit there is the potential for the use of wind to reduce the size and therefore the cost of the additional propulsion system. We have also taken account of factors affecting the uptake of ZEVs. Although shipping may not be held directly accountable for upstream CO2 emissions, we need to consider them to avoid unintended consequences of investing in technologies that may ultimately prove no more sustainable than conventional fuels when taking a whole systems perspective.

Comparisons are drawn against a baseline ship that represents current fossil-fuelled technology. For all relative comparisons that follow, this baseline ship's technology is assumed to combust HFO in a two-stroke engine, with scrubber and NOx mitigation equipment installed on board, ensuring regulatory compliance with current and forthcoming (2020) regulations for other pollutants.

3.2 Candidate Ships

These technology groups must be considered in the context of the operational profile of ships representative of current fleets, as a result, the modelling processes carried out in this study applies the three technology groups to each of the three ship types given in Table 1.

	Bulk carrier	Containership	Tanker
Size	53,594 dwt	8,893 TEU	109,678 dwt
Main engine Power	8,958 kW	67,879 kW	14,008 kW
Design speed	14 knots	25 knots	15 knots

Table 1: Representative ships being used in the scope of this study

3.3 Future Scenarios

Determining the future economic feasibility of ZEVs is highly dependent upon a range of factors associated with the regulatory and economic environment that shipping operates within. As a result, this study uses a scenario based approach, simulating two different outlooks of the economic framework that may exist in 2030.

Both scenarios are fundamentally based upon the availability of a renewably generated electricity or hydrogen. The associated impacts of having a green supply of either of these fuels is then determined, such as the cost and maturity of the enabling technology. For each scenario, the analysis is performed upon all candidate ships and all feasible technologies, so while a strong correlation may exist between the outcome of a certain technology and the scenario in which it is modelled, it is also important to consider the secondary impacts of the associated scenario against each technology.

For this reason, both scenarios are inclusive of the entire economic and technological environment that is being modelled. They consider fuel prices of electricity, hydrogen, biofuels and HFO as well as the upstream generation methods and associated upstream emissions for each fuel. A comparison of certain key components of the scenarios is shown in Figure 2.

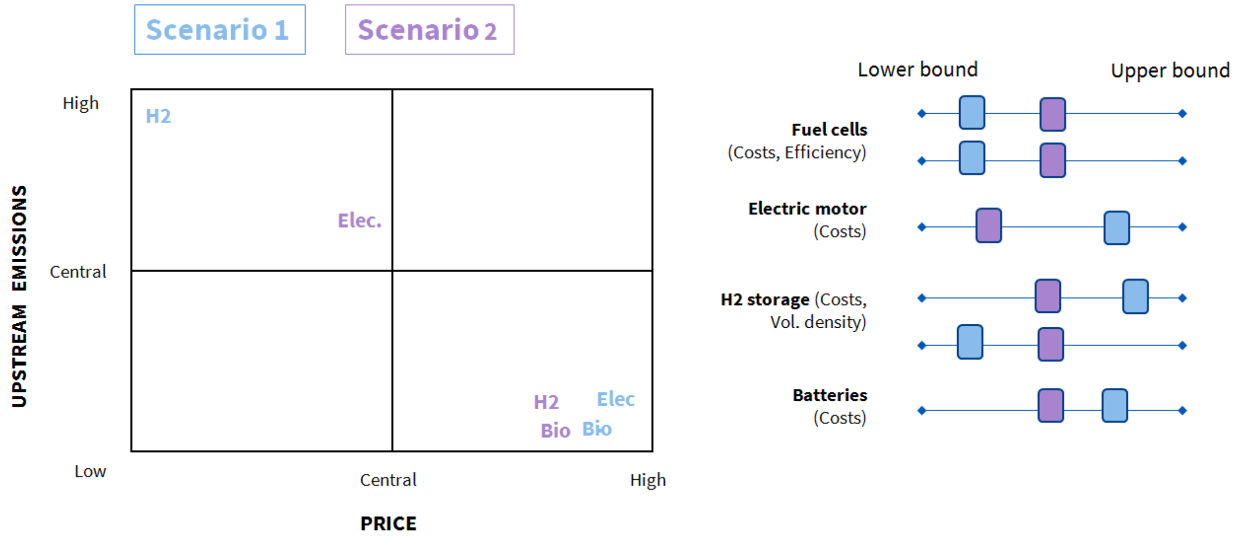

Figure 2: Upstream Emission v Price for Scenario 1 and 2

The technological maturity and associated cost is also projected. Full details of the two scenarios used are given in Table 2.

	Scenario 1	Scenario 2
Alternative fuels’ availability/economy		
Biofuels	Third-generation biofuels are available worldwide and accessible for the shipping industry at a price of about 1,000 $/tonne in 2030	The same as Scenario 1
Electricity	Electricity is produced mainly from renewable energy sources. Carbon sequestration is also common in electricity production. The price is about 0.10 $/kWh in 2030	Electricity is produced from a mix of renewable and fossil resources. Its price is very low and stable over time at about 0.05 $/kWh
Hydrogen	Hydrogen is mainly produced from fossil energy sources and it is available for shipping worldwide at a price of 2 $/kg in 2030	Expensive
Alternative fuels’ footprint		
Biofuels	CO_2 emissions from biofuel production are assumed to be nearly zero and therefore negligible	The same as Scenario 1
Electricity	CO_2 emissions from electricity production, in 2030, are assumed to be 100 gCO_2 per each kWh produced. They decrease over time, reaching negative values (about 200 gCO_2 captured per each kWh produced)	CO2 emissions from electricity production, in 2030, are at a medium level of 280 gCO2 per each kWh produced, decreasing to 220 gCO2/kWh in 2045
Hydrogen	In 2030, CO_2 emissions from hydrogen production are relatively high at about 5.6 tonne CO_2/tonne hydrogen. However, it is assumed that the production becomes cleaner over time, reaching 3.82 tonne CO_2/tonne hydrogen	Only green hydrogen with nearly zero CO_2 emissions is used in shipping
Technology developments		
Fuel cells	Marine fuel cells are available at any power requirement. However, they are mainly used in combination with gaseous hydrogen and other hydrocarbons with a reformer. Capital costs are 900 $/kW, and efficiency is close to the lower bound of 40%	Further improvements are made in terms of efficiency using heat recovery systems and reaching about 75%. As a consequence, capital costs increase to 1,500 $/kW

Battery	Green electricity encourages the development of battery technology; however, as the price of electricity remains high, capital costs only reach 100 $/kW	An increase in production reduces the capital costs to 50 $/kW
Hydrogen storage	Liquid hydrogen storage is developed, but not as well as the storage in gaseous form. It has a capital cost of 300 $/kg, and it is assumed to have an 'efficiency' of 60%, which accounts for the effectiveness of the tank insulation	Further improvements are made in tank insulation and, as a consequence, efficiency increases to 80%. This, along with its use in combination with more efficient fuel cells, encourages mass production, with a reduction of capital costs to 30 $/kg
Biofuels-related technology	The use of existing infrastructure without the need for additional components/costs	The same as Scenario 1

Table 2: Detailed assumptions used in future scenarios

Both scenarios are modelled as projections of economic, technical and environmental conditions in 2030. As detailed in Table 2 the projections are derived based upon a holistic view of the situation in 2030, including primary and secondary consequences of direct predictions, for example, how battery costs are impacted by electricity prices, which themselves are impacted by the energy generation method. Given this, the individual projections shown in Table 2 ought to only be considered as part of the entire scenario, making comparisons to technology and costs of today over simplistic. While prices certain costs or efficiencies used in the projections may initially appear to be very different to 'today's' direct equivalents, when considered alongside the associated technological advancements (or lack of), the regulatory landscape, and the dominant energy source available to the industry, as detailed in Table 2 the projections can be explained. The basis of many of the predictions, such as technological maturity, arises from the assumed requirements of the SSI members, derived from the survey results as shown in Section 2 of this report.

3.4 Methodology description

As detailed in Figure 3, the inputs to the modelling process can be grouped into three categories that reflect the above assumptions. The baseline technical and operation specifications of the different candidate ships are used to build an operational profile to which new technologies can be applied and evaluated. These new technologies, the ZEV groups, are as detailed in section 3.1. Finally, the two scenarios are used to simulate the outlook of 2030 as detailed in section 3.3.

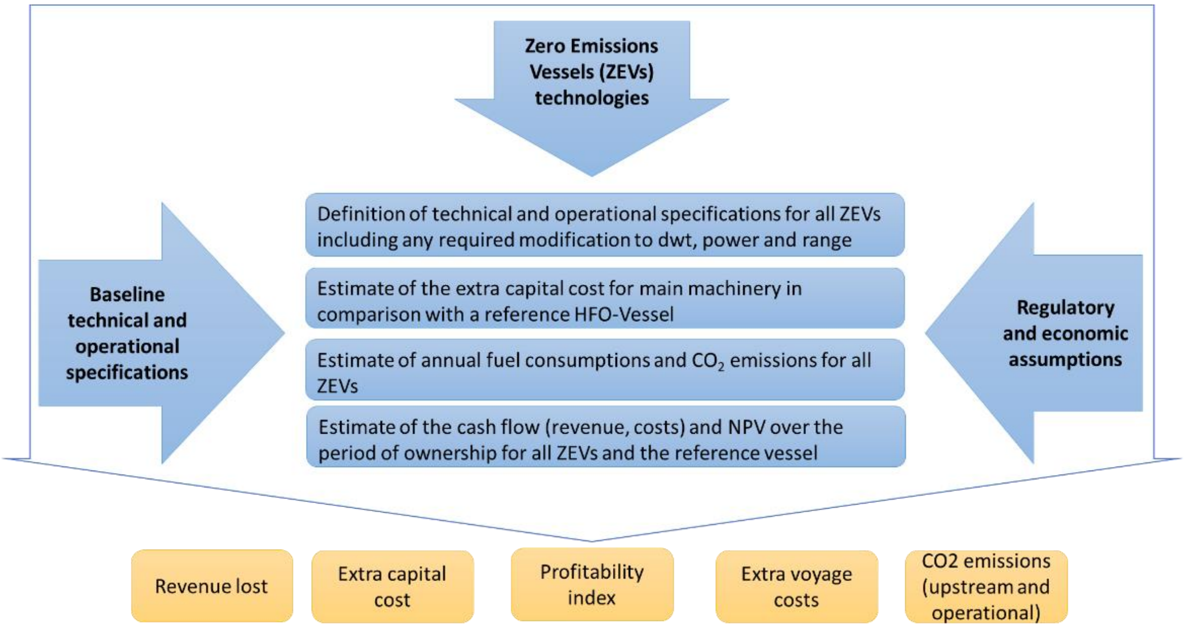

Figure 3: Modelling and analysis methodology and outputs

The outputs of the above method are used to shape and present the results found later, and include:

- The revenue lost; due to the different volumetric energy density of the alternative fuel stored on board, extra space may be required which means a loss of cargo capacity and as a consequence a loss of revenue for the operators.
- The extra capital cost; new technologies may require higher capital cost than the reference internal combustion engine, therefore, extra capital costs are needed for the engine machinery and fuel storage.
- The extra voyage cost; technology developments (e.g. efficiency) and fuel price projections may have an impact of voyage costs in comparison with a reference HFO-vessel, which means extra voyage cost.
- The annual shipowner profit and the profitability index which include all the above parameters and it's used to indicates how the ZEVs may compete to each other
- Annual CO_2 upstream emissions which can be compared to the upstream and operational CO_2 of the reference HFO-vessel.

4. Results

The following results present a range of interpretations of the profitability and associated costs of the ZEV technologies. The profitability over the period of ownership is presented relative to the baseline reference of a HFO ship. To further refine these results, the cost implications are broken down on a normalised scale of 0-1, with 0 once again representing the baseline reference. A further sensitivity analysis is presented to show the impact of changing an imposed carbon price. Finally the upstream emissions are evaluated, as previously noted to be of significant importance at this stage of a decision making process regarding future investment in ZEV technologies and fuels.

4.1 Profitability ranking

The lifetime profitability of all three ships is presented for the three ZEV technology groups being considered. Results are also shows for both scenarios, showing the variation that can occur depending on the economic environment that is being simulated.

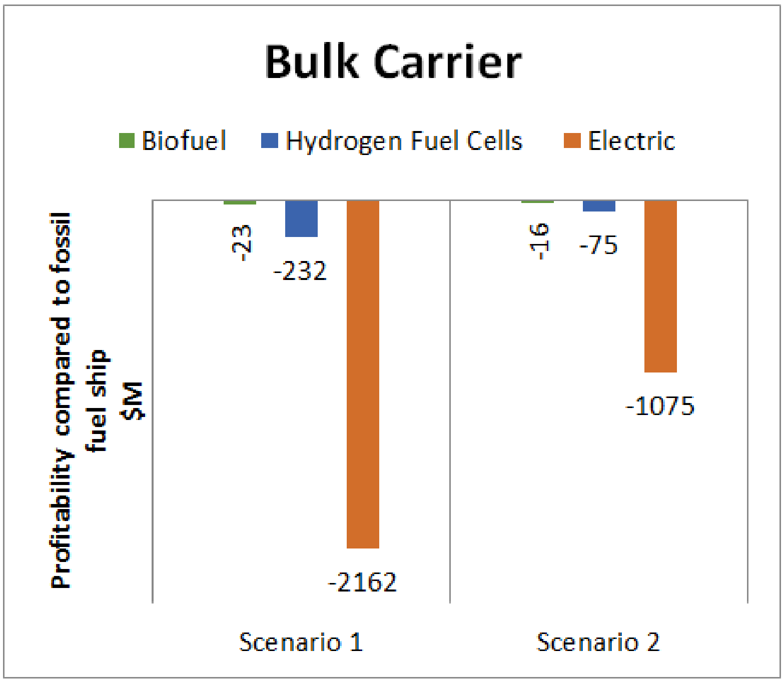

Figure 4: Relative profitability, in $M, of ZEV technologies for a Bulk Carrier

As shown in Figure 4, none of the considered technologies are more profitable than a conventional ship. This underlines the importance for a shift in regulatory policy as an enabling factor, given that a free market implies preference to fossil fuels into the future. Biofuels represent the closest option to economic feasibility, which in the second scenario, are shown to be $16million less profitable over the lifetime of the ship.

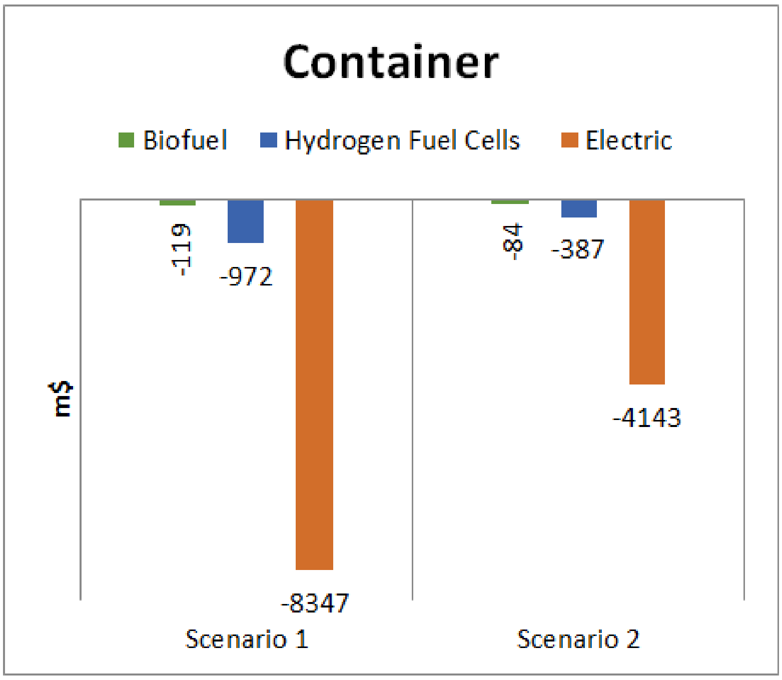

Figure 5: Relative profitability, in $M, of ZEV technologies for a Container Ship

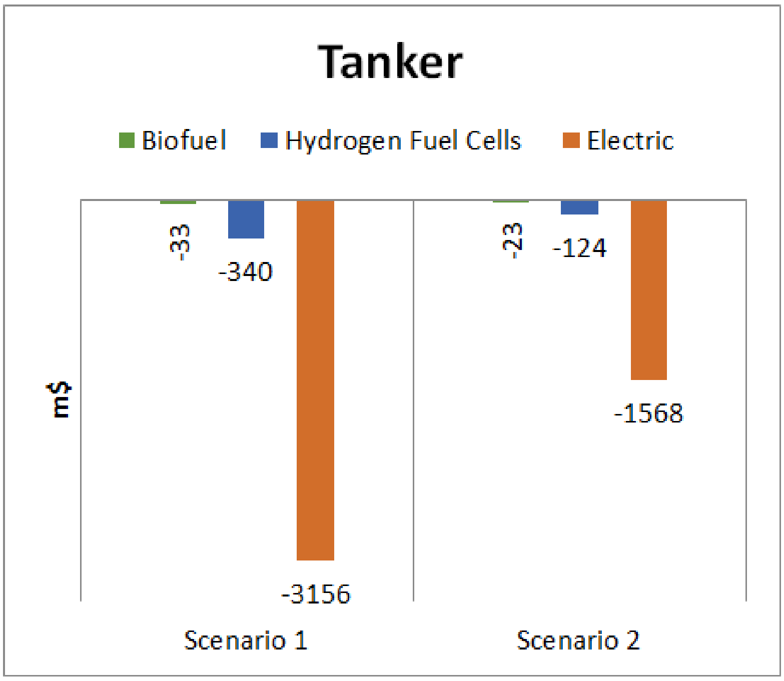

Figure 6: Relative profitability, in $M, of ZEV technologies for a Tanker

Figure 5 and Figure 6 present the lifetime profitability results for the Container ship and the Tanker under consideration respectively. For both of these ships, the trend of biofuels presenting the nearest competitor to the reference ship remains. These results also highlight the spread of the findings for the three different ZEV technology groups. While the order does not change, the absolute numbers do vary, but still show that certain options remain orders of magnitude less competitive than others. For the fully electric option, results vary between $1billion and $8.5billion less profitable than the reference ship. This represents a figure that is quite drastically not feasible for the operational profiles demanded by transoceanic shipping with unaltered bunkering regularity.

4.2 Cost contributions

The results shown in section 4.1 can be broken down further to explore the contributions to the profitability. On a normalised scale, presented for the second scenario only, the contributions to the cost are shown for each of the three ships and each of the three technologies.

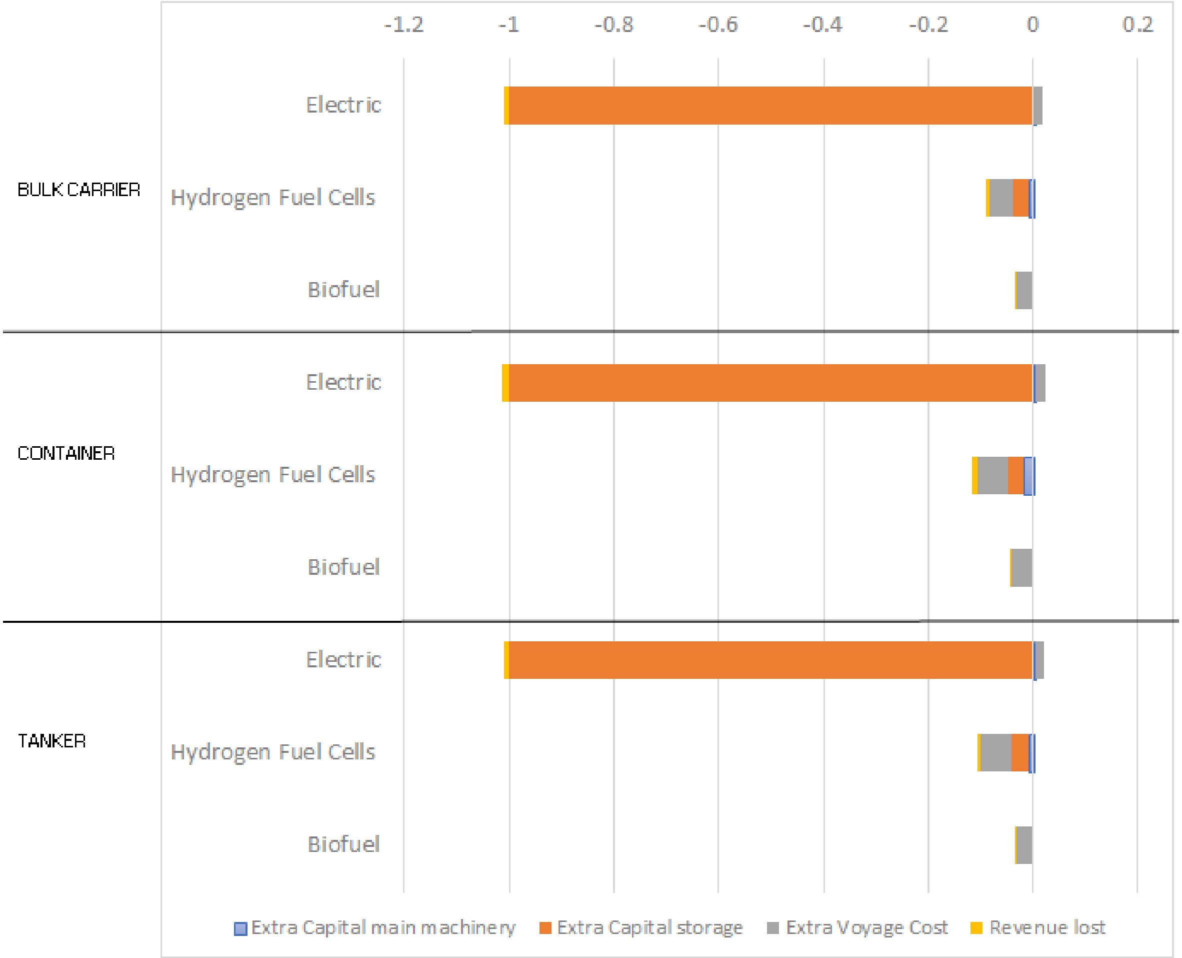

Figure 7: Cost contributions for ZEV technologies

As shown in Figure 7, the profitability results can be understood by considering what components outweigh others. For the electric ships, the normalised cost is dominated by the additional capital cost of storage – batteries. The electric vessel does have a positive contribution in the form of voyage costs – this comes from the fact that under this scenario, projected costs of electricity are cheaper than the HFO alternative, however, this positive does not compensate for the much larger associated cost of the batteries.

For hydrogen fuel cells, the contributions to the cost from all four measured components are noticeable, with the voyage costs coming from the hydrogen fuel cost, being the largest component. Biofuels have no associated additional capital costs for machinery or storage when compared to the reference ship, given that biofuels can be stored and combusted in machinery with identical costs of conventional HFO engines.

4.3 Carbon pricing

A secondary analysis was undertaken to determine the impact on the profitability of ZEVs with a changing carbon price. As noted from the survey and previous results, a policy change may be needed to ensure the uptake of new technology, while many members of the industry have begun to assume some carbon pricing structure to be in place when modelling future investments.

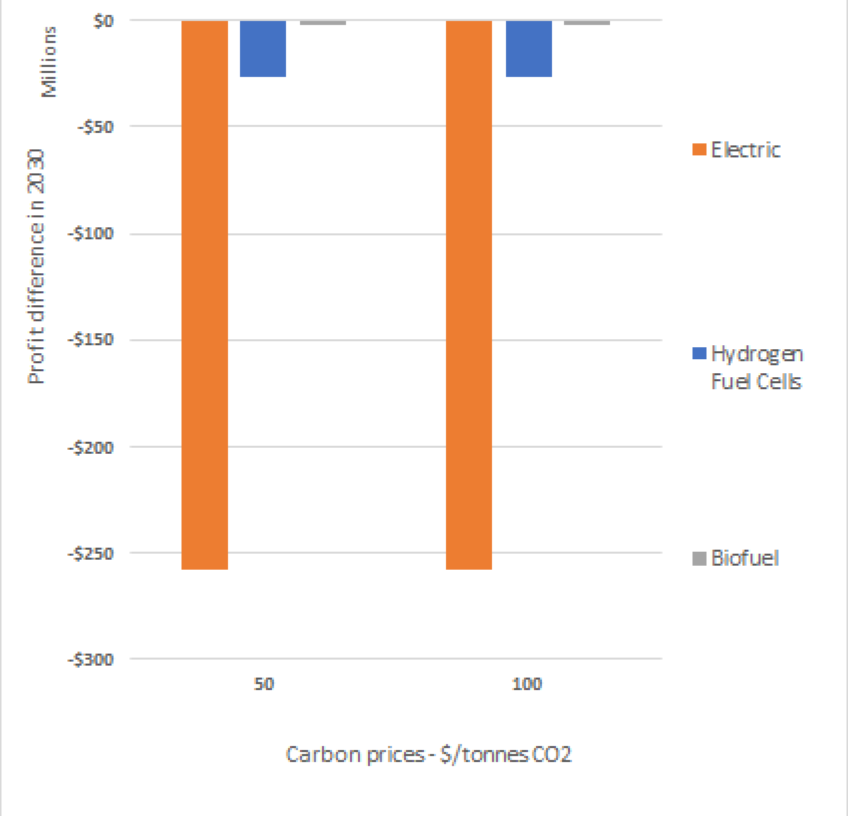

Figure 8: Carbon price sensitivity study presented for the Bulk Carrier under the first scenario

Figure 8 shows that while there is a change in the profitability of all three technologies, at these levels of carbon pricing, the change is virtually negligible, with the HFO reference ship remaining more profitable than all ZEV alternatives. Further analysis has shown that the imposed carbon price must be increased by an order of magnitude for the reference ship to be made less economically favourable than any of the alternative technologies.

4.4 Upstream emissions

The upstream emissions of the associated ZEVs need to be considered in order to fully understand the development trends that need to be seen to ensure decarbonising the operational end of the spectrum does lead to overall reduced carbon emissions. For each technology group, the upstream emissions are calculated when factoring in the methods used to generate the fuels, in both scenarios.

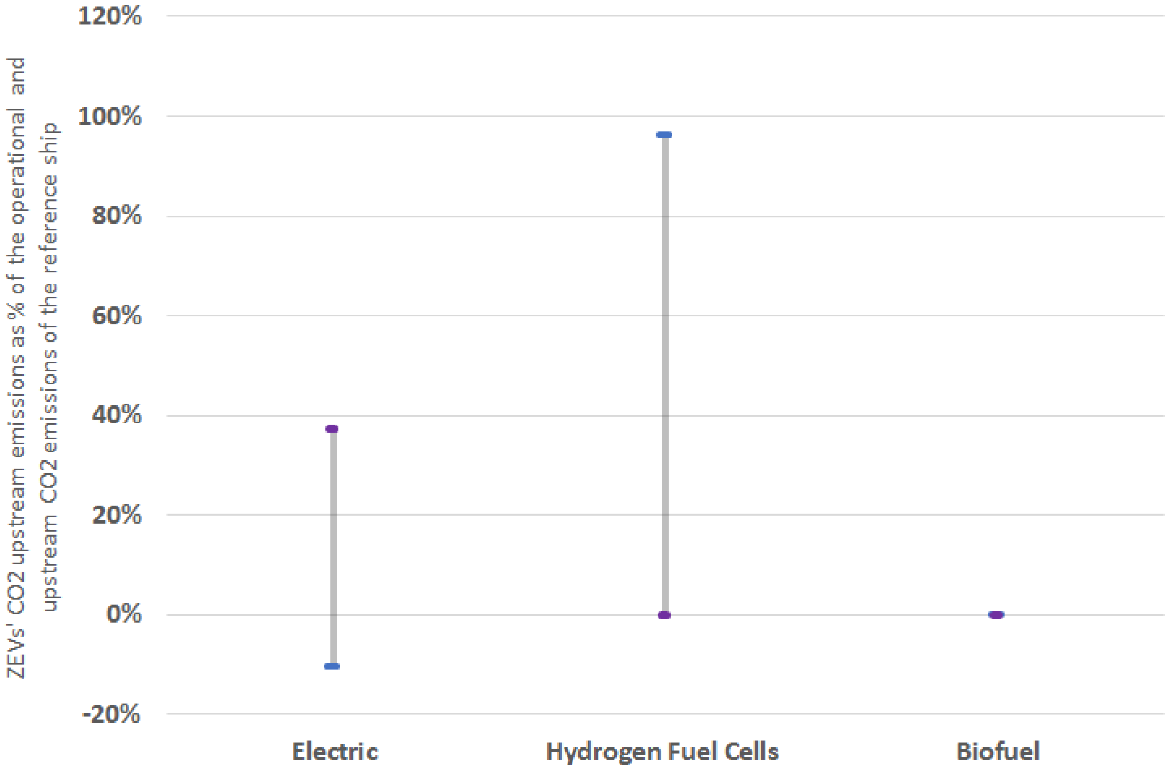

Figure 9: Upstream emissions associated with ZEV technologies

As shown in Figure 9, a spread exists for the technologies, which occurs when considering both scenarios. For all technology groups, there is potential for the upstream emissions to be 0% of current associated emissions from the reference ship's operational and upstream contributions. For the electric ship, when projecting widespread carbon sequestration, the upstream emissions of producing the electricity are in fact negative.

For both electric and hydrogen fuel cells, however, there is also potential for the upstream emissions to be close to current combined levels of upstream + operational emissions, where 100% represents the situation where there is no overall reduction in carbon emissions. For example, one scenario in which this occurs is where hydrogen is produced cheaply from reformation of fossil fuels (with significant corresponding carbon emissions) which is then to be used on board the vessels, offsetting the benefit of zero operational emissions.

The associated upstream emissions of biofuels have been included under the assumptions that only third generation, advanced biofuels are being used as a fuel. Where other biofuels are included, major concerns surrounding land usage and supply capability become apparent. With the numerous ethical considerations that this also brings, they are not included in the development of these results.

5. Conclusions

The results consistently show that advanced biofuels may represent the most economically feasible zero-emission alternative for the shipping industry. The fact that biofuels can be used in a way that very closely mirrors current technology, i.e. through internal combustion, means that associated additional costs are kept to a minimum of the fuel price itself. Under the scenarios projected in this study, these costs are within the realm of acceptability for many in the industry. Biofuels, however, may not be the answer to the question of decarbonisation, due to two important, and coupled, considerations – sustainability and availability.

Advanced (e.g. non-food derived), sustainability-certified biofuels will be required if production in the quantities needed as a full replacement shipping fuel is not to clash with other more basic societal objectives such as production of food for a growing population or need for biofuels for other energy consumers. Whether this results in a finite and partial supply taking a share of overall shipping energy sources, or practical limits on production, this may mean prices rise above the prices used in this paper and to the point where other options (e.g. hydrogen) become more competitive. Further work would be useful to understand the potential pricing dynamics.

For the ships considered in this study, with trans-oceanic operating profiles, batteries remain uncompetitive under the assumptions used. Much development is needed, in terms of performance, energy density, and cost, for them to be worthy of consideration for use in the context of the ships being analysed, even with the addition of a carbon price to attempt to level the playing field.

For hydrogen fuel cell options, the associated costs of the technology on board (both hydrogen storage and the fuel cell) weighs significantly on the overall profitability, however, given certain projections used in this report, these costs may not be prohibitive, particularly if the development of the technology and its efficiency is encouraged through other industries or through policy changes.

Particularly when exploring the viability of the hydrogen option, is it important to take into account the range of different hydrogen-derived propulsion approaches. For example, electrolysis with renewable electricity can also be used to produce ammonia (indirectly from hydrogen or directly), which is less costly to store on board. Both hydrogen and ammonia can be used directly in internal combustion engines, which can also help control capital costs. The scope of this report was limited to just three potential fuel/technology combinations and so has not gone into these alternative pathways.

The voyage costs, however, remain the largest contributory factor to the poor competitiveness of hydrogen fuel cells. This becomes particularly apparent when preference is given to the greenest supply of hydrogen, given the costs currently assumed associated with renewably generated electricity and electrolysis technology. This gap in competitiveness does however show great potential for reduction, even within the timescales used in this study- out to 2030. With the ability to pass on voyage cost excess to the supply chain, effectively providing a premium on a zero emission service, the magnitude of the competitiveness gap decreases hugely, and may indeed already render hydrogen fuel cells economically feasible for certain operators and routes.

As noted by the members of SSI, the technological maturity of the above considered options remains a concern when considered in the context of the current stage of development. Projected technology costs rely upon an evolving regulatory policy and technological development environment. For this to move closer toward reality commitment must be made now to ensure that industry debate is fuelled with a level of ambition aligned with that of what is detailed in this report. In order to bridge the gap towards the required development between now and 2030, further analysis is needed alongside a plan to encourage and invest in such development. For this to be possible, the economic analysis of the options conducted in this study needs to be factored into a wider decision making process by the industry into the most suitable pathway towards zero emissions, no doubt requiring the most ambitious members of the industry to challenge the status quo.

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