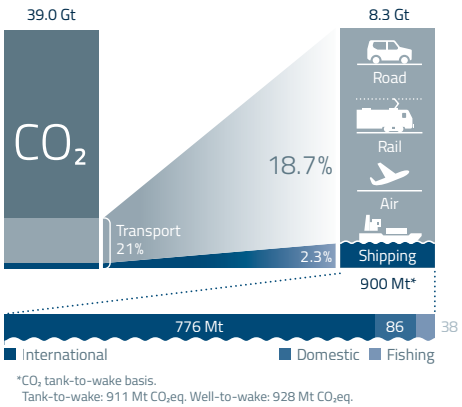


SHIPPING AND CLIMATE CHANGE

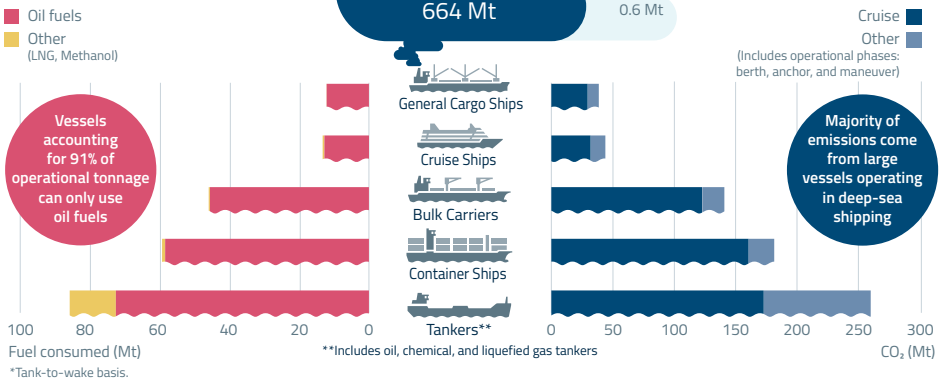
Shipping accounts for 2.3% of global CO₂ emissions, 86% of which comes from international shipping

Global emissions (2023)



Five vessel types account for nearly 75% of total CO₂ emissions

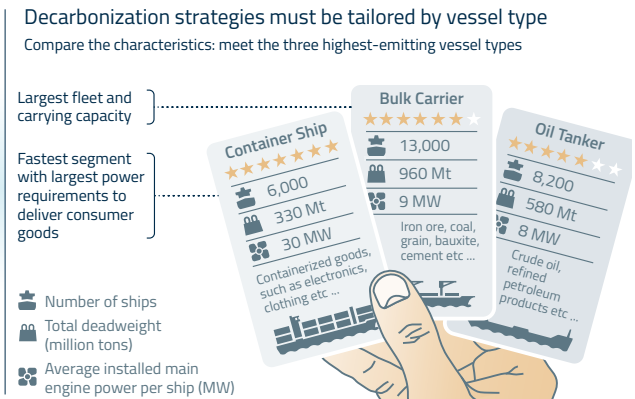
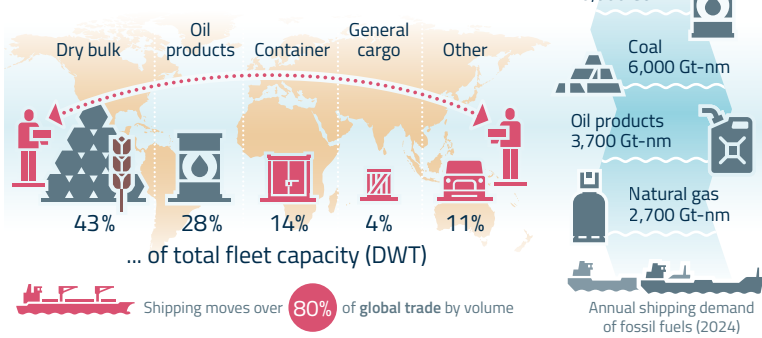
Fuel consumption and CO₂ emissions* by vessel type (2023)



SECTOR OVERVIEW

Shipping is the backbone of international trade

Fossil fuels account for 33% of shipping demand



MARINE FUELS: INCUMBENTS AND GREEN ALTERNATIVES

Conventional marine fuels are hard to replace

Conventional oil fuels offer superior energy density and cost, while alternative fuels face trade-offs in energy density, cost, technology readiness level (TRL), environmental performance, and safety.

Fuels	Type	Volumetric Energy Density (MJ/L)	Average Cost (\$/MWh)*	TRL 1-9		Lifecycle Emissions (gCO ₂ eq/MJ)**	Local Emissions (% of baseline HFO)***			Toxicity
				Production	Propulsion		NO _x	SO _x	PM	
Heavy Fuel Oil (HFO)	Fossil	38.2	\$	██████████	██████████	91.6 ¹	██████████	██████████	██████████	☹️
Very Low Sulfur Fuel Oil (VLSFO)	Fossil	37.0	\$	██████████	██████████	91.3	██████████	██████████	██████████	☹️
Liquefied Natural Gas (LNG)	Fossil + CCS	20.3	\$ \$ \$	██████████	██████████	76.1 ²	██████████	██████████	██████████	☹️
Bio-LNG (LBG)	Biogenic	20.3	\$ \$ \$ \$ \$	██████████	██████████	19.6 ³	██████████	██████████	██████████	☹️
e-Liquefied Natural Gas (e-LNG)	Low-carbon	20.3	\$ \$ \$ \$ \$ \$ \$ \$	██████████	██████████	28.2 ⁴	██████████	██████████	██████████	☹️
Liquefied Petroleum Gas (LPG)	Fossil	24.6	\$	██████████	██████████	74.1	██████████	██████████	██████████	☹️
Ammonia	Fossil	12.7	\$ \$	██████████	██████████	123.6	██████████	██████████	██████████	☹️
Blue Ammonia	Fossil + CCS	12.7	\$ \$	██████████	██████████	58.9 ⁵	██████████	██████████	██████████	☹️
e-Ammonia	Low-carbon	12.7	\$ \$ \$ \$ \$ \$ \$ \$	██████████	██████████	28.2 ⁴	██████████	██████████	██████████	☹️
Liquid Green Hydrogen	Low-carbon	8.0	\$ \$ \$ \$ \$ \$ \$ \$	██████████	██████████	39.2	██████████	██████████	██████████	☹️
Compressed Green Hydrogen	Low-carbon	5.6	\$ \$ \$ \$ \$ \$ \$ \$	██████████	██████████	28.2	██████████	██████████	██████████	☹️
Methanol	Fossil	15.8	\$ \$	██████████	██████████	102.9	██████████	██████████	██████████	☹️
Bio-Methanol	Biogenic	15.8	\$ \$ \$ \$ \$	██████████	██████████	20.5 ³	██████████	██████████	██████████	☹️
e-Methanol	Low-carbon	15.8	\$ \$ \$ \$ \$ \$ \$ \$	██████████	██████████	28.2 ⁴	██████████	██████████	██████████	☹️
Fatty Acid Methyl Ester (FAME)	Biogenic	33.3	\$ \$ \$ \$	██████████	██████████	19.3 ³	██████████	██████████	██████████	☹️
Hydrotreated Vegetable Oil (HVO)	Biogenic	36.0	\$ \$ \$ \$ \$	██████████	██████████	19.1 ³	██████████	██████████	██████████	☹️

■ Fossil ■ Fossil + CCS ■ Biogenic ■ Low-carbon \$ Average cost in \$50 increments ☹️ Highly toxic ☹️ Low acute toxicity ☹️ Not toxic

*Based on the latest available data and Rotterdam port prices where available. | **Based on FuelEU Maritime where available. As per AR4: CO₂ (GWP100 = 1), CH₄ (GWP100 = 25), and N₂O (GWP100 = 298). | ***Exact emission factors will deviate depending on the specific fuel grade, batch, engine type, settings, and environmental conditions. | See the methodology document for footnote references.

THE BASICS & THE GAPS

Climate Innovation Factsheet Series #7/ 2026

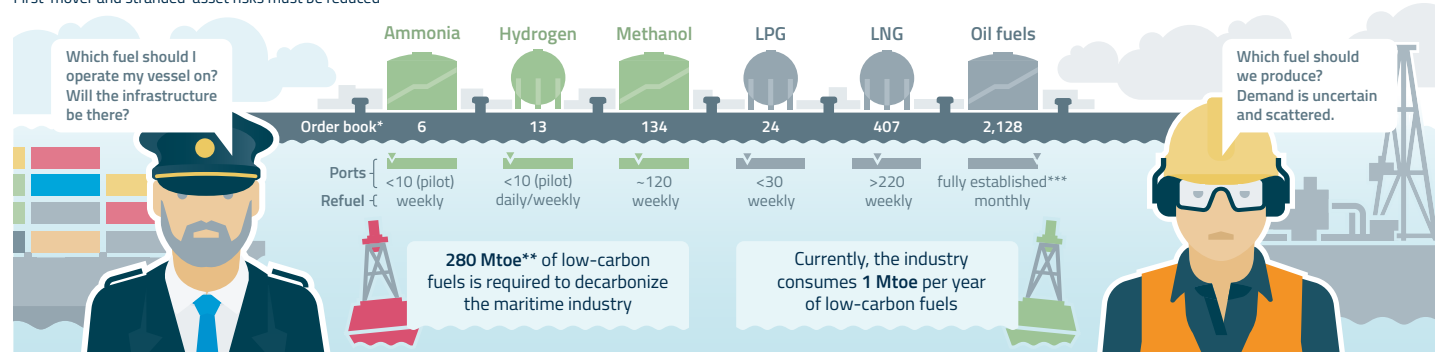
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SHIPPING

KEY SECTORAL CHALLENGES: INFRASTRUCTURE BUILD-UP AND EARLY MARKETS

Insufficient sustained demand for low-carbon fuels due to high costs is preventing supply scale-up

First-mover and stranded-asset risks must be reduced

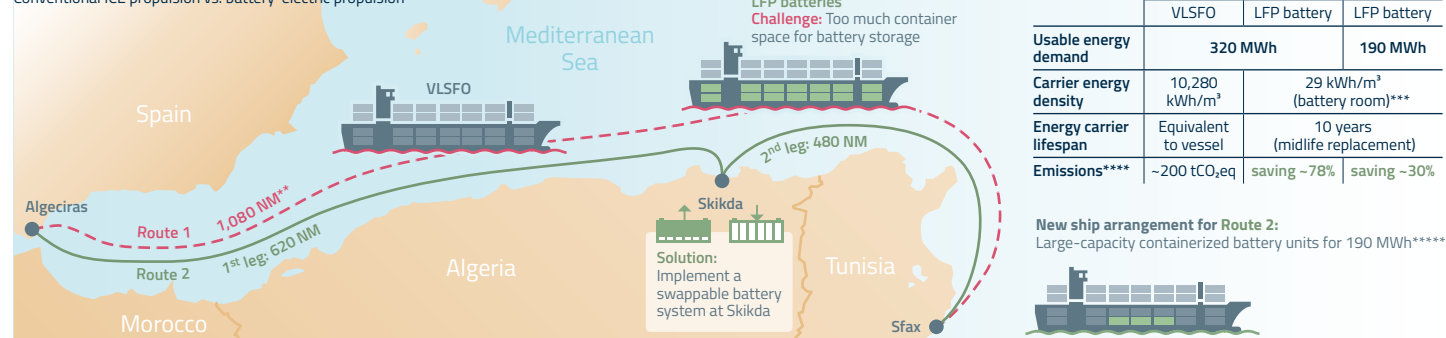


*Number of ships with each fuel capability in the 2025 order book. | **This is a direct-substitution estimate. | ***Depending on the blend, most bio-derived diesel fuels are compatible with existing oil fuel infrastructure.

PROPULSION TECHNOLOGIES: CHALLENGES AND SOLUTIONS

Battery Propulsion: pushing the boundaries past short-sea shipping

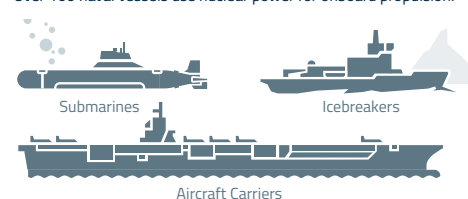
Illustrative voyage comparison for a 1,100 TEU* container ship traveling from Spain to Tunisia
Conventional ICE propulsion vs. battery-electric propulsion



*TEU: twenty-foot (container) equivalent unit. | **Nautical mile = 1.852 km. | ***Represents effective installed energy density at battery room level. | ****Based on Spanish and Algerian grid-average carbon intensities. | *****Battery capacity: 58 MWh = 16 TEU.

Nuclear Propulsion: technology has yet to be deployed in the shipping sector beyond military activity

Today
Over 160 naval vessels use nuclear power for onboard propulsion.

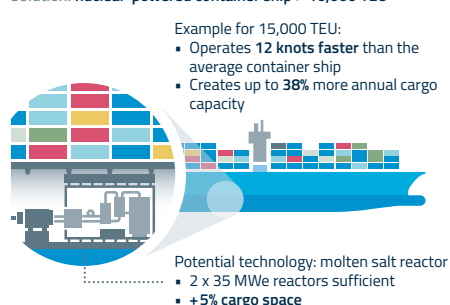


Challenge: translating this to commercial shipping

- Naval vessels optimize for endurance, stealth, and mission capability - not cost.
- Military reactors operate outside civil nuclear licensing, port state control, and IMO conventions.

Technical possibilities

Solution: nuclear-powered container ship > 10,000 TEU



Future determined by:

- Well-suited and accepted regulatory framework, e.g., an updated IMO Code of Safety for Nuclear Merchant Ships and relevant IAEA** frameworks.
- Well-accepted commercial nuclear technology with passive cooling systems and standardized modular units.
- Well-established business models, e.g., third parties own the reactors and lease them to ship operators under a service agreement.

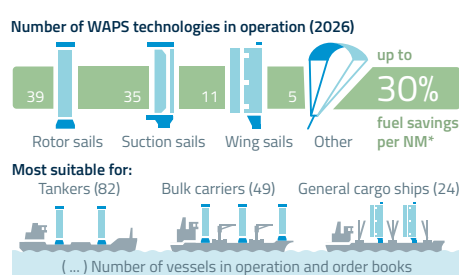
* Specific to molten salt reactors. | **International Atomic Energy Agency.

REDUCTION TECHNOLOGIES FOR FUEL AND EMISSIONS

Efficiency Improvements

Area	Category	Potential energy efficiency gains per ship
Operational Measures	Voyage optimization	1 - 10%
	Fleet strategies	1 - 15%
Technological Solutions	Hull efficiency	1 - 8%
	Propeller efficiency	1 - 8%
	Engines and propulsion systems	1 - 5%

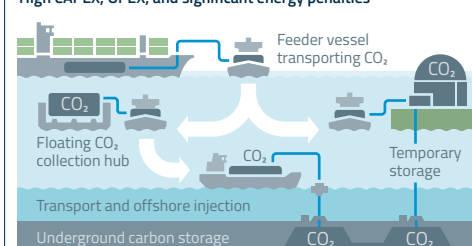
Wind-assisted propulsion systems (WAPS)



*Dependent on wind conditions and vessel characteristics.

Onboard Carbon Capture

High CAPEX, OPEX, and significant energy penalties

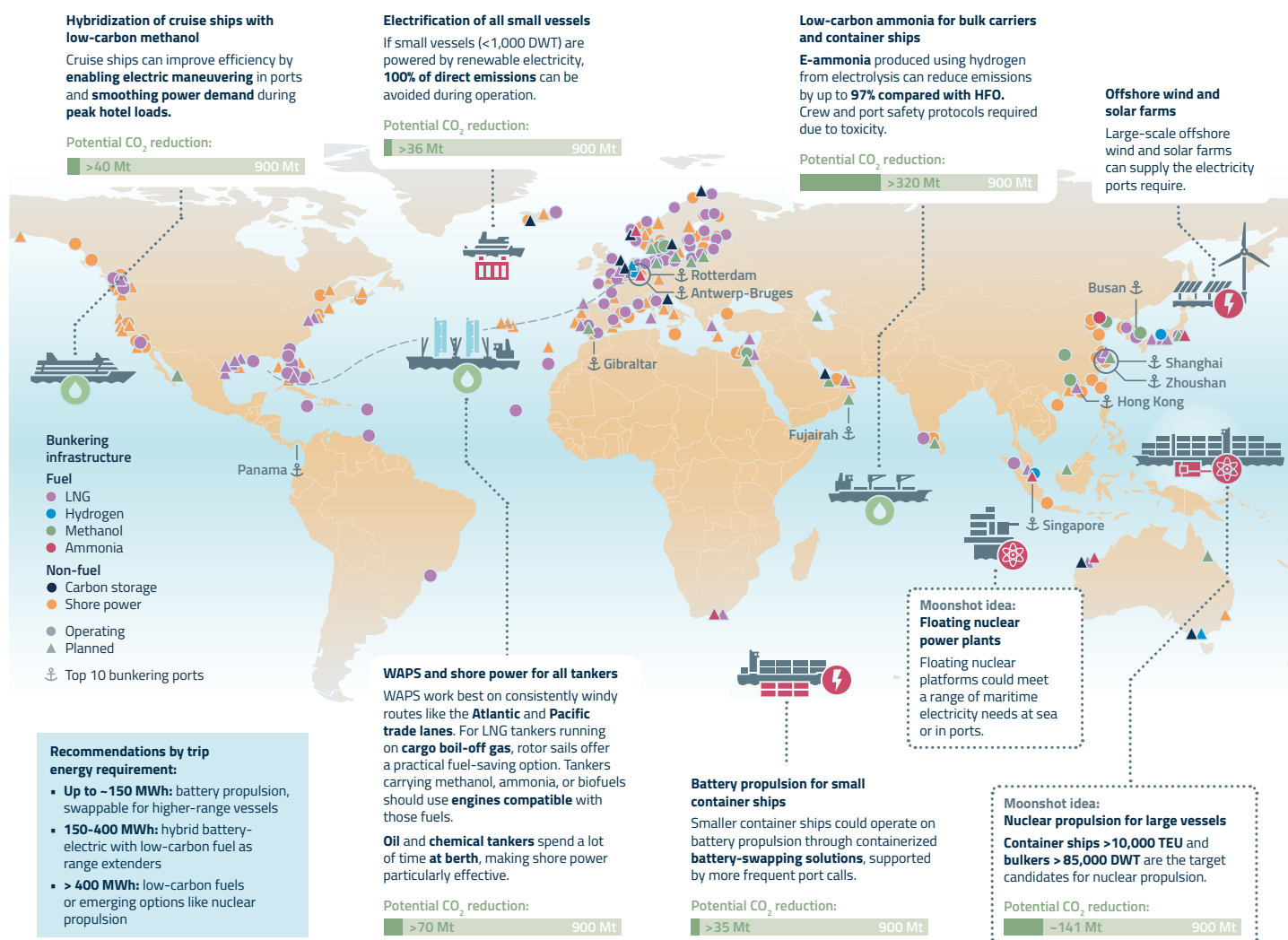


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ILLUSTRATIVE SOLUTION PATHWAY

There is no silver bullet for shipping decarbonization. The most appropriate solution will vary by vessel type, trade pattern, energy requirements, operational profile, access to bunkering infrastructure, and fuel availability. This map illustrates what a future low-carbon shipping system could look like.



OUR RECOMMENDATIONS

	Low-carbon energy and propulsion	Ports and energy infrastructure	Efficiency and emissions abatement	Regulation and emerging markets
Technology	- Prioritize battery-electric propulsion for all vessels requiring up to 150 MWh per voyage and WAPS for tankers. - Focus hydrogen as a feedstock for fuels rather than direct propulsion. - Accelerate deployment of low-carbon methanol through dual-fuel engines and standardized bunkering. - Support ammonia engine commercial pilots for safety training.	- Standardize shore power and require zero-emission operations at berth. - Extend shore power infrastructure beyond major hub ports to secondary and regional ports. - Deploy containerized and modular battery systems, paired with standardized battery-swap stations for fast turnaround. - Develop ports as clean energy hubs, combining co-located renewables with bidirectional ship-to-grid capability.	- Support R&D to improve battery performance by increasing energy density and charging efficiency. - Accelerate existing vessel efficiency through advanced coatings, air lubrication systems, and regular hull cleaning. - Minimize methane slip from vessels already operating on LNG-based fuels through engine optimization and improved monitoring systems.	- Advance dual-fuel engine designs to reduce long-term technology lock-in and enable compliance with future regulatory standards. - Support R&D and pilot projects for nuclear propulsion as a potential zero-emission option for large vessels. - Pilot onboard carbon capture on large vessels with predictable routes and develop accounting rules allowing captured CO₂ to be reflected in lifecycle emissions calculations as fossil fuels are phased out.
Policy	- Provide long-term regulatory certainty on decarbonization targets and fuel sustainability, and support fuel offtake agreements in low-carbon fuels. - Develop international training frameworks through updated STCW (Standards of Training, Certification, and Watchkeeping) courses for methanol, ammonia, and hydrogen. - Redirect limited low-carbon fuel pathways, such as sustainable biofuel feedstocks and e-fuels, away from road transport and toward hard-to-abate sectors like shipping.	- Introduce international standards for megawatt-scale charging to support maritime electrification. - Create demand for low-carbon technologies and fuels through public procurement, public service obligation rules, and infrastructure targets. - Promote and expand green shipping corridors to accelerate the deployment of bunkering infrastructure for low-carbon fuels and port electrification infrastructure. - Develop clean bunkering and shore power infrastructure at major global ports.	- Strengthen international standards and reduction targets for NO_x, N₂O, H₂, SO_x, black carbon, PM10, and PM2.5, and integrate these pollutants into carbon pricing and monitoring frameworks. - Expand Emission Control Areas (ECAs) and apply stricter pollution standards to new and existing vessels, including the use of ultra-low sulfur fuel oil (≤0.10 wt%) across additional regions. - Mandate operational efficiency measures, including slow steaming and digital voyage optimization.	- Adopt the IMO Net-Zero Framework and strengthen the targets and GHG pricing over time. - Recognize nuclear as a zero-emission onboard technology under global frameworks. - Phase out fossil fuel tax exemptions, reform taxation, and pricing frameworks to incentivize low-carbon technologies. - Include smaller vessels in all decarbonization frameworks to maximize emissions reductions and incentivize innovation.



For sources, methodology and references please scan the QR-code and visit our factsheet page.

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