# Existing technologies and scientific advancements to reduce CO2 emissions from ships by retrofitting

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## Introduction

The shipping industry is a significant contributor to global greenhouse gas emissions, and urgent action is required to reduce these emissions in line with global climate goals. Currently, the International Maritime Organization aims to reduce CO2 emissions from shipping by 40% in 2030 and the total annual greenhouse gas (GHG) emissions by 70 % in 2040 compared to the benchmark values of 2008[1,2]. Shipping decarbonization can be achieved by two main actions: building new “green” ships and retrofitting old ships to make them “greener”. In the present study, we concentrate on the second issue: how to use existing and developing zero- and low-emission fuel technologies and energy-efficient technologies for ship retrofitting. We analyzed the published scientific literature on alternative innovative technological paths to decarbonize shipping, concentrating on specific pros and cons and the compatibility of different technologies.

## Materials and methods

This study reviews the available technologies for decarbonizing shipping through retrofitting, considering promising alternative energy sources and novel ship design and operation solutions, and evaluates their practical application together with a brief lifecycle analysis (LCA). In addition, promising academic research areas are analyzed to understand the potential for future shipping. The figure shows clouds of the most frequent word tags appearing in the abstracts and titles of analyzed literature. The tags form two separate clouds, representing policy-and-practice-oriented studies (the purple cloud) and technical studies (the cyan cloud). Analyzing both groups of scientific studies allows for balanced conclusions simultaneously, considering the opinions of scientists and practitioners. Our survey accounts for many promising alternative energy sources, e.g., hydrogen, ammonia, battery power, methanol, biofuels, wind energy, liquified biogas and synthetic methane, solar energy, liquified natural gas, and nuclear power. Moreover, we also considered ship design solutions improving energy efficiency, e.g., hull and propulsion retrofitting, wind-assisted propulsion, air lubrication system, ship-based carbon capture, and anti-biofouling solutions. We finalized our study by reviewing existing technologies for decarbonizing ship operations, e.g., weather routing, logistics planning frameworks, and system-level ship operation simulation solutions.

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[1] Resolution MEPC.304(72) - The Initial IMO Strategy on Reduction of GHG Emissions from Ships 2018.

[2] Resolution MEPC.377(80) - 2023 IMO Strategy on Reduction of GHG Emissions from Ships.

## Results

This study has identified three promising strategies for reducing carbon emissions in the shipping industry through retrofitting. The first approach, which involves adopting green fuels, is the most popular but comes with a relatively high cost. However, it offers exceptional potential for decarbonization if we increase fuel and battery production transparency. This transparency is crucial to prevent the transfer of $CO_2$ emissions from one industry to another. The second pathway involves implementing ship-based carbon capture technologies, optimizing ship design, and enhancing operational practices. This approach offers a moderate cost with a significant potential for reducing emissions, but it requires the sustainable management of liquified $CO_2$. The third option is to utilize biodiesel in combination with ship design and operational enhancements. This approach offers a high level of decarbonization efficiency at a lower retrofitting cost and throughout its lifecycle. However, the availability of biodiesel feedstock is currently limited due to competition from other industries.

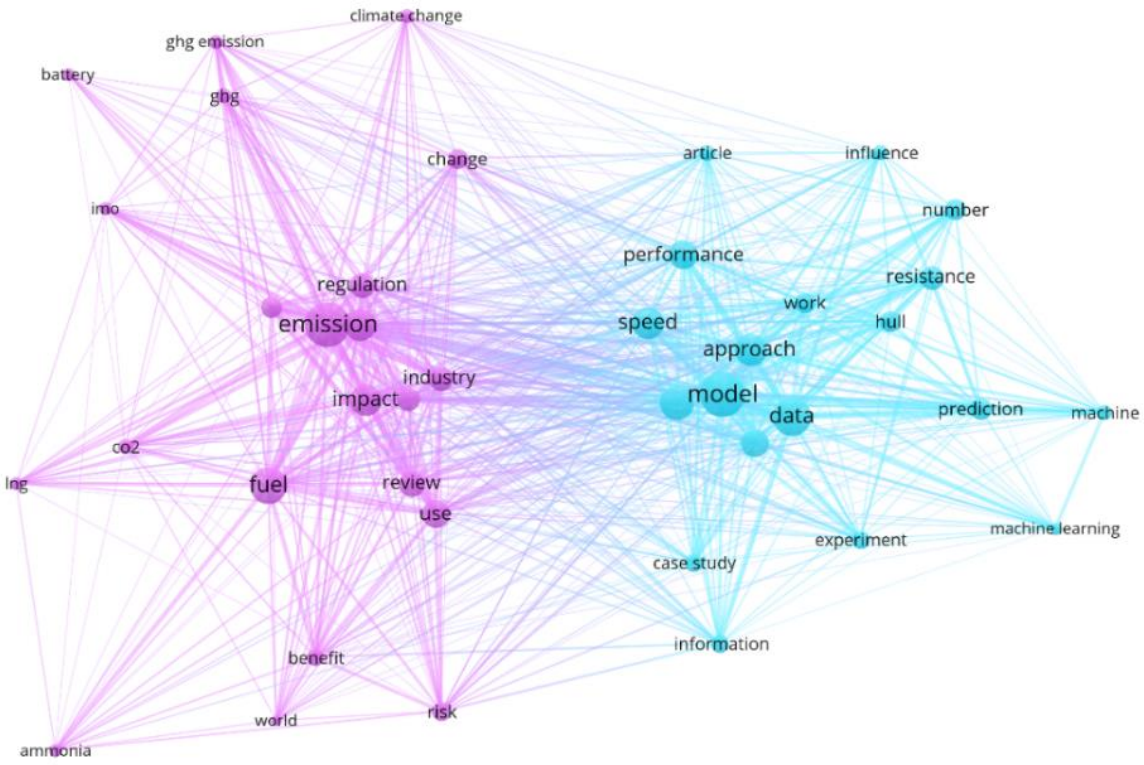


Figure. Clouds of the most frequent terms appeared in the abstracts and titles of analyzed literature and their co-occurrence. The purple cloud represents articles on policy and practice, and the cyan cloud represents technical articles.

## Implications for sustainable maritime operation

We conclude that while many promising technologies are available for reducing shipping emissions, a comprehensive and coordinated approach will be necessary to achieve the required reductions to meet global climate targets. The study recommends specific ship retrofitting policies for alternative energy sources, ship design solutions, and operational technologies to decarbonize the lifecycle of ships, depending on their characteristics, e.g., age, size, and ship type. However, the most innovative technologies are actively scaling up, and their constraints may be diminished soon. This may result in the need to reevaluate the role and prospects of some technologies in the future retrofitting of ships.