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Financing zero-emission vessel shipbuilding in China

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Summary

There is broad consensus that zero-emission vessels (ZEVs) must begin operating on deep-sea routes by 2030 if the shipping sector is to help keep global warming in line with the temperature goals of the Paris Agreement. ZEVs are generally expected to be more expensive to build and operate than conventional ships, but there is little information available about the costs of ZEV shipbuilding and the relative benefits of different policy instruments to support ZEV adoption. As the world's largest shipbuilding country, China will be critical to managing the global ZEV transition.

This paper aims to quantify the additional cost of building ZEVs in China and describe how revenue from carbon pricing mechanisms could be used to pay for it. Specifically, we estimate the incremental capital expenditure for ZEV shipbuilding compared with fossil-fueled ships and relate that to international proposals for carbon pricing for the maritime shipping sector. We estimate that building only ZEVs would cost Chinese shipyards an additional $125 billion to $444 billion over 2025-2050, depending on the choice of fuel and propulsion option. An international carbon price for shipping—starting at $50 per tonne of carbon dioxide in 2025 and escalating to $250 per tonne in 2045—could generate enough revenue to cover between 20.8% and 73.8% of this incremental expenditure. Carbon revenues would peak in the decade from 2030 to 2040, making this the critical time window to jumpstart the ZEV transition in shipbuilding.

Introduction

Shipping emitted about 1 billion tonnes of carbon dioxide (CO_2) in 2018, according to the International Maritime Organization's *Fourth IMO Greenhouse Gas Study* (Faber et al., 2021). Shipping greenhouse gases (GHGs) increased by 9.6% from 2012 to 2018 and are expected to grow further by up to 135% from 2018 to 2050 (Faber et al., 2021). In response to this growth of GHG emissions, in 2018, the IMO adopted the *Initial IMO Strategy on reduction of GHG emissions from ships*, which it revised in July 2023 to include a target of achieving net-zero GHG emissions from international shipping by or around 2050. This goal is estimated to be compatible with the well below 2°C target of the Paris Agreement (Comer & Carvalho, 2023; IMO, 2023b).

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Zero-emission fuels and technologies will be key to achieving the IMO's net-zero goal. There is widespread agreement that zero-emission vessels (ZEVs) must begin operating on deep-sea routes by 2030 if the shipping sector is to contribute to achieving the Paris Agreement temperature targets (Global Maritime Forum, 2019; Lloyd's Register, 2017). However, ZEVs will be more expensive to build and operate than conventional ships powered by fossil fuels. Commercial advisory service UMAS estimates that a total investment of $1 trillion to $1.9 trillion will be needed for shipping decarbonization from 2030 to 2050 under a scenario dominated by the use of ammonia for fuel (Raucci et al., 2020).

Many economists believe that imposing a price on pollution can reduce pollution in an economically efficient manner, in part by generating revenue that can be recycled to support demonstrations of lower-emission technologies (Maersk Mc-Kinney Møller Center for Zero Carbon Shipping, 2021b). UMAS researchers have concluded that achieving carbon neutrality in shipping emissions will require a carbon price of up to $358 per tonne of CO_2 in 2050 (Baresic et al., 2022). Several proposals for carbon pricing now being debated at the IMO could be used to subsidize zero-emission vessels, including a carbon levy, a market-based cap-and-trade system, and a feebate system that would reward the use of zero-emission vessels and charge a tax on fossil-fueled ships (IMO, 2023a). At a regional level, the European Union Emissions Trading System (EU ETS) is slated to cover 100% of emissions on intra-EU voyages and 50% of emissions on extra-EU voyages, with a 3-year phase-in period starting in 2024 (Det Norske Veritas, 2023). Revenue from 20 million emissions allowances worth 1.8 billion Euros per year at today's EU ETS carbon price (€90 per tonne of CO_2) will be used to support the demonstration and deployment of low-carbon shipping technologies (Council of the European Union, 2022; Transport & Environment, 2022).

China, a key shipbuilding nation and major flag state for registering ships, has also expressed concerns about the environmental impact of shipping. In 2021, the Chinese government released its "1+N" policy framework for carbon peaking and carbon neutrality. The 1 refers to an overarching strategy released in 2021 for reaching carbon neutrality, while the N refers to a series of continuously released sector- and issue-specific implementation plans, beginning with The *Action Plan for Carbon Dioxide Peaking Before 2030*. The *Action Plan* aims to increase the share of newly-built vehicles (including ships) fueled by clean energy to 40% by 2030 (National Development and Reform Commission, 2021). China also has a national ETS covering the power sector, which charged an average of ¥55.30 (about $8.20) per tonne of CO_2 in 2022 (International Carbon Action Partnership, n.d.-a). There is also a local Shanghai pilot ETS that is partially applied to local ports and shipbuilding (International Carbon Action Partnership, n.d.-b).

This paper aims to quantify the transition costs of building ZEVs in China and describe how revenue from carbon pricing mechanisms could be recycled to pay for it. First, we summarize the current state of Chinese shipbuilding, along with fuel and power options for ZEVs. The next section outlines how we modeled the cost of producing ZEVs for Chinese shipbuilders using the Maersk Mc-Kinney Møller Center for Zero Carbon Shipping's Total Cost of Ownership Calculator. We then analyze how much of the incremental capital expenditure (CapEx) of building ZEVs could be covered using revenue from carbon pricing. The paper concludes with policy implications.

Overview of the Chinese shipbuilding industry

China's shipbuilding industry, aided by cost advantages and strong policy support, has grown since the 1980s to encompass a large share of the global market. Production, as measured by share of global gross tonnage (GT), grew by 17.5% between 2014 and 2021, when China accounted for 44% of the gross tonnage of ships built globally

(Figure 1).[1] South Korea and Japan accounted for most of the world's remaining ship production, with only 5% of global GT produced in other countries (United Nations Conference on Trade and Development, 2023).

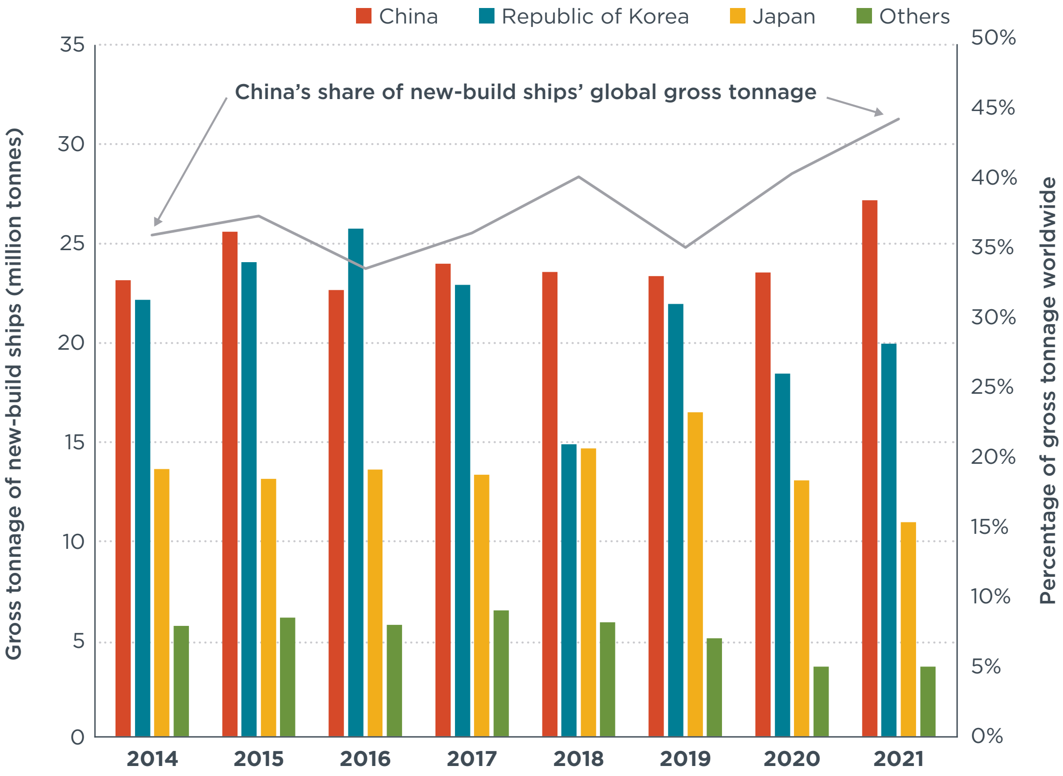

Figure 1. Shipbuilding by country and China's share of the global market, 2014-2021

Source: United Nations Conference on Trade and Development, 2023

Oceangoing vessels (OGVs) account for the largest share of Chinese shipbuilding activity, as measured in GT and deadweight tonnage (DWT).[2] Production by ship type in 2020 is shown in Table 1. Bulk carriers were the most-produced OGV, accounting for one third of ships built by number, half of DWT, and 41% of GT. Tankers (oil and chemical) were the next leading ship type, responsible for 13% of ships, 23% of DWT, and 18% of GT, followed by container ships, which accounted for 10% of ships, 18% of DWT, and 27% of GT. These three ship types are, on average, larger than other vessels built in China.

1 GT is a measure of a ship's total interior volume, including the crew, machinery, navigation, engine room, and fuel.

2 DWT is a measure of how much weight a ship can carry. It includes the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew. It does not include the empty weight of the ship.

Table 1. Summary of shipbuilding in China by ship type, 2020

Ship type	Number		DWT (tonnes)		GT (tonnes)	
	Total	Percent	Total	Percent	Total	Percent
Bulk carrier	255	32%	15,032,864	51%	8,363,105	41%
Container	82	10%	5,320,173	18%	5,488,588	27%
Chemical tanker	82	10%	3,470,610	12%	2,041,856	10%
Oil tanker (single and double hull)	21	3%	3,240,460	11%	1,647,504	8%
LPG ship	20	3%	769,850	3%	1,099,399	5%
General cargo	35	4%	427,041	1%	296,145	2%
LNG ship	5	1%	327,300	1%	446,310	2%
Fishing	115	14%	184,327	1%	119,306	1%
Vehicle ship	4	1%	69,160	0%	172,710	1%
Ferry	2	0%	23,000	0%	129,000	1%
Ro-ro	2	0%	20,000	0%	50,000	0%
Cruise	3	0%	13,622	0%	13,950	0%
Others	80	10%	479,111	2%	404,034	2%
OGVs subtotal	**706**	**89%**	**29,377,518**	**99.6%**	**20,271,907**	**99.5%**
Inland vessel	**89**	**11%**	**118,293**	**0.4%**	**103,610**	**0.5%**
Total	**795**	**100%**	**29,495,811**	**100%**	**20,375,517**	**100%**

Source: China Association of the National Shipbuilding Industry, 2022

Figure 2 shows the predominance of these three vessel types in China's shipbuilding industry: In 2020, bulk carriers, container ships, and tankers constituted 62% of OGVs and 87% of GT built in China.

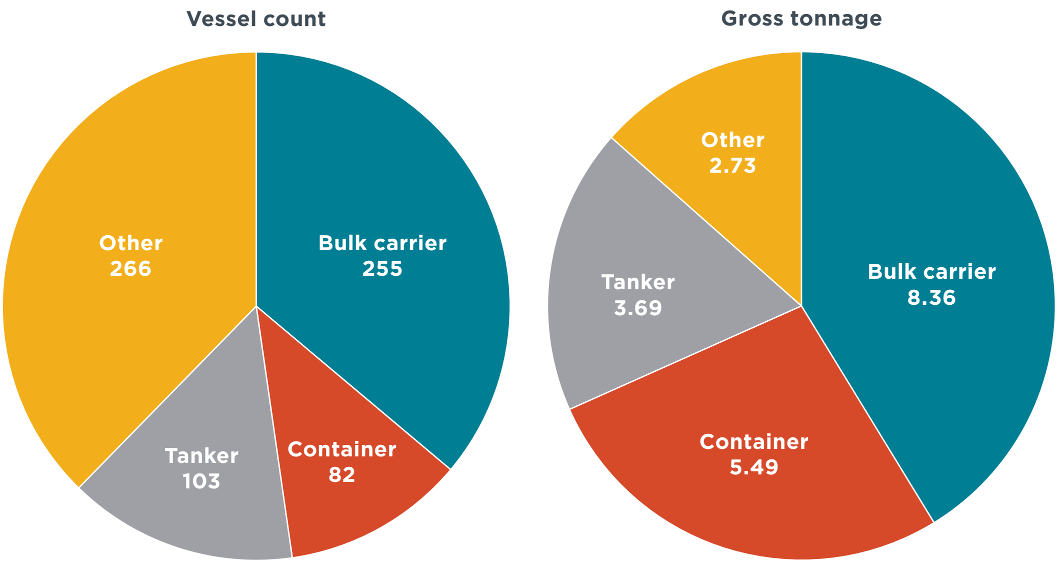

Figure 2. Oceangoing vessel count (left) and gross tonnage (million tonnes, right) by ship type built in China, 2020

Source: China Association of the National Shipbuilding Industry, 2022

Overview of potential propulsion options for ZEVs

Several zero-emission fuel and power options are expected to power deep-sea ZEVs.[3] This study considers three low-carbon fuels—hydrogen, ammonia, and methanol—and two power options: the internal combustion engine (ICE) and the fuel cell.[4]

Liquid hydrogen, which contains no carbon, has attracted interest as a potential marine fuel. It may be mostly suitable for shorter-range ships because of its low energy density (it is up to 8 times less dense, considering space needed for storage, than conventional marine gas oil) and the challenges of maintaining the hydrogen on board under cryogenic temperatures. Liquifying hydrogen gas also requires significant amounts of energy.

Ammonia, which is widely used in agriculture and industrial applications, also contains no carbon, is more easily stored than hydrogen, and can be produced from renewable sources. On the other hand, it is highly toxic, carries significant spillage and eutrophication risks, and requires aftertreatment to control combustion byproducts.

Methanol, which is the simplest form of liquid oxygenated hydrocarbon, burns cleanly and can already be used in marine engines. However, unlike hydrogen and ammonia, it contains carbon. To reduce methanol's life-cycle emissions to near zero, it should be produced from waste products such as power plant exhaust or from carbon captured through direct air capture or other technologies.

ICEs are the workhorses of international shipping, but when powered by fossil fuels, or even some biofuels or e-fuels, they generate GHGs and air pollution. Slow-speed diesel engines propel most deep-sea ships. High-speed diesel engines power smaller ships, such as port tugs and fishing vessels, and are also valued in hybrid applications with very large electrical auxiliary loads, like cruise ships. ICEs can currently be powered by methanol, and there is high interest in the shipping industry in developing and trialing slow-speed diesel engines powered by ammonia by 2024 (Fürstenberg Maritime Advisory and Global Maritime Forum, 2021).

One alternative to an ICE is the fuel cell, which combines hydrogen from fuel with oxygen from the air and converts the chemical energy to electrical energy for propulsion. Hydrogen fuel cells release no climate or air pollutants, only water, and are typically modular. However, they are significantly more expensive than a traditional ICE for the same amount of power (Elkafas et al., 2022; Wang & Wright, 2021).

Based on research published by the Global Maritime Forum (Fahnestock & Bingham, 2021), as of 2021, more than half of all pilot and demonstration projects in the maritime sector globally were related to hydrogen, ammonia, and methanol. Table 2 summarizes the demonstration projects underway in China at that time. For larger ships, China's zero-emission pilot projects were focused on ammonia dual-fuel engines. For smaller river vessels, the major focus was on hydrogen fuel cell and battery electric propulsion.

3 Here, we use "zero emission" to refer to fuel and power options that either contain no carbon (hydrogen and ammonia) or could be produced with very low life-cycle emissions (methanol).

4 Two other potential low-carbon options for shipping—electrification and "drop-in" biofuels or e-fuels—are not expected to be representative of ZEV transition costs and are therefore beyond the scope of this work. Electrification is likely to be most appropriate for near-port applications with limited power demand and abundant recharging options, but the intense power requirements for deep-sea shipping implies very high CapEx costs. In contrast, drop-in fuels will have very limited CapEx requirements and would allow for low incremental CapEx costs. The supply of sustainable biofuel is limited, however, and operating costs are expected to remain high for many biofuel feedstocks.

Table 2. Zero-emission pilot projects in China

Fuel focus	Engine focus	Project details
Ammonia	Dual-fuel internal combustion	• Large container ship concept study • Ultra-large container ship concept study • Very large crude carrier concept study
Methanol	N/A	• Fuel applicability laboratory test • Inland cargo barge trial and verification
Hydrogen and battery power	Proton exchange membrane fuel cell, battery	• Inland river cargo carrier demonstration • Inland river ferry demonstration

Source: Fahnestock & Bingham, 2021

Methodology for calculating shipbuilding costs

CapEx modeling

We used the Total Cost of Ownership (TCO) Calculator from the Maersk Mc-Kinney Møller Center for Zero Carbon Shipping (2021a) to develop a bottom-up TCO analysis of both fossil fuel ships and ZEVs. The Calculator considers all relevant CapEx costs—including the cost of ship hull, propulsion machinery, the tank and fuel system, and efficiency improvements—plus operating costs (OpEx), including fuel consumption and maintenance. All relevant databases and parameters input in the Calculator are drawn from the Maersk Mc-Kinney Møller Center's partners and expert knowledge.

The Calculator was used to model the base CapEx costs for building ships powered by very low sulphur fuel oil (VLSFO) and the incremental CapEx costs of ZEV shipbuilding. We applied the model's default assumptions, supplemented by the following:[5]

» Ships were assumed to last 25 years, with the CapEx increment for ZEVs being accrued in the initial year.

» The cost of the ship hull was assumed to be constant over the period studied.

» The engine cost was based on the power of the engine (megawatts), and the tank cost was based on the tank size (m^3). The fuel supply system cost varied for different propulsion types.

» The fuel cell cost was assumed to decrease over time, and the lifetime of a fuel cell was assumed to increase over time with an upper limit of 13 years.

Because China builds a broad portfolio of vessels of varying sizes, installed power, and cost, we analyzed a representative set of ships across the three main ship types built in China noted above (containers, oil tankers, and bulk carriers). The Calculator provides detailed parameters of representative medium-sized ships, including container ships under 8,000 twenty-foot equivalent units (TEUs), oil tankers under 100,000 DWT, and bulk carriers between 70,000 DWT and 100,000 DWT. To cover more ships built in China, we extended the representative ship set to small and large sizes, referencing the size category definition from Annex Table 81 in the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2021). For engine power, we used the average results from the same table in the IMO's study. The fuel tank size was scaled up or down based on the difference in DWT from medium-sized ships. Details of the parameters are shown in the Appendix.

5 The TCO Calculator, and information on its underlying assumptions, are accessible by request at https://forms.office.com/pages/responsepage.aspx?id=ocIYUsyBzkCvmXUFFDvCY3Ipey9J0r9BoWGulkpHRsxUMVFUV0k2MzZCUktLQldJNVpNRVpJRTFBSC4u. Some detailed assumptions and inputs of the calculator are not described here due to terms of use restrictions.

To scale up the results of representative ships to new-build ships in China, we used Equation 1 and Equation 2 below.

$$C_{average\ i,j} = \frac{C_{ZEV\ i,j} - C_{VLSFO\ i,j}}{GT_{i,j}} \tag{1}$$

Where:

- $C_{average\ i,j}$ is the average additional CapEx per unit GT of ship type *i*, size *j*, in dollars/tonne
- $C_{ZEV\ i,j}$ is the CapEx of representative ZEV of ship type *i*, size *j*, in dollars
- $C_{VLSFO\ i,j}$ is the CapEx of representative VLSFO ship of ship type *i*, size *j*, in dollars
- $GT_{i,j}$ is the GT of the representative ship of ship type *i*, size *j*, in tonnes

$$C_{main} = \sum C_{\ average\ i,j} \times TGT_{i,j} \tag{2}$$

Where:

- C_{main} is the total additional CapEx of the bulk carrier, container, and oil tanker, in dollars
- $TGT_{i,j}$ is the total GT of ship type *i*, size *j*, in tonnes

The findings from those ship types were then scaled up across all ship types using the concept of compensated gross tonnage (CGT).[6] Bulk carriers accounted for about one third (36%) of CGT from Chinese shipbuilding in 2020, followed by container ships (24%) and tankers (19%), together accounting for 79% of Chinese shipbuilding. ZEV transition costs for these three ship types were thus adjusted upward by a factor of 1.27 (1/0.79) to calculate the total cost of ZEV shipbuilding in China in a given year. Chinese shipbuilding volumes in GT were assumed to grow by 2.3% per year to 2050, based on the average annual growth rate of Chinese new-build ship volumes from 2014 to 2021 (United Nations Conference on Trade and Development, 2023).

Zero-emission fuel and propulsion scenarios

We then selected zero-emission fuel and propulsion options to estimate the incremental CapEx for ZEVs of these ship types and sizes. We developed two scenarios—Low CapEx, which is an ammonia-dominant scenario, and High CapEx, which includes higher-cost technologies such as hydrogen fuel cells—to bridge the potential range of transition costs. The fuel and propulsion options analyzed are for cost estimation only and should not be interpreted as actual technologies to be deployed on a given ship type or size. Table 3 summarizes the ship sizes and propulsion types assessed in this study.

6 Compensated gross tonnage is used to measure shipyard productivity. It takes into account variation in the level of effort needed to produce different ship types and reflects economies of scale (i.e., marginally decreasing level of effort per unit GT).

Table 3. Fuel and propulsion analyzed by ship type, ship size, and CapEx scenario

Ship type	CapEx scenario	Small			Medium			Large		
		Gross tonnage	Fuel	Propulsion	Gross tonnage	Fuel	Propulsion	Gross tonnage	Fuel	Propulsion
Container	Low	47,500	Ammonia	ICE	105,000	Ammonia	ICE	179,100	Ammonia	ICE
	High		Hydrogen	Fuel cell		Hydrogen	Fuel cell		Methanol	ICE
Tanker	Low	40,600	Ammonia	ICE	60,500	Ammonia	ICE	82,800	Ammonia	ICE
	High		Methanol	ICE		Hydrogen	Fuel cell		Ammonia	ICE
Bulk carrier	Low	34,300	Ammonia	ICE	44,000	Ammonia	ICE	88,200	Ammonia	ICE
	High		Hydrogen	Fuel cell		Methanol	ICE		Ammonia	ICE

Using the TCO Calculator, we estimated the costs of these ZEVs compared to the reference VLSFO ship to determine the incremental CapEx of ZEVs in 5-year periods starting in 2025 (see Table 5, below).

Carbon pricing assumptions

We also modeled revenues from carbon pricing, assuming an international carbon price with revenue recycled through IMO member states. In 2022, Japan called for a global carbon price of $56 per tonne of CO_2 beginning in 2025 (International Transport Forum, 2022). Researchers have estimated that in order to reach the IMO's initial strategy goal, the price of carbon needs to increase to about $100 per tonne of CO_2 in the early 2030s and further to around $230–$260 per tonne of CO_2 between 2035 and 2045 (Baresic et al., 2022). To model revenue generated from carbon pricing, we therefore assumed a global carbon price starting at $50 per tonne of CO_2 in 2025, increasing to $250 per tonne by 2045.

We then estimated the total revenue raised from international shipping emissions. A base inventory of 1,026 million tonnes Mt CO_2 in 2020 was derived from the *Fourth IMO Greenhouse Gas Study* under scenario SSP2_RCP2.6_L (Faber et al., 2021). Future emission patterns were assumed to align with the minimum ambitions of the IMO's revised GHG reduction strategy, entailing reductions from 2008 levels of 20%, 70%, and 100% in 2030, 2040, and 2050, respectively (IMO, 2023b).

We assumed that the price imposed was revenue neutral, with 100% of the revenue being refunded either to ship operators (to offset increased OpEx) or shipbuilders (to offset the extra CapEx of ZEVs). The shipbuilders' share of the revenue was based on results from UMAS under an ammonia-dominant scenario, in which building and retrofitting ships account for 13% of additional investment costs (Raucci et al., 2020).

As the revenue refunded to shipbuilders would be used to support ZEV building technologies, we allocate these rebates by country according to each country's relative share (by CGT) of the alternative-fuel shipbuilding market. Data from Clarksons Research show that China accounts for 35% (by CGT) of orders of alternative-fuel ships scheduled for delivery in 2025 (Clarksons Research, 2023). We assumed China would increase its overall shipbuilding market share by 0.8% annually, the level of average annual growth it recorded from 2012 to 2022. We therefore assumed that China's shipbuilding market share would grow to 49.5% by 2030 and 59.0% by 2050.

These assumptions are shown in Table 4 below:

Table 4. Carbon pricing assumptions

	2025	2030	2035	2040	2045	2050
Carbon price	$50	$100	$150	$200	$250	$250
CO_2 emissions (million tonnes)	965	908	624	341	170	0
Shipbuilder share of revenue from carbon pricing	13%					
Global share of alternative-fuel ships delivered by Chinese shipbuilders	35%	49.5%	51.8%	54.1%	56.5%	59.0%

Results

Table 5 summarizes our findings on the incremental CapEx costs of building ZEV ships in China from 2025 to 2050 under Low and High CapEx scenarios. Costs are presented by ship type and CapEx scenario; we also present totals for the three main ship types (bulk carriers, containers, and tankers), and scale up by CGT to present total costs of all ship types built in China. Containers are responsible for about half of incremental ZEV costs for the three modeled ship types, while tankers are responsible for the smallest share, about 10%. The total annual incremental CapEx for all ships ranges from $3.6 billion in 2025 in the Low CapEx case to $18.2 billion in 2050 in the High CapEx case.

Table 5. Incremental CapEx expenditure in China by ship type and year

Ship type	CapEx scenario	Incremental CapEx by year (billion USD)					
		2025	2030	2035	2040	2045	2050
Bulk carrier	Low	$1.0	$1.1	$1.3	$1.4	$1.6	$1.8
	High	$4.4	$4.2	$4.1	$4.2	$4.3	$4.6
Container	Low	$1.3	$1.5	$1.7	$1.9	$2.1	$2.4
	High	$8.5	$7.8	$7.6	$7.7	$7.9	$8.3
Tanker	Low	$0.5	$0.5	$0.6	$0.6	$0.7	$0.8
	High	$1.2	$1.2	$1.2	$1.3	$1.3	$1.4
Total of three ship types	Low	$2.8	$3.1	$3.5	$3.9	$4.4	$5.0
	High	$14.1	$13.2	$13.0	$13.1	$13.5	$14.3
Total of all ships[a]	Low	$3.6	$4.0	$4.5	$5.0	$5.6	$6.3
	High	$18.0	$16.8	$16.5	$16.7	$17.2	$18.2

[a] Scaled upward by CGT to cover all ship types built in China.

For the Low CapEx case, which is dominated by the ammonia fuel option, costs increase linearly over time as the volume (in GT) of shipbuilding increases. From 2025 to 2050, an incremental investment of $125.1 billion would be required for Chinese shipbuilders to build vessels powered by ammonia rather than fossil fuels. Of this $125.1 billion, we estimate that $106.4 billion would be required between 2030, China's target year for carbon dioxide peaking, and 2050. Considering that China was building around half of all new-build ships globally in 2021, and that its market share is growing, we estimate that total additional investment between 2030 and 2050 globally would be $212.8 billion in the ammonia-dominant scenario. This result is comparable with

UMAS's estimate that $214.5 billion would be needed from 2030 to 2050 for additional ship-side investments globally under the ammonia scenario (Raucci et al., 2020).

In the High CapEx case, costs fall modestly through 2035 as fuel cell technologies mature, before rising again due to growth in delivered tonnage. We estimate that total additional investment between 2025 and 2050 in China would be $444.3 billion because of the higher CapEx of hydrogen fuel cells.

We also find that an IMO-level carbon pricing and revenue rebate could help cover the potential investment gap from fossil fuel ships to ZEVs. Figure 3 shows the projections for maritime CO_2 emissions and associated carbon revenues. Under the IMO's revised GHG reduction strategy, we forecast that maritime CO_2 emissions will decrease to 908 Mt in 2030, 341 Mt in 2040, and to net-zero by 2050. Carbon prices, for their part, will increase every 5 years, such that carbon revenue would increase and then drop on a cyclical basis.

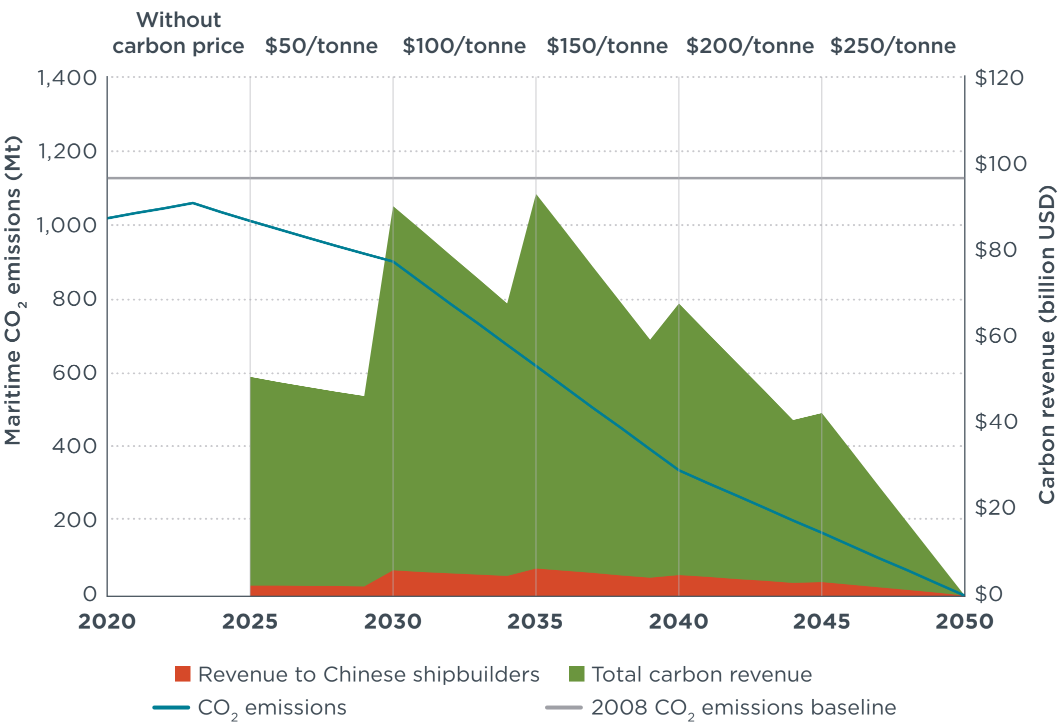

Figure 3. Projection of maritime CO_2 emissions and carbon revenue

Our results show that the decade from 2030 to 2040 would be the most significant time window for the ZEV transition in shipbuilding, with annual revenues peaking at $93.6 billion in 2035 before dropping as the accelerated decarbonization of shipping reduces CO_2 emissions and associated revenues. In total, from 2025 to 2050, IMO-level carbon pricing could generate $1.4 trillion to support maritime decarbonization. If 13% of that revenue were rebated to shipbuilders around the world, it could trigger more technology development to spur the transition to ZEVs. Based on their ZEV market share, Chinese shipbuilders could potentially receive $92.3 billion in revenue, which would be 6.5% of the entire carbon revenue pool. Figure 4 illustrates the annual carbon price revenue earmarked for Chinese ZEV shipbuilders in comparison with the two incremental CapEx scenarios. Consistent with global trends, expected revenues to Chinese shipbuilders would peak between 2030 and 2040, ranging from $4.2 billion to $6.3 billion per year.

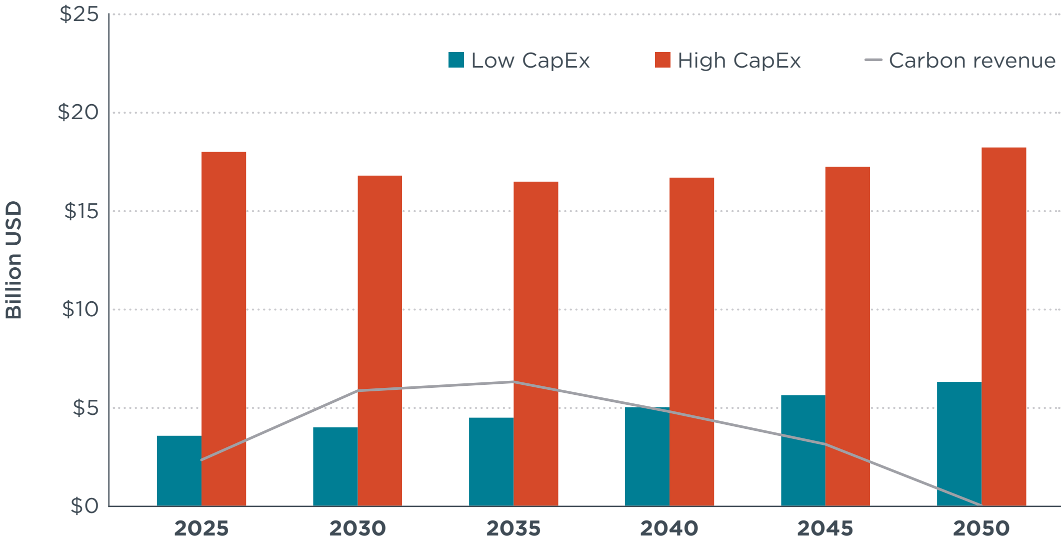

Figure 4. Carbon revenue versus incremental CapEx cost of building ZEVs

Table 6 specifies the shares of ZEV production costs for Chinese shipbuilders covered by rebated carbon revenues in each CapEx scenario in 5-year increments. Starting in 2025, a carbon price of $50 per tonne could jumpstart the Chinese ZEV shipbuilding industry by covering a significant share (13%-66%) of the extra cost of producing ZEVs. Shares of production costs covered by rebated revenue would peak between 2030 and 2040. Under the Low CapEx scenario, revenues from carbon pricing would fully cover the incremental costs of building ZEVs during this period, while for the High CapEx scenario, such revenues would cover around a third of the additional cost (34.8% in 2030, 38.2% in 2035, and 28.7% in 2040). Aggregating for all years, carbon revenues would cover between 20.8% (in the High CapEx scenario) and 73.8% (in the Low CapEx scenario) of China's incremental CapEx from 2025 to 2050.

Table 6. Carbon revenue contribution to Chinese shipbuilding by CapEx scenario

CapEx scenario	Percentage of incremental ZEV costs covered by carbon revenue					
	2025	2030	2035	2040	2045	2050
Low	65.5%	100%[a]	100%[a]	95.4%	55.6%	0%
High	13.0%	34.8%	38.2%	28.7%	18.1%	0%

[a] Maximum allowed; earmarked revenue exceeds the CapEx increment

Although the revenue from a carbon tax could not cover all of the additional CapEx cost of building ZEVs, especially under the High CapEx scenario, we expect other sources of policy support to be made available. For instance, funding from government projects, such as the Zero Emission Vessels and Infrastructure competition announced by the UK Government in 2023, can help to both support faster technology maturation and trigger new market-driven actions (Cameron-Smith, 2023). Public funding can also promote the transition to ZEVs by supporting ZEV demonstration projects (Rosenberg & Leitão, 2023).

Conclusions and policy implications

This study assessed how a potential IMO-level carbon pricing system could support China in building ZEVs. We found that:

» The total amount of additional investment needed for China to build ZEVs, rather than fossil-fueled ships, is substantial, ranging between $125.1 billion and $444.3 billion over 2025-2050, depending on the fuel and propulsion scenario. However, the revenue from a potential IMO-level carbon pricing plan could cover between

20.8% and 73.8% of this incremental cost in the high- and low-expenditure cases, respectively.

» The most significant time window for shipbuilders and shipbuilding countries to transition to ZEVs would be between 2030 and 2040, when revenue from carbon pricing would be the highest and shipbuilders would receive the most financial support for ZEV development.

These findings suggest that carbon pricing with revenue recycled for shipbuilding could effectively trigger and support the development of ZEV shipbuilding in China. To encourage the ZEV transition, China should consider supporting IMO proposals for international carbon pricing as well as strengthening and extending its national emissions trading system to include shipping. As one of the biggest shipbuilding countries, China is positioned to play a critical role in the development of the ZEV shipbuilding industry and to help lead the transition to a zero-emission shipping future.

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Appendix

Table A1. Detailed parameters of representative ships applied in the TCO Calculator

Ship type	Size category[a]	DWT/TEU	Average GT	Main engine max power (MW)	Auxiliary engine max power (MW)	Fuel tank size (m^3)
Container	Small	3,000–7,999 TEU	47,500	42	8.8	6,750
	Medium	8,000 TEU	105,000	50	12.4	9,000
	Large	15,000 TEU or more	179,100	60	14.4	15,000
Tanker	Small	60,000–80,000	40,600	11	2.2	2,100
	Medium	80,000–120,000	60,500	12	3	3,000
	Large	120,000–200,000	82,800	17	3.4	4,500
Bulk carrier	Small	35,000–70,000	34,300	8	1.5	2,100
	Medium	70,000–100,000	44,000	8.2	2	3,000
	Large	100,000–200,000	88,200	17	3.4	4,000

[a] Medium is the default parameter in the TCO Calculator; assumptions were made to extend the application range for the small and large categories.