Green steel and shipping

Exploring the material flow of steel and potential for green steel in the shipping sector

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About the author

The Sustainable Shipping Initiative (SSI)

The Sustainable Shipping Initiative (SSI) is a multi-stakeholder collective of ambitious and like-minded leaders, driving change through cross-sectoral collaboration to contribute to – and thrive in – a more sustainable maritime industry. Spanning the entire shipping value chain, SSI members are shipowners and charterers; ports; shipyards; marine product, equipment and service providers; banks, ship finance and insurance providers; classification societies; and sustainability non-profits.

Guided by the *Roadmap to a sustainable shipping industry*, SSI works on a range of issues related to enabling and furthering sustainable shipping, including shipping's decarbonisation, and seafarers' labour and human rights.

www.sustainableshipping.org

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About this report

Green steel and shipping looks at the material flow of steel in the shipping sector and explores some of the drivers and barriers to increase uptake of green steel in shipping. It follows two prior pieces of work relating to circularity and materials in shipping. The first, 2013's *Closed Loop Materials Management* focused on the need for transparency and traceability of materials throughout the lifecycle of a vessel. The second, 2021's *Exploring shipping's transition to a circular industry* explored the concept of circularity for shipping, including design for recycling, better traceability of materials and, in particular, the circularity potential of steel as it makes up 75-85% of a vessel by weight.

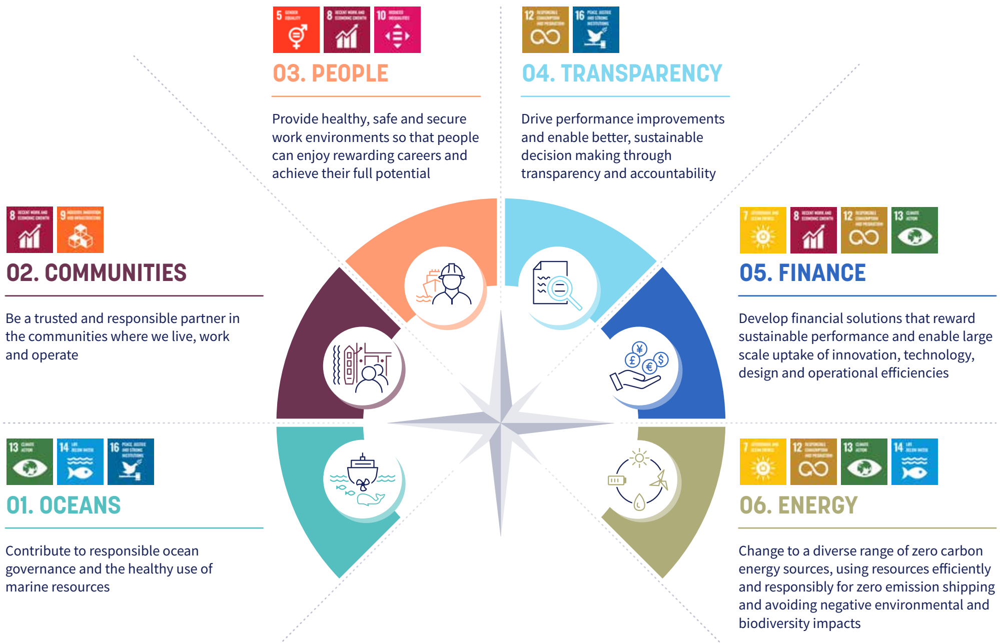


FIGURE 1

Roadmap to a sustainable shipping industry

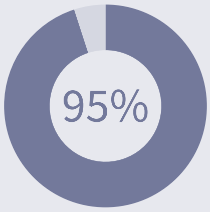
This report is part of SSI's work towards a sustainable shipping industry as presented in the *Roadmap to a sustainable shipping industry*. Circularity has a key role to play in shipping's sustainability journey, and ensuring the rapid and sustainable decarbonisation of the industry contributes to all six vision areas.

Acronyms

BF-BOF	Blast furnace-basic oxygen furnace
CO_2	Carbon dioxide
CCU	Carbon capture and utilisation
CCUS	Carbon capture, utilisation, and storage
DRI	Direct reduced iron
EAF	Electric arc furnace
EOL	End-of-life
EU	European Union
EU DPP	European Union Digital Product Passport
EU SRR	European Union Ship Recycling Regulation
ESG	Environmental, Social, and Governance
GHG	Greenhouse gas
GPP	Green Public Procurement
IACS	International Association of Classification Societies
IDDI	Industrial Deep Decarbonization Initiative
IEA	International Energy Agency
IHM	Inventory of Hazardous Materials
IMO	International Maritime Organization
SSI	Sustainable Shipping Initiative
SBTi	Science-Based Targets initiative

Executive summary

Mitigating the climate crisis requires dramatic, rapid reductions in greenhouse gas (GHG) emissions. An effort from all sectors to move to zero emissions, on pathways aligned with achieving the Paris Agreement goal of limiting warming to below 1.5°C, is necessary.



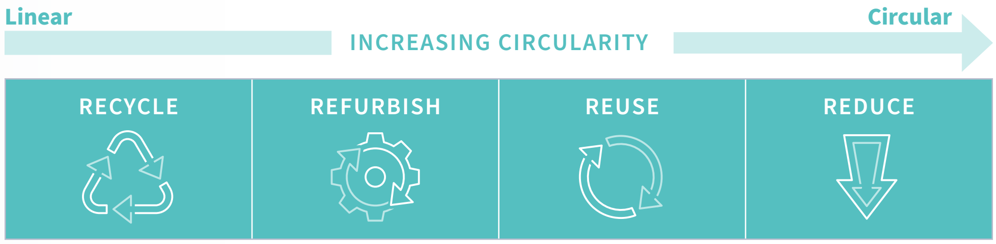
For shipping, fuel-related GHG emissions are responsible for over 95% of Scope 1 GHG emissions

For shipping, fuel-related GHG emissions remain the core focus of the sector's decarbonisation efforts as these are responsible for over 95% of Scope 1 GHG emissions. However, decarbonising shipping will undoubtedly require changes to today's commercial fleet. This presents an opportunity to explore the way we design and build ships, the materials we build them with, and what happens at the end of a vessel's operational life.

This report looks to start a discussion around the non-fuel related GHG emissions in the maritime sector and actions that can be taken to reduce them, through e.g., using materials with lower embodied GHG emissions in shipbuilding and embedding circular economy principles into the vessel lifecycle, among others.

Circularity

Fully decarbonising the shipping industry will require an understanding of circularity principles and how they can be embedded across the entire shipping value chain. The 4R material hierarchy proposed shows recycling as the least circular, as it requires the most energy to re-process, with reduce and reuse as the most circular, as they utilise the material or item in its current form. All four Rs in the material hierarchy are critical to decarbonising shipping. However, identifying ways to build ships with greater efficiency in mind – both for fuels and materials, ensuring repairability, and using more sustainable materials are all ways to embed circularity into shipping.



This report also outlines two primary ways to achieve a closed-loop system for shipping: closing a physical loop, i.e. using the same steel taken from a ship at end-of-life to build a new ship, or closing a net loop, i.e. using steel taken from a ship in another industry, while using scrap steel from other sectors to build new ships.

CLOSED-LOOP SYSTEMS

"Closed-loop systems keep products, components and materials at their highest utility and value – reducing the need for extracting and processing new resources and, in the process, cutting the related impacts on the environment" (UNGC, n.d.).

The two approaches face similar challenges in terms of material traceability and transparency. A net loop approach is ultimately preferable as it provides greater flexibility for the global shipping industry and recognises its interconnectedness with other sectors. With shipbuilding currently concentrated in East Asia and ship recycling concentrated in South Asia and Turkey, a net loop would prevent additional GHG emissions from transporting scrap steel, and furthermore allows for the scrap steel to be used locally where it may be needed more. However, the net loop faces a risk of downcycling based on current scrap sorting techniques that should be addressed through further research into optimal uses for shipping-grade scrap steel.

Steel

The steel sector is responsible for 7-9% of global GHG emissions and scrap steel – steel that has been previously produced and used, and which has come to the end of its life in that form (ArcelorMittal, n.d.) – forms a core part of the sector's material input. Scrap steel can be infinitely recycled, and shipping is a global supplier of high-quality scrap steel, highlighting the interconnectedness of the shipping and steel sectors.

Scrap steel can be infinitely recycled, and shipping is a global supplier of high-quality scrap steel, highlighting the interconnectedness of the shipping and steel sectors

Efforts to decarbonise steel are focused on production method, energy use, and material inputs (IEA, 2020) and production of steel with low and zero embodied GHG emissions is possible. However, from a sustainability perspective, it is important to look beyond GHG emissions. This report adopts the term "green steel" as referred by SteelZero: "steel that is certified as meeting the highest levels of environmental, social and governance performance (ESG), rather than only addressing the release of greenhouse gases" (SteelZero, 2022).

Using green steel for shipping is possible, though it requires a high level of quality and specific properties to be deemed seaworthy. While more work needs to be done to understand how to best produce green shipping-grade steel, we are beginning to see demand for it within the shipping sector. In the past year, shipowner A.P. Møller-Mærsk and CIMC TCREA, the steel buying division of one of the leading container manufacturers, joined SteelZero and committed to using 50% lower embodied emissions steel by 2030 (SteelZero, 2023).

Towards a decarbonised, circular industry

As shipping advances along its decarbonisation journey, the need to address embodied GHG emissions and rethink material flows is becoming more evident. When combined with broader circularity efforts, increased uptake of green steel in shipbuilding is one way to achieve decarbonisation targets across the entire value chain.

Knowledge, business models, regulation, and technology can both drive and present barriers in the transition to a decarbonised, circular industry.

BUILDING BLOCKS	DRIVING THE TRANSITION	BARRIERS TO CHANGE
Knowledge	• Shipping and steel are interconnected sectors and have the potential to impact one another's Scope 3 GHG emissions through decarbonisation efforts. In addition, scrap steel from shipping impacts steel's Scope 1 GHG emissions. It follows that both sectors would thus gain from collaboration on GHG emissions reduction. • Existing industry-led decarbonisation initiatives show that this form of collaboration is not only possible but beneficial to faster progress. • Progress on transparency and reporting points to a future where data sharing is the norm, facilitating collaboration and intra- and inter-sector understanding.	• Currently there are few incentives for well-coordinated joint efforts and cross-sectoral collaborations to explore practical ways of embedding circularity. • Poor awareness of how sustainability issues are interconnected at a global level slows down progress. • Imprecise terminology and vague targets, lead to narrow interpretations and actions.
Business model	• A track and trace system based on the verification of steel throughout the supply chain can allow for greater retention of steel within shipping, as well as more efficient use of shipping scrap steel. • Market-based measures already being discussed and developed, such as carbon pricing and a voluntary carbon market, have the potential to accelerate progress by creating financial incentives for green steel. • Climate-aligned finance agreements, such as the Poseidon Principles and the Sustainable STEEL Principles, can help lenders set GHG emissions reduction targets for their portfolios and support decarbonisation action within the steel and shipping sectors. • Investments in green hydrogen-based DRI produced using a zero and low GHG emissions energy source can increase the global supply of green steel.	• End-of-life vessels are priced according to the global scrap steel market, without consideration for the onward uptake of green steel. • Shipping-grade scrap steel is often used for lower-quality applications local to the ship recycling facilities resulting in loss of value. • Lack of scrap steel availability presents a significant barrier to producing green steel and eventual uptake in shipping.
Regulation	• The EU is leading the way on carbon pricing through the EU ETS, which will include both steel and shipping and motivate action to decarbonise both sectors. A carbon price set by the IMO would similarly encourage rapid action on decarbonisation. • Reducing unnecessary trade flows can also increase circularity and additional research should be done to identify the most efficient way to use scrap steel globally. • Cooperation among governments and Green Public Procurement (GPP) policies can create avenues for an efficient flow of materials and harmonise procurement frameworks.	• Shipping and ship recycling regulation lacks references to a circular economy, limiting understanding and action from shipping stakeholders. • Lack of harmonised international and national regulations may inhibit the transition to circularity by adding complexity and uncertainty when different approaches, requirements, and standards are in force along the steel value chain.
Technology	• Improving traceability of steel across a ship's lifecycle through e.g., the implementation of standardised frameworks and material, passports can be a key driver to uptake of green steel for shipping. Data sharing and cross-sectoral collaborative efforts are needed to show this is possible. • Digital technologies can offer solutions for greater traceability and visibility of the steel value chain and allow for the verification of GHG emissions savings and sustainability benefits associated with green steel.	• Low market demand for ships designed for circularity. • Traceability of steel can be inhibited by complex value chains and the presence of multiple actors, which can make it challenging to obtain and maintain accurate and comprehensive data. • Lack of a standardised frameworks for developing and implementing tracing systems and material passports.

Introduction

Mitigating the climate crisis requires dramatic reductions in greenhouse gas (GHG) emissions and an effort from all industries to move to zero emissions. In the shipping sector, fuel combustion is currently responsible for over 95% of a ship's Scope 1 GHG emissions, and as such this is the area where emission reduction efforts are concentrated today. However, the industry's decarbonisation is expected to shift this balance, leading to GHG emissions embodied in components and materials, building, and recycling taking up a larger share of a vessel's total lifecycle emissions.

This report is part of the start of a discussion around the non-fuel related GHG emissions

This report is part of the start of a discussion around the non-fuel related GHG emissions in the maritime sector and action that can be taken to reduce them, through e.g., using materials with lower embodied GHG emissions in shipbuilding and embedding circular economy principles into the vessel lifecycle, among others.

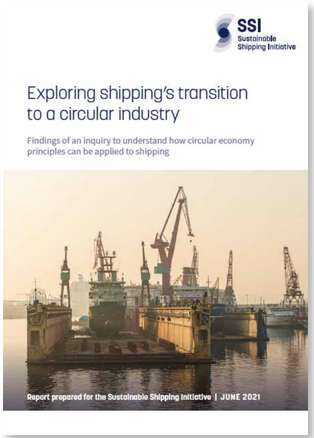
EMBODIED EMISSIONS

Embodied emissions (also referred to as embedded emissions) refer to "GHG emissions generated during the production and transportation of goods, from the extraction of raw materials to the manufacturing process and final delivery" (E3G, 2023).

Circularity in shipping

A CIRCULAR ECONOMY

A circular economy is “an economy that is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. As a result, the economy is restorative and regenerative by design” (Ellen MacArthur Foundation, n.d.).



Download SSI’s report *Exploring shipping’s transition to a circular industry*

Adopting circularity principles in shipping will be necessary in order to fully decarbonise the sector. By embedding concepts, such as designing for recycling, reducing resource use, increasing repairability of components, and extending the lifecycle of a vessel, the sector can address sources of GHG emissions beyond fuel, which will ensure that shipping decarbonises more sustainably.

SSI’s 2021 report on *Exploring shipping’s transition to a circular industry* identified opportunities and barriers for moving toward greater circularity, with a focus on steel as the primary material used in shipbuilding. The research yielded three conclusions:

1. Accelerating trends and patterns in both shipping and ship recycling set the scene for a transition to a circular shipping industry.

2. Circular economy principles should be built into every stage of the ship lifecycle – from design to construction; to operations and recycling.

3. Global regulation and multi-stakeholder collaboration are essential to realise the transition to a circular shipping industry.

Steel in shipping

For shipping, steel is a key source of Scope 3 GHG emissions as it is a significant source of embodied emissions on a vessel

Steel is responsible for 7-9% of GHG emissions globally, with current production methods requiring high amounts of energy. For shipping, steel is a key source of Scope 3 GHG emissions as it is a significant source of embodied emissions on a vessel. In addition to this, steel is also used for containers and port infrastructure, though this report is limited to steel in shipbuilding. This makes shipping one of many demand sectors for steel, with the International Energy Agency (IEA) estimating that all transport modes make up approximately 16% of steel demand globally, with the majority of that going to the automotive sector (IEA, 2022). Even though shipping is not considered to be a big steel demand sector globally, steel constitutes a large fraction of the material flows for shipping.

Steel makes up 75-85% of a vessel by weight, making it the clear priority when we discuss material flows in shipping (SSI, 2021). However, steel does not occupy just one spot along the shipping value chain. Instead, it is deeply intertwined across a network of stakeholders and activities that should be acknowledged and included in identifying and implementing solutions that addresses steel in shipbuilding.

Figure 2 (see following page) illustrates a simplified value chain for steel in shipping alongside the network of stakeholders for each step in the value chain, with a focus on the vessel.

VALUE CHAIN FOR STEEL IN SHIPPING

Once produced, steel is certified by a classification society and purchased by a yard to be used for shipbuilding. The ship is then owned and operated by one or several shipowners for up to 30 years. At end-of-life (EOL), a ship is sold to a recycling yard often by way of an intermediary (e.g., a cash buyer), and the recycling yard will dismantle the ship and sell the steel and components on for melting or further use. There are multiple interactions in material flows, information dissemination, transactions, and regulatory oversight between the stakeholders along the steel value chain in shipping.

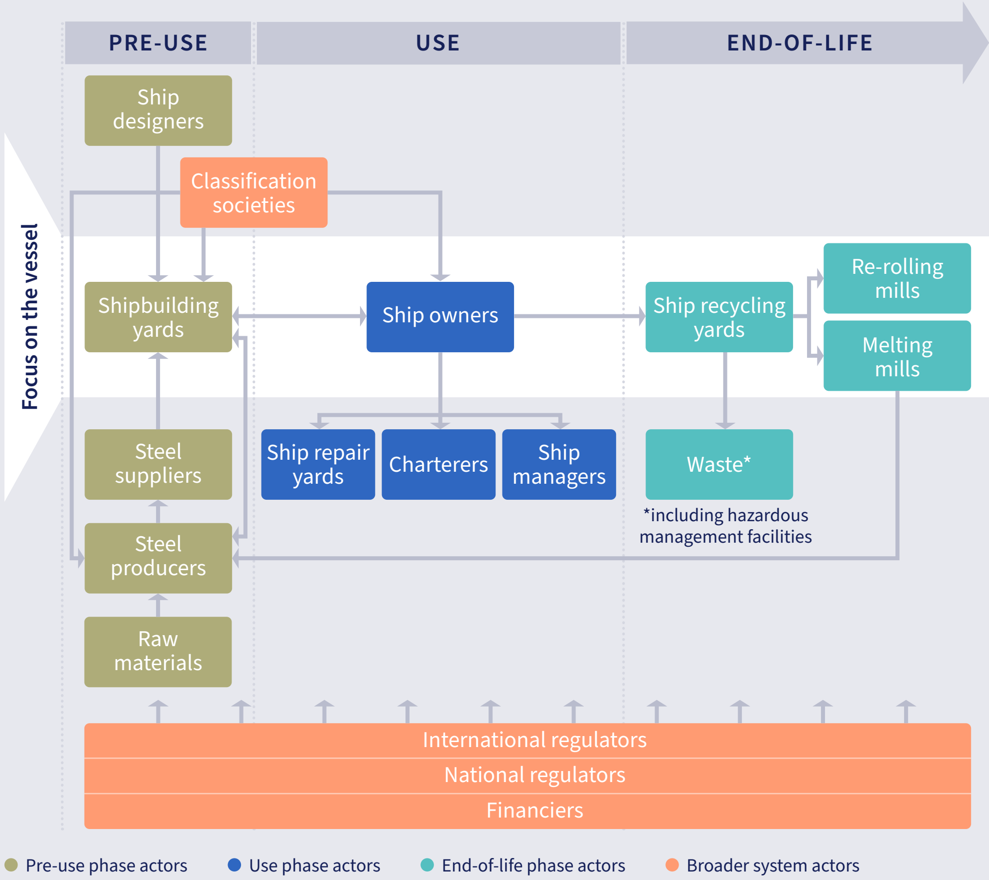


FIGURE 2

Value chain of steel in the shipping industry. The arrows in the figure signify interactions in material flows, information dissemination, transactions, and regulatory oversight

Some key stakeholders and their interactions:

- Classification societies interact with ship designers and shipbuilders to provide technical expertise and regulatory compliance assessments during the design and building process.
- Shipbuilders work with steel producers and suppliers to select the steel, specifying their requirements including desired grade, quantity, etc. After the selection process, the steel producers provide relevant documentation to verify that the steel meets the required specifications and standards.
- Shipowners collaborate with the shipbuilding yard to specify design requirements for the ship and can be involved in the steel selection process. While rare, charterers could also play a role in this process by setting specific requirements regarding the materials used in the construction of the ship they charter.
- Ship repair yards maintain, repair, and replace the steel components as needed and work with classification societies to ensure compliance with regulatory and classification standards. Ship repair yards also procure new steel products.
- Ship recycling yards buy a ship (often through an intermediary) based on, among others, the quantity and quality of steel available. Specifications, such as the grade and type of steel used in the ship's construction, are also considered in the purchasing process as different steel grades can have varying market values. While shipping is a supplier of desirable scrap steel due to its quality, SSI's 2021 report found that much of shipping's steel is currently recycled and used in other sectors.

Creating a sustainable shipping industry

Reducing material demand and consumption is always preferable

As shipping advances along its decarbonisation journey, the need to rethink the lifecycle of steel in shipping and address embodied GHG emissions is becoming more evident. Using steel with lower embodied GHG emissions in shipbuilding is one way to achieve decarbonisation targets. Reducing material demand and consumption is, however, always preferable, and a key part of the discussion should therefore be focused on ways to optimise material flows, through:

- Focusing on reducing material use through innovative ship design and shipbuilding.
- Ensuring that parts can be easily repaired or replaced, extending the lifetime of a vessel.
- Improving traceability of materials to maximise value at end-of-life, ensuring that materials can more easily be removed and reused, repaired, or recycled.

Other aspects of sustainability must also be taken into account. For example, current ship recycling practices, though improving, still encounter challenges related to environmental pollution and labour rights. Considering environmental, social, and socioeconomic sustainability principles, as well as governance issues in shipping, is critical to building a sustainable shipping industry for future generations.

GREEN STEEL

In this report green steel is considered to be “steel that is certified as meeting the highest levels of environmental, social and governance performance (ESG), rather than only addressing the release of greenhouse gases” (as referred to by SteelZero, 2022).

However, it should be noted that there are multiple terms and definitions used in the steel sector that refer to lower GHG emissions steel, usually not taking into consideration broader sustainability consideration. This lack of harmonised terminology can hinder progress and a term such as ‘sustainable steel’, based on clear GHG emissions reduction thresholds that take into account environmental, social, and socioeconomic sustainability aspects has the potential to offer a more holistic definition that unites stakeholders.

Report aims and structure

This report aims to inform the maritime sector around pathways to increased circularity in shipping by exploring the concepts of a net loop and physical loop. The report then dives into the topic of steel, covering current developments in steel decarbonisation and how they may be relevant to shipping, including the topic of green steel in shipbuilding and shipping as a source of high-quality scrap steel.

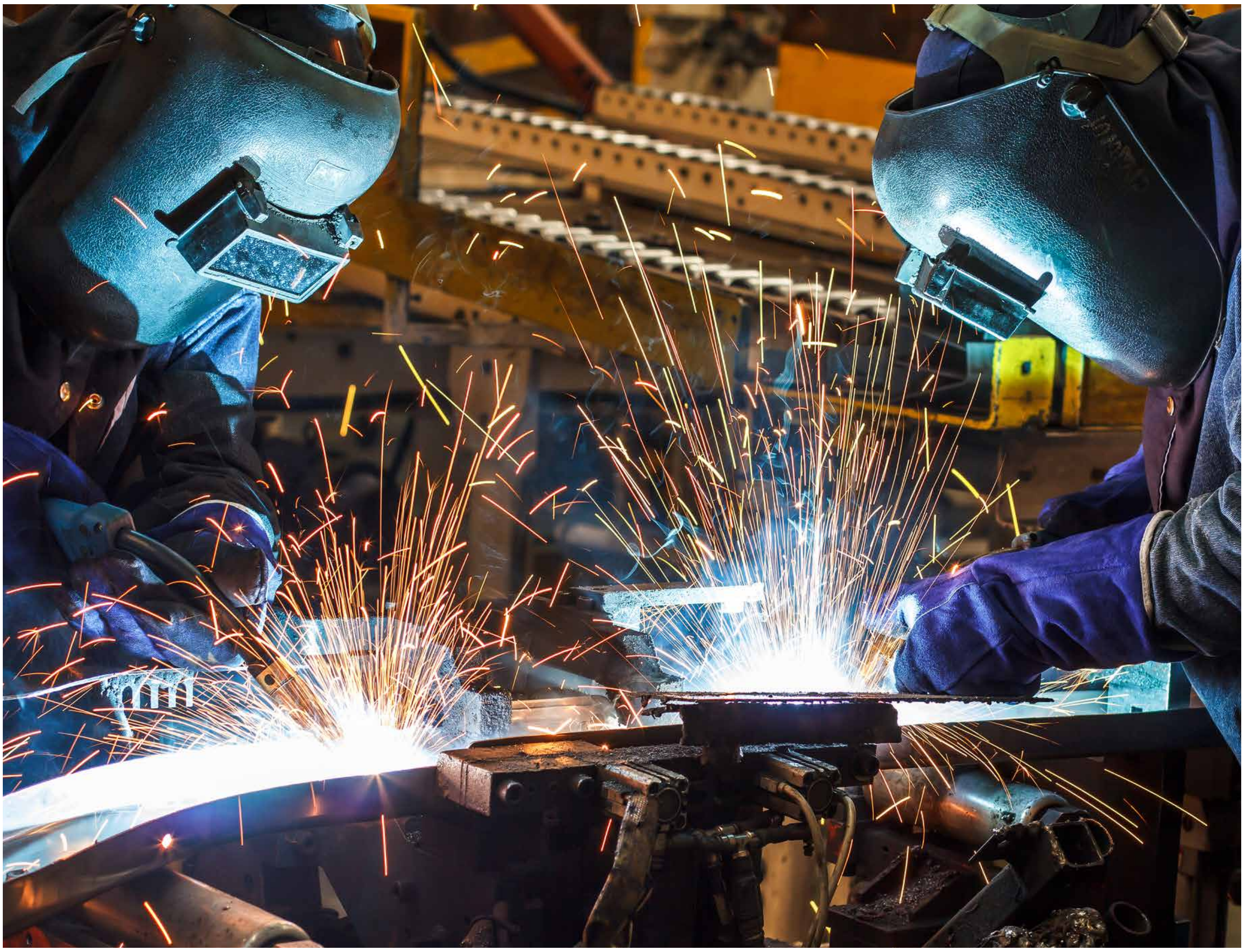
Finally, the report discusses the drivers and current barriers to increased circularity through steel material flows across the four categories identified in SSI’s 2021 report: Knowledge, Business models, Regulation, and Technology.

Circularity in shipping

For the shipping industry, which already sees a large percentage of recycling at end-of-life (EOL) (approximatively 95% of a ship is recycled at EOL) (SSI, 2021), moving towards a more circular economy means shifting from material recycling towards higher steps in the material hierarchy – from refurbishing to reusing, to reducing (see the the 4R model on the following page).

A 'cradle-to-cradle' framework would be adopted in a fully circular world

In a fully circular world, all components and materials of a product that reaches its EOL would feed into the making of another product – this is referred to as a 'cradle-to-cradle' framework. Working toward this ideal is one way to maximise circularity and consider how each material and component can best be eliminated from the material flow (reduced), reused, or remanufactured for other uses, and ultimately recycled into something else entirely.



THE 4R MODEL FOR SHIPPING

Material hierarchies are developed to operationalise the concept of a circular economy. In SSI's 2021 report *Exploring shipping's transition to a circular industry*, we proposed a 4R model for shipping (from the bottom up): Recycle, Refurbish, Reuse, and Reduce.

When considering the 4R model, the most circular action we can take is to reduce the amount of material used

When considering the 4R model, the most circular action we can take is to reduce the amount of material used. It is therefore important to acknowledge that there is a need to reduce material demand and consumption in order to build a truly circular and sustainable shipping sector.

Identifying ways to build ships more sustainably, use green steel, and recycle well at end-of-life does not replace the need for broader societal and industrial shifts in the amount we produce, use, and thus need to recycle.

Circular

INCREASING CIRCULARITY

REDUCE	**Refuse**	Make a product or component redundant, either by abandoning its function or by fulfilling the same function in a different manner
	Reduce	Consume fewer natural resources and materials during production to achieve the same outcome, therefore increasing resource efficiency
REUSE	**Reuse**	Reuse a discarded product which remains in good condition and fulfils its original function
	Repair	Repair and maintain a defective product so it can perform its original function
	Restore	Restore an old product to bring it up to date
REFURBISH	**Remanufacture**	Use parts of a discarded product in a new product with the same function
	Repurpose	Use a discarded product or its parts in a new product with a different function
RECYCLE	**Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	Recover	Incineration of materials with energy recovery

Linear

FIGURE 3

The 4R Hierarchy from recycling to reducing material use. Developed by 2BHonest for SSI (2021)

To facilitate the uptake of circularity within the shipping sector we look at the concept of "closing the loop".

CLOSED-LOOP SYSTEM

This report adopts UNGC's definition of a closed-loop system as a system that "keep[s] products, components and materials at their highest utility and value – reducing the need for extracting and processing new resources and, in the process, cutting the related impacts on the environment." (UNGC, n.d.).

This report proposes two primary ways of closing the loop in shipping, shown in Figure 4.

- Closing the **physical loop**, which would entail a physical connection in material flows between shipbuilding and recycling (i.e. the same steel taken from a ship at end-of-life is used to build a new ship).
- Closing the **net loop**, which would entail a virtual connection in material flows between shipbuilding and ship recycling (i.e. a steel taken from a ship at end-of-life goes into another industry, while scrap steel used for shipbuilding came from another sector, e.g., construction).

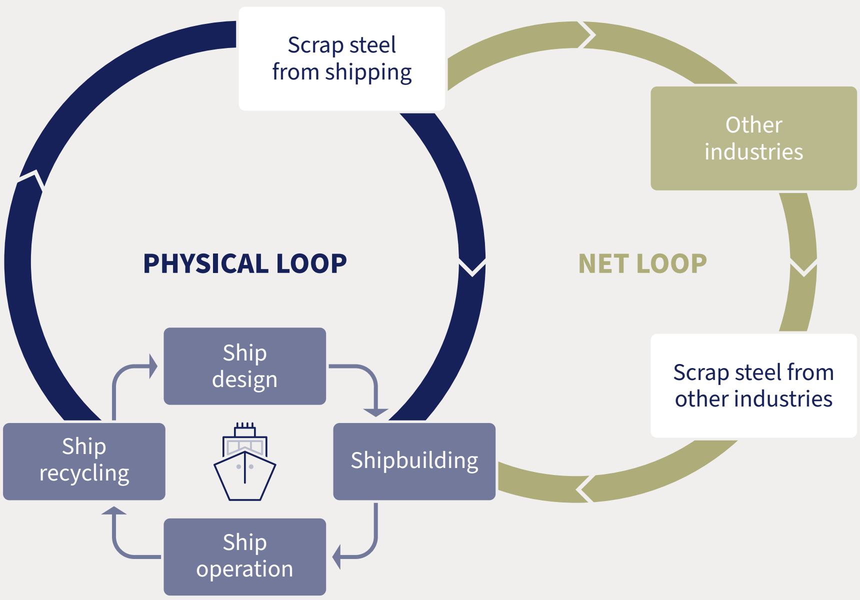


FIGURE 4

The physical and net loops

Closing the physical loop

One can visualise it simply as breaking down a vessel at its end-of-life and rebuilding it again from its own re-processed scrap steel, creating a 100% recycled ship

Closing the physical loop for shipping entails recycling all physical materials used in shipping back into the industry. As such, all materials in a ship are retained in the shipping loop and remade into other ships. One can visualise it simply as breaking down a vessel at its end-of-life and rebuilding it again from its own re-processed scrap steel, creating a 100% recycled ship.

While closing the physical loop is the simplest form of circularity, as it would mean recirculating the same materials within the shipping sector, it is not the easiest to put into practice.

Fully closing the physical loop is difficult for a number of reasons, including:

- Some scrap steel is lost in each recycling process, meaning scrap steel would need to be supplemented from outside the loop.
- The current geography of the shipping sector, as ship recycling takes place primarily in South Asia (India, Bangladesh, Pakistan) and Turkey and shipbuilding takes place primarily in East Asia (China, Japan, South Korea). Moving scrap steel from one to another would entail additional costs and GHG emissions that could offset the benefits of closing the physical loop.
- The current lack of traceability of materials and components across a vessel's lifecycle. Without this, it is not feasible to build a closed-loop system. Advances in traceability are, however, taking place and discussed in further detail in the drivers and barriers section of this report.

Closing the net loop

Closing the net loop allows materials to be used for other applications where preferable

A different approach is closing the net loop. Closing the net loop acknowledges that shipping does not exist in isolation, but instead is part of a much broader system of material consumption. This is more realistic, as it allows materials to be used for other applications where preferable. In some cases, other sectors may have a greater need for scrap steel, or it may be beneficial due to geographic location (e.g., where there is an opportunity to recycle and reuse the steel locally, eliminating the need for additional transport). In addition, as the shipping sector constitutes only a relatively small proportion of the global steel demand (all transport sectors constitute approximately 16% of steel demand globally, with the majority of that going to the automotive sector), a net loop would be a more feasible alternative when compared to keeping the fraction of steel recycled from ships in the shipping sector in a physical loop.

Similarly to the physical loop, closing the net loop comes with its own set of challenges:

- The current end-of-life model for vessels contributes to a net loop approach by selling ship scrap steel for use in other sectors. However, most scrap sorting techniques treat all scrap steel the same, regardless of origin, which can pose a barrier to the production of scrap-based, higher steel grades, such as for shipping. It is thus necessary to work further to understand demand sectors for this scrap steel, and the best ways to incentivise optimising its use.
- A lack of traceability and transparency remains a key concern, as closing the net loop would require clear assurance mechanisms to be in place.
- Closing the net loop requires collaboration across industries, with steel producers and other steel demand sectors.

From a sustainability perspective, closing the physical loop presents more of a challenge

From a sustainability perspective, closing the physical loop presents more of a challenge, as it would require additional efforts and potential added GHG emissions from e.g., transport, without significant added value compared to a net loop approach. If the traceability and sorting challenges can be addressed, closing the net loop thus presents an attractive option for building a more circular – and sustainable – shipping industry.

Steel

The steel sector is one of the top GHG emitters globally, contributing between 7% and 9% of global GHG emissions (World Steel Association, 2021) and 28% of global industrial emissions (SBTi, n.d.). In addition to this, steel makes up 75-85% of a vessel by weight, making it a critical factor to address when looking at shipping's Scope 3 GHG emissions, and steel recovered at a ship's end-of-life is considered high-quality and desirable scrap steel.

Steel recovered at a ship's end-of-life is considered high-quality and desirable scrap steel

There are synergies to be explored between both the steel and the shipping sector as they work to decrease GHG emissions and incorporate social, environmental, and socioeconomic sustainability elements into their operations.

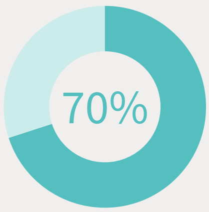
This section explores steel production methods, as well as actions taken and technologies developed to decarbonise the steel sector, followed by a discussion on the role of shipping as both a demand sector for green steel and a supply sector for scrap steel.

Steel production and decarbonisation

Steel is produced via two main routes: blast furnace-basic oxygen furnace (BF-BOF), which primarily uses iron ore, coke, and limestone as inputs, and electrical steelmaking through electric arc furnace (EAF), which predominantly uses scrap steel or direct reduced iron (DRI) and electricity (EUROFER, n.d.). All steel production uses scrap steel, up to 30% in the BF-BOF and up to 100% in the EAF (World Steel Association, 2023).

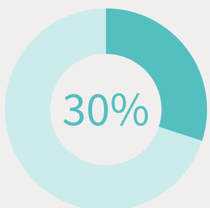
GHG emissions from steel production are primarily derived from the energy inputs required to power the furnaces, as well as the iron ore reducing agents used in the BF-BOF method, which are most commonly coking coal or pulverised coal, oil, natural gas or a combination of these. Nearly 90% of BF-BOF energy comes from coal (World Steel Association, 2021). EAF, by comparison, is powered by electricity, which may be derived fully, or in part, from national grids (and thus, related GHG emissions depend on the location of the steel plant and the energy mix available, as well as grid capacity), or may be produced on-site from a variety of sources, including fossil fuels such as coal and natural gas (RMI, 2019).

Blast furnace-basic oxygen furnace (BF-BOF) is currently the most common method for steelmaking, responsible for 70% of current steel production. It is the most energy-intensive method and involves the mining of virgin iron ore, coal, and limestone, all of which present environmental and social sustainability concerns. In addition, it requires the use of iron ore reducing agents. This method is associated with high GHG emissions and other emissions to air including mercury and persistent organic pollutants (IEA, 2020).



BF-BOF method: 70% of current steel production

Electric arc furnace (EAF) produces around 30% of steel today, and is reliant on electricity, so its GHG emissions may be dependent on the local energy mix. The main material inputs can be scrap steel and direct reduced iron (DRI). While considered less GHG emissions-intensive when compared with BF-BOF, this method is still associated with other emissions to air including mercury and persistent organic pollutants.



EAF method: 30% of current steel production

EFFORTS TO DECARBONISE STEEL

Production method and energy use

One option for decarbonising the steel sector is increasing the proportion of steel produced using the EAF method, which combined with a zero and low GHG emissions energy source could address the bulk of GHG emissions. However, switching from BF-BOF to EAF production is not always feasible, as the two methods use different material inputs and high-quality steel is currently produced primarily via the BF-BOF method.

Zero and low GHG emissions energy sources to power the production process are also an option to reduce emissions, and stop-gap measures such as carbon capture and utilisation (CCU) and carbon capture, utilisation, and storage (CCUS) are also being considered (IEA, 2020).

Material input

One key challenge is the need for reducing agents to reduce iron ore to iron in the BF-BOF process or to create DRI for use with EAF. Options being explored to reduce iron ore while reducing or eliminating GHG emissions include biogenic carbon sources and hydrogen produced with zero and low carbon energy sources.

In addition to this, the industry is also exploring increasing the use of scrap steel as a material input in both BF-BOF and EAF. EAF production can use up to 100% scrap steel, which combined with a zero or low GHG emission energy source can be a low emission production method. It can also be supplemented with green hydrogen-based DRI if sufficient scrap is not available.

The role of scrap steel in decarbonising the steel sector

The World Steel Association (2023) estimates that every tonne of scrap steel used for steel production avoids 1.5 tonnes of CO_2 emissions, as well as considerable quantities of raw material. Increased use of scrap steel thus presents an opportunity to reduce emissions from steelmaking.

Increasing the use of scrap steel alone without decarbonising the production processes is not sufficient to align the steel sector with a 1.5°C trajectory

Much like shipping, there is not one silver bullet to decarbonise the steel sector. Increasing the use of scrap steel alone without decarbonising the production processes is not sufficient to align the steel sector with a 1.5°C trajectory. In addition to this, scrap steel availability today is roughly 400 Mt, expected to grow to 900 Mt by 2050, falling significantly short of current demand, which sits at approximatively 1800 Mt (World Steel Association, 2023).

Even with increased scrap steel availability, the Mission Possible Partnership estimates that 60% of global demand will still be met by BF-BOF production in 2050, unless there are major material or circularity breakthroughs (Mission Possible Partnership, 2022).

SHIPPING AS A SOURCE OF HIGH-QUALITY SCRAP STEEL

Steel from ships is usually obtained by breaking a ship up into several different parts before breaking them down further. Through this process, most steel is sorted based on thickness, quality, and other properties. The scrap steel from ships is typically cut into plates or shredded into small pieces at the recycling yard and distributed to traders, who later sell the scrap steel again to steel mills, re-rollers, and other industries. The steel mills will usually pool the ship scrap steel with scrap steel from other sources and melt them together for further processing.

Shipping steel is originally of high-quality, some possessing high tensile strength and yield strength which can be recycled into products with high-quality applications. Shipping grade scrap steel is desirable as its higher quality makes it easier to reuse without much processing (Climate Group, 2023). Nevertheless, some processing is required due to surface corrosion and contamination.

Green steel

It is necessary to look beyond GHG emissions reduction to ensure a sustainable decarbonisation for any sector. Environmental issues, such as air pollution and biodiversity; social issues, like workers' rights and a just and equitable transition; and socioeconomic issues, like food security all need to be considered to ensure a sustainable and successful transition.

The steel sector currently lacks clarity around terminology, leading to a variety of terms that describe zero or near zero GHG emissions steel products and production, each with its own emissions calculation methodologies and thresholds (IEA , 2023). Terms range from 'low carbon' to 'net-zero', 'green', 'fossil free' and 'zero carbon' (IEA, 2023; Global Efficiency Intelligence, 2023). In order to align the steel sector to a 1.5°C pathway, the Science-Based Targets initiative (SBTi) is developing a target-setting guidance for the steel sector (SBTi, n.d.).

It is important to note that terms like 'green' and 'sustainable' should actively take other sustainability considerations and criteria into account. A term such as 'sustainable steel', based on clear GHG emissions reduction thresholds that considers environmental, social, and socioeconomic sustainability aspects has the potential to be a more holistic definition that unites stakeholders. However, as such a term has not yet been defined, this report adopts the term 'green steel' as referred to by SteelZero, an initiative of the Climate Group in partnership with ResponsibleSteel that focuses on driving demand for net-zero steel by improving dialogue between steel producers and customers.

GREEN STEEL

Green steel is "steel that is certified as meeting the highest levels of environmental, social and governance performance (ESG), rather than only addressing the release of greenhouse gases" (as referred to by SteelZero, 2022).

Green steel for shipping

Steel used for shipbuilding is required to possess a certain level of quality and specific properties in order to withstand the load from their hulls and cargo and to secure and promote seaworthiness. These are mandated by International Maritime Organization (IMO) conventions and regulations, requirements of the International Association of Classification Societies (IACS), and the rules and regulations of individual classification societies[1] and include chemical compositions, physical and mechanical proprieties, and heat treatment to name a few. Steel used in shipbuilding must be approved by a classification society based on engineering applications in general, as well as the mechanical and chemical properties.

Steel used in shipbuilding must be approved by a classification society

Due to the long lifetime and harsh conditions faced by vessels, as well as the need for strict safety considerations, stakeholders in shipping are primarily concerned with the technical requirements and quality of steel rather than the production process or material input. However, due to quality concerns with steel that has a high percentage of recycled content, most steel for shipping is currently produced using BF-BOF.

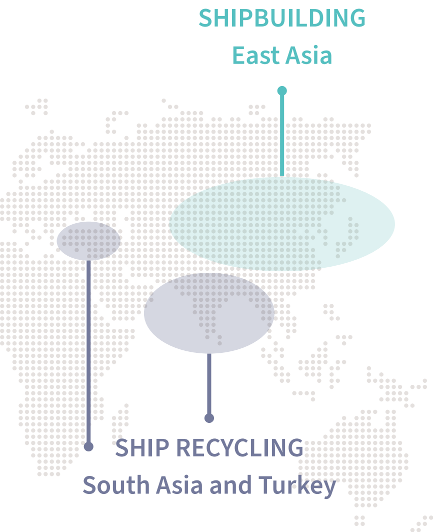
Challenges associated with controlling impurities when producing steel from scrap steel may impact the end product and disqualify scrap-based green steel from high-grade applications (RMI, 2019). This is due to the source of the scrap steel input – if the quality of scrap steel is sufficiently high, it is possible to produce shipping-grade steel from a scrap-based EAF production method. It should however be highlighted that green hydrogen-based DRI EAF production would not present the same quality concerns, which may allow for green steel for shipping to be produced using this method. However, green hydrogen DRI production has its own challenges as it relies on high quality iron ore which is not universally available.

Although green steel is a new area for shipping, some demand for green steel is beginning to appear in the sector, with shipowner A.P. Møller-Mærsk and CIMC TCREA, the steel buying division of one of the leading container manufacturers, joining SteelZero and committing to using 50% lower embodied emissions steel by 2030 and setting a clear pathway to 100% net zero steel (SteelZero, 2023).

[1] The classification society rules for materials specify the permitted manufacturing methods, chemical compositions, and mechanical properties for a range of steel grades. In addition, the weldability and application-specific properties may also be defined. The grade of steel selected for each specific application on a ship depends on the suitability of its properties. For example, higher strength grades are used for some hull construction but are more often used for other specific applications such as hatch coamings on container ships (Lloyd's Register, 2022).

Closing the steel loop in shipping

Closing the loop on steel at a global level requires exploring two critical steps in the ship lifecycle: shipbuilding and ship recycling, and their global distributions.



Approximately 95% of all ships in 2021 were built in three countries in East Asia: China, Japan and South Korea (UNCTAD, 2022). In these countries shipbuilding can demand a high proportion of national steel production. For example, shipbuilding was one of the three largest customers of steel in Korea, demanding almost 20% of the national steel production in 2019 (SFOC, 2022).

Ship recycling, conversely, takes place primarily in South Asia (India, Bangladesh and Pakistan) as well as Turkey. At the end of a ship's operational life, it is sold to a ship recycling yard where valuable components, such as the main engine and propellers, are extracted and the steel hull is cut into metal plates that can be re-rolled or melted (Sornn-Friese, *et al*., 2021). In some cases, steel plates from recycling can also be sold to shipbuilders to be used for ship repairs or for building small vessels (Sarraf, *et al*., 2010).

Closing the steel loop in shipping requires close collaboration between actors across the shipping value chain, from steel mills to shipbuilders to ship recyclers. Where all these actors are in the same region, e.g., China, it would be possible to close the physical loop at a smaller scale. However, at a larger scale systemic shifts are required across the areas of knowledge and awareness raising; business model innovation; regulation; and technology.

Drivers and barriers of circularity in shipping and steel

SSI's 2021, *Exploring shipping's transition to a circular industry*, report identified four main building blocks to a circular shipping industry, as follows:

1. **Knowledge**: Generating awareness, knowledge, and a willingness to apply the concept of circular economy to shipping.

2. **Business model**: Developing business and finance models to support the need for cost-efficient solutions.

3. **Regulation**: Connecting regulatory forces at all levels to enable a regulatory framework that fits the global nature of the industry while mitigating adverse social and environmental impacts.

4. **Technology**: Understanding how decarbonisation, closed loop infrastructure, and value capture along the supply chain can support the transition needed.

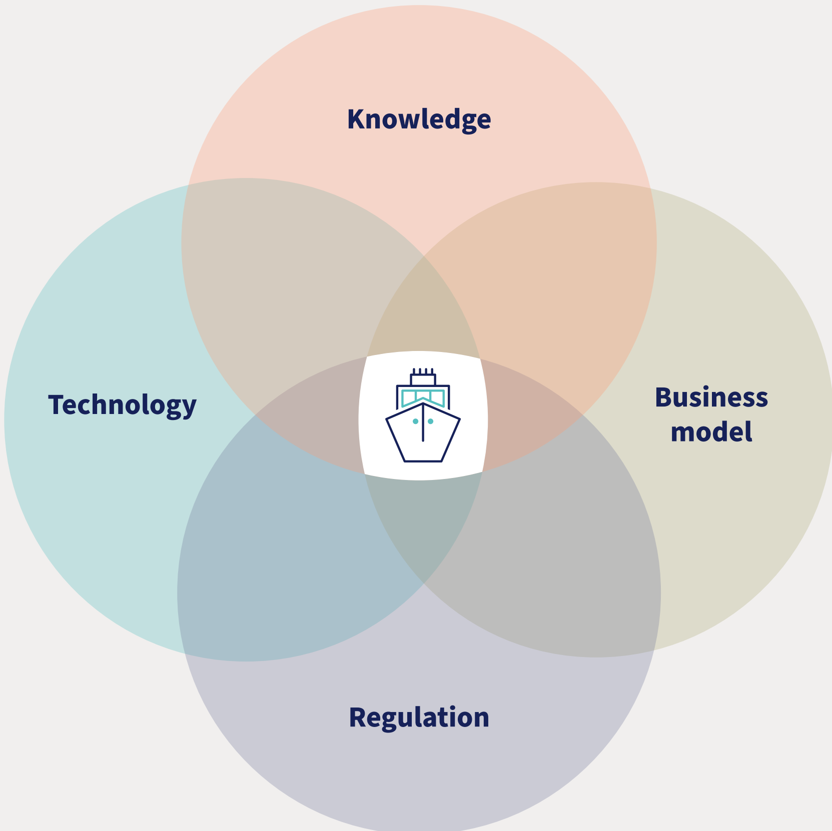


FIGURE 5

Building blocks of a circular shipping industry. Developed by 2BHonest

This section will explore several existing and potential drivers and barriers of circularity in shipping and steel, according to these four categories.

KNOWLEDGE

Inter- and intra-sectoral collaboration

Shipping is responsible for 3% of global GHG emissions, and steel is responsible for 7-9%. As both sectors work to decarbonise, there is a key opportunity for the steel and shipping sectors to work together to address their Scope 1 and Scope 3 GHG emissions.

Decarbonisation has been an area of collaboration in previous years, with a significant increase in the number of initiatives that bring together stakeholders across the sector to work on solutions to the challenges presented by the energy transition. Successful examples of this are the Getting to Zero Coalition, the Mærsk McKinney Møller Center for Zero Carbon Shipping, the Mission Possible Partnership, the Silk Alliance led by the Lloyd's Register Maritime Decarbonisation Hub, and the Poseidon Principles. It is thus reasonable to imagine similar examples appearing to tackle the challenge of shipping and steel.

Cross-sectoral initiatives, such as The Climate Group's SteelZero, are already in place. SteelZero works collaboratively to improve dialogue between steel producers and customers like shipping, aiming to understand the action that can be taken to build demand for green steel. Companies that join SteelZero commit to procuring, stocking or specifying 50% "low embodied carbon steel" by 2030, on a pathway to 100% "net zero steel" by 2050 (SteelZero, 2023).

Companies that join SteelZero commit to procuring, stocking or specifying 50% "low embodied carbon steel" by 2030

Additionally, as shipping is one of a group of key industries procuring steel globally, there are clear benefits to working with other sectors such as automotive and renewable energy infrastructure to identify possible ways forward. The Circular Cars Initiative, to give an example from the automotive sector, is a collaboration between the World Economic Forum and the World Business Council for Sustainable Development which aims to bring together stakeholders in the automotive ecosystem to address the challenge of curbing GHG emissions related to the manufacturing process (WEF, n.d.).

Successful collaboration, within and beyond the shipping sector, is built on knowledge sharing and transparency, ensuring that decision-making is based on accurate and equal information. Industry initiatives such as the Ship Recycling Transparency Initiative, the Poseidon Principles, and the Sea Cargo Charter focus on the voluntary collection and sharing of data. However, regulation is quickly catching up and widespread sustainability reporting requirements are on the horizon (for example, the EU's Corporate Sustainability Reporting Directive), hinting at a future where transparency is the norm.

Aligning on terminology

Decarbonisation has required everyone to learn a new language – zero, net zero, near zero, low and/or zero, carbon, emissions, GHG, etc. This is the case for both shipping and steel, and if both sectors do not align on terminology and what this means for overall decarbonisation targets, then this has the potential to create barriers to progress.

This report discussed some of the terminology used in the steel sector and the importance of using a term that incorporates more than GHG emissions reduction and considers other sustainability impacts, such as green or sustainable steel. Similar discussions have taken place in shipping, with the recent rise in the term 'sustainable marine fuels' part of an effort to bring more than GHG emissions to the discussion.

However, there is still fragmentation across industry segments and levels of ambition. To ensure a high level of ambition, as well as consideration of sustainability, alignment on terminology can be both a key driver and barrier.

FIGURE 6

Drivers and Barriers relating to the *Knowledge* building block

DRIVERS	• Shipping and steel are interconnected sectors and have the potential to impact one another's Scope 3 GHG emissions through decarbonisation efforts. In addition, scrap steel from shipping impacts steel's Scope 1 GHG emissions. It follows that both sectors would thus gain from collaboration on GHG emissions reduction. • Existing industry-led decarbonisation initiatives show that this form of collaboration is not only possible but beneficial to faster progress. • Progress on transparency and reporting points to a future where data sharing is the norm, facilitating collaboration and intra- and inter-sector understanding.
BARRIERS	• Currently there are few incentives for well-coordinated joint efforts and cross-sectoral collaborations to explore practical ways of embedding circularity. • Poor awareness of how sustainability issues are interconnected at a global level slows down progress. • Imprecise terminology and vague targets, lead to narrow interpretations and actions.

BUSINESS MODEL

Current end-of-life models

The current business model for ship recycling incentivises steel to be repurposed or recycled in the regions where recycling takes place, with the steel being used locally. Due to the high-quality nature of shipping scrap steel, the current business model for ship recycling could imply that this goes towards lower-quality steel production. In addition to this, end-of-life vessels are currently priced according to the global scrap steel market (SSI, 2021), without consideration for the use of green steel. Without a change to this business model, shipowners are not incentivised to demand the more expensive green steel, as its value will not be retained beyond the 30-year lifespan of one vessel.

At the same time, significant percentages of steel from ships are already recycled, contributing to a net closed loop as the steel is used in other sectors. While this does not contribute to a closed loop within shipping, if the sector were to adopt an approach based on tracking and verification of steel, it would allow for a more efficient use of shipping scrap steel. In addition to this, there is the possibility to extend tracking and verification beyond GHG emissions and to other sustainability benefits across environmental, social, and socioeconomic factors.

It should nevertheless be noted that current ship recycling practices can pose several environmental, societal, and safety issues including environmental pollution, poor worker health and safety, poor labour conditions, low wages, and exploitation of workers. In order for steel recycling at end-of-life to be sustainable, these risks and challenges must be addressed.

Green steel in shipping

Incentivising the use of green steel in shipping is critical to driving up demand

Incentivising the use of green steel in shipping is critical to driving up demand, which in turn will incentivise steel producers to increase green steel production. As shipowners begin to understand and explore ways to reduce their Scope 3 GHG emissions, there is an expectation that interest in green steel will increase.

Thus, developing ways to make this shift feasible is important to ensuring that steel suppliers can meet demand. This may be in the form of regulatory mechanisms such as market-based measures, which could, for example, establish a carbon price that disincentivises investment in traditional steel production and instead favours green steel production. Similarly, a voluntary market for carbon credits could incentivise actors to produce and purchase green steel, and the revenue from the sale of these credits can be reinvested into technologies and projects supporting the transition (Blaufelder, *et al*., 2020).

The availability of scrap steel is an unavoidable barrier to a green steel future, as the current supply of scrap steel is not sufficient to meet demand

The availability of scrap steel is an unavoidable barrier to a green steel future, as the current supply of scrap steel is not sufficient to meet demand. According to the World Steel Association (2022), current scrap steel availability (around 400 Mt) falls short of current global steel demand (1800 Mt), and this is only expected to increase to 900 Mt by 2050. In addition to this, steel products have a long lifecycle, and it can be decades until steel re-enters value chains as scrap steel. Developing business models, that ensure scrap steel value is maximised, is thus critical to optimising scrap steel value chains. At the same time, investments should be made in green-hydrogen based DRI produced using a zero and low GHG emissions energy source, to ensure a global supply of green steel regardless of production method.

Furthermore, while in theory it is possible to produce shipping-grade steel based on scrap-based EAF production, the issue remains that the quality of the scrap steel needs to be high enough to produce high-quality steel. Nonetheless, as highlighted in previous sections, DRI-based EAF production could not present the same quality concerns, which allows for green steel for shipping to be produced using this method. In both cases, further research and guidance are needed at the classification society level to understand how shipping-grade steel can meet class requirements.

The role of the finance sector

A major driver for shifting to sustainable materials and circularity can come from the financial sector, which can bridge consumer demands and market trends with sustainability standards. One example comes from the Poseidon Principles, which provide a framework for integrating climate-related factors into lending decisions. In the steel sector, a similar framework was introduced and modelled after the Poseidon Principles: the Sustainable STEEL Principles. Both frameworks provide a methodology for lenders to measure and report on the emissions in their portfolios, enabling them to understand how their lending aligns with a net-zero pathway. This, in turn, encourages lenders to demand GHG emissions reductions across the sectors they lend to and to work directly with clients to find financing opportunities for decarbonisation.

Climate-aligned finance agreements such as the Sustainable STEEL Principles can help banks set impactful targets for their portfolios and support the practical achievement of GHG emissions reduction targets in industries like steel and shipping (RMI, 2022). For example, banks could stop financially supporting new exploitation (or expansion of) metallurgical coal mines, as well as coal-based production methods. Furthermore, financial institutions can put pressure on companies in both the shipping and steel sector to adopt measures that align with a 1.5°C pathway (Reclaim Finance, 2023).

DRIVERS	• A track and trace system based on the verification of steel throughout the supply chain can allow for greater retention of steel within shipping, as well as more efficient use of shipping scrap steel. • Market-based measures already being discussed and developed, such as carbon pricing and a voluntary carbon market, have the potential to accelerate progress by creating financial incentives for green steel. • Climate-aligned finance agreements, such as the Poseidon Principles and the Sustainable STEEL Principles, can help lenders set GHG emissions reduction targets for their portfolios and support decarbonisation action within the steel and shipping sectors. • Investments in hydrogen-based DRI produced using a zero and low GHG emissions energy source can increase the global supply of green steel.
BARRIERS	• End-of-life vessels are priced according to the global scrap steel market, without consideration for the onward uptake of green steel. • Shipping-grade scrap steel is often used for lower-quality applications local to the ship recycling facilities resulting in loss of value. • Lack of scrap steel availability presents a significant barrier to producing green steel and eventual uptake in shipping.

FIGURE 7

Drivers and Barriers relating to the *Business Model* building block

REGULATION

International and regional regulation: Circular economy

Regulation within the circular economy is developing rapidly, primarily within the EU. The 2020 EU Green Deal included the EU Circular Economy Action Plan, which creates a stronger basis for legislative and non-legislative measures on circular economy. Aimed at initiatives along the entire lifecycle of products, the Action Plan takes into consideration design, use, and recycling (European Commission, 2020).

Within shipping, relevant regulation is primarily within ship recycling, which is governed by the IMO Hong Kong Convention (not in force) and the EU Ship Recycling Regulation[2]. Both focus on safe and environmentally sound recycling of ships but fail to consider design for recycling, or the life of materials refurbished or reused after recovery from a ship. This is not surprising considering that these were published in 2009 and 2013 respectively (the EU Ship Recycling Regulation is undergoing a revision process expected to be completed in Q1 2024 (European Commission, 2023)).

Both regulations require the development and upkeep of an Inventory of Hazardous Materials (IHM), which keeps track of a number of hazardous substances within the structures and components of a ship and must remain with the ship from its build through to recycling. This marks a significant step in ensuring traceability and accountability across the lifecycle, regardless of how many times a ship may change hands, and can be seen as a key first step towards greater circularity and collaboration throughout the lifecycle.

International and regional regulation: Carbon

The EU has recently adopted the Carbon Border Adjustment Mechanism (CBAM) to put a fair price on carbon-intensive goods imported into the EU by ensuring that emissions

[2] SSI's 2021 report *Exploring shipping's transition to a circular* industry discusses these regulations in more depth.

from the production process have been paid for. This regulation includes steel and is put in place to avoid carbon leakage from Europe to other regions as European producers are taxed through the EU Emissions Trading Scheme (EU ETS) (European Commission, 2023).

Market-based measures such as a carbon price are also under consideration, with the intention that proceeds will be used to support climate vulnerable countries in their energy transition

At the IMO level, market-based measures such as a carbon price are also under consideration, with some calling for prices as high as $100 per tonne of CO_2 (Lloyd's List, 2021), with the intention that proceeds will be used to support climate vulnerable countries in their energy transition.

National regulation

National governments can influence the transition towards a circular economy for steel by implementing policies aimed at the responsible management of steel products throughout their lifecycle, waste reduction and material recovery, and by setting standards for ship recycling, to name a few. They can also set rules for the trade flow of materials such as scrap steel between regions.

Green Public Procurement (GPP) policies that favour steel products with low and zero embodied emissions as well as other sustainability criteria can also stimulate demand across sectors and facilitate the circular flow of materials at a global level. By creating growth in demand, GPP can also stimulate the increase in decarbonisation such as material input substitution and energy efficiency. Furthermore, global coalitions of governments, such as the Industrial Deep Decarbonization Initiative (IDDI), have the potential to harmonise GPP frameworks for the procurement of materials such as green steel (IDDI, 2022) and create regional cooperation avenues for an efficient flow of materials.

National regulations can also help support a just and equitable transition by recognising that some countries may be disproportionately affected by the transition to economies based on circular, decarbonised steel. Scrap steel is a finite and scarce resource, and further consideration should be given to the just transition elements of its global distribution. Countries with less financial, infrastructure, and technological capacity could be prioritised as destinations for scrap steel while more developed nations rely on DRI produced using a zero and low GHG emissions energy source as the main material input.

FIGURE 8

Drivers and Barriers relating to the *Regulation* building block

DRIVERS	• The EU is leading the way on carbon pricing through the EU ETS, which will include both steel and shipping and motivate action to decarbonise both sectors. A carbon price set by the IMO would similarly encourage rapid action on decarbonisation. • Reducing unnecessary trade flows can also increase circularity and additional research should be done to identify the most efficient way to use scrap steel globally. • Cooperation among governments and Green Public Procurement (GPP) policies can create avenues for an efficient flow of materials and harmonise procurement frameworks.
BARRIERS	• Shipping and ship recycling regulation lacks references to a circular economy, limiting understanding and action from shipping stakeholders. • Lack of harmonised international and national regulations may inhibit the transition to circularity by adding complexity and uncertainty when different approaches, requirements, and standards are in force along the steel value chain.

TECHNOLOGY

Design for circularity

Designing ships with greater circularity in mind is the best way to ensure a more circular shipping industry. Starting at the design stage has the potential to shift the sector's approach to new vessels, aiming to maximise resource efficiency, minimise waste generation, and promote sustainable practices.

Circular design considers the entire lifecycle of a ship, designing it for durability, repairability, and recyclability, with materials that can be preserved and reused – thus conserving resources. Designing ships for circularity can also minimise waste by designing ships that can be more easily repaired, remanufactured, or recycled at the end of their life. Designing ships for circularity can also provide economic opportunities as it could create avenues for more repair services and secondary markets.

Furthermore, by incorporating green steel from the design stage, the overall embodied emissions of a ship can also be reduced throughout its lifecycle contributing to lowering the industry's Scope 3 GHG emissions.

Traceability of steel through the whole lifecycle

Tracing steel through its lifecycle can support the circular economy by facilitating the tracking of steel components from production to EOL, making them easier to recycle. It can also help identify and isolate steel components in need of repair or refurbishment. When transitioning to green steel, increasing traceability can be a lever for action, as data is made available, and it becomes possible to prove the sustainability credentials and GHG emissions savings embedded in the materials used to build a ship.

Greater traceability can therefore enable the availability of green steel, as it is easier for shipbuilding yards to procure the material and justify the benefits of choosing it over traditional steel

Greater traceability can therefore enable the availability of green steel, as it is easier for shipbuilding yards to procure the material and justify the benefits of choosing it over traditional steel. Conversely, a shipowner would also be better positioned to demand green steel as well as promote its use to customers with evidence-backed sustainability claims.

These benefits depend on a transparent, traceable, and verifiable system. While this may take many shapes, product information in the form of a declaration, label, or certificate originating at production and used across the lifecycle of the material is one option for recognising the benefits of green steel. Such a system could start at the design and building stages, mapping (and labelling) parts and products made using green steel. The green steel product information would then record details such as GHG emissions savings and other sustainability credentials, including the stakeholder who achieved the emissions savings. As this information stays with the ship during its lifecycle, the sources, GHG savings, and sustainability credentials of the steel would be tracked.

However, the current lack of common rules and standardisation is making tracking GHG emissions savings and sustainability credentials difficult and can create a risk of greenwashing for both the product and throughout its lifecycle. At product level, WWF Finland found that some companies have claimed emissions abatement and labelled their products as virtually green, without significant emissions reduction or other changes to their production process (WWF Finland, 2023). At a product lifecycle level, a lack of a transparent, traceable, and verifiable system can create a risk of double counting of GHG savings and sustainability credentials. Thus, there is a need for a verifiable and auditable system, that can help build the evidence base for green steel in terms of GHG savings and other sustainability benefits. Such a system could support informed purchasing decisions and assist the process of gaining classification society recognition and verification for steel products for shipping.

Material passports

Material passports are documents that, among others, list all the materials included in a product and yield insight into the sustainability and circularity characteristics (van Capelleveen *et al.*, 2023). They can enable better resource management, promote resource efficiency, and facilitate the identification of components that can easily be separated and reused.

Efforts towards the adoption of material passports are already being made

Efforts towards the adoption of material passports are already being made. In the EU, the European Commission proposed the introduction of a Digital Product Passport (DPP) to share product information for every product placed on the EU market across its entire value chain. This enables greater transparency and promotes the circular economy by fostering collaboration across the product value chain (WBCSD, 2022).

In shipping, a stepping stone towards material passports is the Inventory of Hazardous Materials (IHM) required by the Hong Kong Convention and the EU Ship Recycling Regulation, which keeps track of a number of hazardous substances within the structures and components of a ship. While an IHM is different in scope and focus to a material passport, it shares a few key similarities such as cataloguing information about the materials present and an element of traceability throughout the lifecycle. Thus, the concept of lifecycle traceability through a passport already exists in shipping, making it easier to later expand the scope to include other materials and components.

FIGURE 9

Drivers and Barriers relating to the *Technology* building block

DRIVERS	• Improving traceability of steel across a ship's lifecycle through e.g., the implementation of standardised frameworks and material passports can be a key driver to uptake of green steel for shipping. Data sharing and cross-sectoral collaborative efforts are needed to show this is possible. • Digital technologies can offer solutions for greater traceability and visibility of the steel value chain and allow for the verification of GHG emissions savings and sustainability benefits associated with green steel.
BARRIERS	• Low market demand for ships designed for circularity. • Traceability of steel can be inhibited by complex value chains and the presence of multiple actors, which can make it challenging to obtain and maintain accurate and comprehensive data. • Lack of a standardised frameworks for developing and implementing tracing systems and material passports.

Conclusion and next steps

Creating a sustainable, future-proof shipping industry requires rethinking current ways of building, operating, and recycling vessels. While fuels have been the obvious starting point in transforming the sector due to their GHG emissions reduction potential, broadening the scope of what we mean when we talk about decarbonisation is crucial to ensuring a successful energy transition.

Ensuring that steel from end-of-life is used again has the potential to create value, in particular when considering the potential for shipping as a supplier of high-quality scrap steel

It is also important to discuss all the ways in which we can optimise resource use, by using less, using for longer, and recycling responsibly. This report explored the idea of closing the loop and looked specifically at steel as the primary material of a ship (making up 75-85% of a vessel's weight). Closing the loop and ensuring that steel from end-of-life is used again has the potential to create value, in particular when considering the potential for shipping as a supplier of high-quality scrap steel. The most likely way to address this is by closing the net loop, which entails scrap steel from ship recycling and scrap steel used for shipbuilding to come from and go to different sectors. For this to work, further research is needed on several topics:

- Improvements need to be made when it comes to traceability of materials across the ship lifecycle. The Inventory of Hazardous Materials (IHM) shows a blueprint of how traceability can work for shipping, and learnings could be applied to cataloguing and tracking materials such as steel.
- Understanding how tracking, verification, and assurance of GHG emissions savings, and sustainability benefits associated with green steel can work, both within shipping and more broadly for steel demand sectors.
- Despite the possibilities for production of shipping steel without compromising quality this needs to be widely understood and promoted by classification societies, working in tandem with shipbuilding yards to raise awareness of the possibilities for green steel in shipping.
- Additional research should be undertaken to understand existing material flows for steel at end-of-life with a focus on high-quality uses in regions with current or potential ship recycling industries.

The decarbonisation of steel presents an opportunity for shipping to optimise its end-of-life material flows

Ongoing efforts to decarbonise the steel sector and create more sustainable steel were also discussed in this report, with options explored from increasing the amount of scrap steel (which is scarce) or direct reduced iron (which is more costly) as material inputs to using low and zero GHG emissions energy sources to significantly reduced emissions across different production methods. The decarbonisation of steel presents an opportunity for shipping to optimise its end-of-life material flows, as well as to act as a demand sector and call for green steel in shipbuilding.

We are starting to see this demand grow in shipping, with A.P. Møller-Mærsk and CIMC TCREA joining SteelZero.

This report has further outlined a range of drivers and barriers for increased circularity and uptake of green steel in shipping across four categories: knowledge, business model, regulation and technology. Across these categories, the clearest trends were around the need for common understanding and collaboration, which can help both the steel and shipping sectors leverage their synergies and address their Scope 3 GHG emissions.

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About the Sustainable Shipping Initiative

The Sustainable Shipping Initiative (SSI) is a multi-stakeholder collective of ambitious and like-minded leaders, driving change through cross-sectoral collaboration to contribute to – and thrive in – a more sustainable maritime industry. Spanning the entire shipping value chain, SSI members are shipowners and charterers; ports, shipyards, marine product, equipment and service providers; banks, ship finance and insurance providers; classification societies; and sustainability non-profits.

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