Decarbonizing Marine Transportation

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1. Introduction

I've visited this topic before (see below), but a recent excellent article in IEEE Spectrum induced your author to take another dive into the sustainable ocean.

I believe the most recent post that was similar to the subject of this post is summarized and linked below.

Oceanic Solutions – Ships and Shipping: Much of the world's goods travel by container ships, the primary subject of this paper. A current challenge is modifying these vessels such that they operate sustainably. This paper will review two potential solutions: a short-term solution, and a limited solution.

https://energycentral.com/c/ec/oceanic-solutions-%E2%80%93-ships-and-shipping

There is no doubt that the title challenge is the most difficult to address of all of the transportation technologies that currently emit greenhouse gases and hence is a major cause of climate change. Start with section 2 below

2. The Challenge

The transportation sector is the largest source of greenhouse gas emissions in the United States, responsible for one third of all emissions. Decarbonizing transportation by eliminating nearly all GHG emissions from the sector is critical to addressing the growing climate crisis, and to meet the goal of net-zero GHG emissions economy-wide by 2050., A decarbonized transportation system can mobilize a sustainable economy that benefits everyone.[1]

A modern Marine Transportation System is critical to national and economic security. About 99% of U.S. overseas trade, by weight, enters or leaves the U.S. by ship. This waterborne cargo and associated activity contribute more than $500 billion to the U.S. GDP and sustains over 10 million U.S. jobs. Global maritime emissions account for about 3% of total GHG emissions each year. Decarbonizing the Marine Transportation System is integral to decarbonizing the transportation sector, as well as the broader economy, and will strengthen the competitiveness of the industry through technology innovations, training a new generation of mariners and shipbuilders, and the adoption of new, clean energy sources.

3. U.S. Maritime Decarbonization Action Plan

Reflecting the complexity of the Marine Transportation System and Marine Recreation, DOE, DOT, EPA, and HUD will publish a Maritime Decarbonization Action Plan in 2024 to outline multiple decarbonization pathways in fuels, energies, and technologies across vessel types and operational profiles.

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[1] U.S. Department of Transportation, The U.S. National Blueprint For Transportation Decarbonization, Maritime Action Plan Preview, Dec 2023, https://www.transportation.gov/sites/dot.gov/files/2023-12/MAP_Preview_Final.pdf

The Action Plan will address commercial maritime activity as well as recreational boats and transit ferry systems. Energy and technology strategies will be coupled with economic and policy levers to promote investment and adoption.

This Action Plan is part of domestic economy-wide decarbonization actions to advance U.S. climate goals for 2030, 2040, and 2050 in step with global maritime climate goals, including at the International Maritime Organization.

3.1. Maritime Action Plan Preview

The Blueprint features three strategies to decarbonize the transportation system: transitioning to clean options, increasing convenience, and improving efficiency. The U.S. Maritime Decarbonization Action Plan is part of the "transitioning to clean" strategy and will outline how the federal government seeks to accelerate the clean transition in maritime through the deployment of zero-emission fuels, technologies, energies, and vessels. A successful transition will must consider full life-cycle emissions.

3.2. U.S. Maritime Decarbonization Action Plan Pathways

3.2.1. Decarbonizing Maritime Vessels and Operations

The U.S. Maritime Decarbonization Action Plan will include a range of vessels – such as ocean-going vessels, ferries, tugboats, and recreational boats – and operational profiles and applications – such as inland waterways, fixed routes, and variable use – to promote fit-for-purpose decarbonization approaches. The Action Plan will describe steps to deploy vessel efficiency technologies, improve data resources that support planning, and improve integration among vessels and shoreside facilities.

3.2.2. Adopting Sustainable, Emerging Maritime Fuels and Energies

The development, production, and use of fuels that are zero or near-zero emission on a lifecycle basis is necessary for long-term maritime decarbonization. But no single energy source will meet the needs of a diverse and resilient maritime sector. As the industry transitions to a multi-fuel future, stronger integration with the broader energy system will help increase availability and decrease cost.

3.2.3. Decarbonizing Maritime Ports, Infrastructure, and Shipbuilding

Ports and terminals are vital economic hubs that serve as the nexus for maritime decarbonization. The confluence of people, technology, design, and commerce positions ports to innovate toward decarbonization. The Action Plan will describe landside investments that support the transition of vessels to zero or near-zero carbon energy sources. The Action Plan will also assess the resources needed to design, build, refit, and maintain a new generation of decarbonized ships.

3.2.4. Strengthening The Workforce

The maritime workforce, whether on land or on water, will power the decarbonized transportation system. Decarbonizing the maritime sector is an opportunity to grow and train the workforce. Prioritizing safety, security, education, and training alongside growing and promoting the workforce are integral to advancing decarbonization. The U.S. prioritizes inclusive economic growth with ambitious climate goals.

3.2.5. Deepening Partnerships and Strategic Planning

The Action Plan will identify opportunities for collaborations to develop innovative solutions, grow markets, and create the policies, standards, and regulations that promote stability. The urgency to advance decarbonization technologies highlights the need for collaborations designed to rapidly bring solutions to market. The U.S. supports new collaborations that are inclusive, transformational, and actionable.

4. Specific Maritime Sectors

The article that started this post is Reference 2 below. Although this article's primary focus is using nuclear reactors to power (large) merchant ships, it is very wide-ranging and brings other power-sources in the mix, albeit within coupled in fleets with large nuclear-powered vessels. Your author agrees that modern nuclear reactors are probably the best energy-source for large vessels, so I can go along with the argument the Spectrum article makes. The referenced article is an excellent, well-written article, and is also much longer than the words I excerpt below.

The shipping industry has been trying to cut its carbon emissions for years, and with little to show for it. Nearly all of the world's ship fleet still runs on diesel fuel, with about a quarter of new ships on order being built to run on somewhat lower-carbon alternatives like liquefied natural gas, methanol, or hybrid propulsion.[2]

The industry now faces serious pressure to pick up the pace. Shipping uses over 300 million tonnes of fossil fuels every year, producing 3 percent of greenhouse gas emissions. At a July meeting of the International Maritime Organization, the U.N. body that governs the industry, representatives doubled down on carbon-reduction ambitions, setting a net-zero emissions goal for 2050. The IMO's previous goal was a 50 percent reduction by 2050 in comparison with 2008 levels. The European Union plans to begin charging shippers for carbon emissions this year.

Hedging its bets, the industry is exploring ammonia, batteries, and hydrogen, among other options for powering ships. A small but growing group of analysts, though, are pushing for a zero-emissions technology that already plows the oceans: nuclear propulsion.

Today, some 200 nuclear reactors are already operating on 160 vessels, mostly naval ships and submarines. Nuclear-powered ships can go years without refueling. They do not need giant fuel tanks, which opens up more space for cargo and passengers… Fourth-generation small modular reactors (SMRs) being developed by companies including U.S.-based TerraPower and London-based Newcleo should be safer and simpler to operate than conventional reactors.

For shipping, nuclear is really the only abundant, realistic, carbon-free option, according to Håvard Lien, vice president of research and innovation at the Norwegian shipbuilding company Vard Group. "It's becoming more and more apparent that we need to do something about emissions," he notes. "At the same time, it's becoming apparent that alternative-fuel solutions we're looking at have big drawbacks, and that producing these fuels will take a lot of green power that will be needed to replace coal and gas on shore. Having an energy source that you can fit onboard a ship and does not compete with shore energy is a very high priority."

[2] Prachi Patel, IEEE Spectrum, "The Case for Nuclear Cargo Ships," Jan 20, 2924, https://spectrum.ieee.org/nuclear-powered-cargo-ship

Vard Group is part of NuProShip, a consortium of the Norwegian maritime authority, universities, shipbuilders, and shipping companies that aims to develop a Generation IV reactor for marine vessels. The group has shortlisted three designs and plan to have picked one by the end of 2024.

Author's comment: See subsection 4.1 below for the three shortlisted designs.

The project hopes to have an SMR prototype to test around 2030. Vard plans to test the SMR on new ships first, but that isn't expected to happen any sooner than 2035. If that goes well, existing ships could be retrofitted by replacing diesel engines with the SMRs, says Lien. The open-ocean vessels that the company builds—ships that lay telecommunication cable, maintenance ships, and fishing vessels—are ideal candidates for nuclear propulsion, he says. "They need high amounts of power for operation and have to be at sea for months at a time. It would be a big advantage if they don't have to break off operations and go to port to refuel."

Other kinds of ships may also get the nuclear treatment. Although nobody expects to ever see nuclear-powered cruise ships, even they might benefit indirectly. Norwegian shipbuilder Ulstein has designed a nuclear vessel with a molten-salt reactor that might conceivably serve as a mobile charging station for a future fleet of small, battery-powered cruise ships.

Author's comment: another major vessel-class that could benefit from the above-described large nuclear server-vessel concept are fishing-fleets. These could use relatively small battery-powered fishing boats with a large nuclear-powered vessel that would serve to recharge the fishing vessels and provide other centralized services like preliminary processing and refrigerated storage of the catch.

Also, later this year, the Italian shipbuilding company Fincantieri and Newcleo expect to wrap up a feasibility study to assess the practicality of deploying a 30-megawatt reactor on marine vessels. Japanese shipping giant Imabari Shipbuilding, along with a dozen other companies, has invested US $80 million in the British startup Core Power to develop a floating nuclear power plant using SMR technology that could also one day be used in ships.

In South Korea, nine organizations, including shipping companies and the Korea Atomic Energy Research Institute, plan to develop and demonstrate large ships powered by SMRs. The U.S. Department of Energy commissioned the American Bureau of Shipping to conduct a study, recently concluded, to identify suitable reactors for a merchant ship and describe R&D challenges that would have to be overcome before nuclear-powered shipping could become a commercial reality.

"Based on the number of players in the United States that are quite far advanced in their development, like TerraPower, my rough guess is that in 10 years we will see the first commercial civilian vessel with [next-generation] nuclear power," says Lien…

Now, the immense scale of shipping's decarbonization challenge, along with new reactor technologies, are prompting a reevaluation of nuclear merchant ships. In fact, for commercial shippers, there aren't any realistic alternatives to nuclear, says Jan Emblemsvåg, professor of ocean operations and civil engineering at the Norwegian University of Science and Technology. "Engines in ordinary ships are the size of houses," says Emblemsvåg, who is leading NuProShip. And a great deal of space is taken up by fuel: "A container vessel going from Amsterdam to Shanghai requires roughly 4,000 tonnes of fuel."

An SMR would be much more compact and lightweight. According to Emblemsvåg, a molten-salt reactor—which uses a mixture of thorium and hot liquid salts as both fuel and coolant—would also save about $70 million over the lifetime of a ship, compared with a similar vessel powered by engines that burn diesel fuel. Another plus for nuclear-propelled ships is easy access to an endless supply of cooling water…

4.1. Which Reactor?

Fourth-generation SMRs avoid all that. Emblemsvåg and the NuProShip team picked three reactor designs after analyzing 93 concepts in the International Atomic Energy Agency's SMR handbook. One is a thorium-fueled molten-salt reactor. The second is a lead-cooled fast reactor, which replaces the water coolant of traditional reactors with molten lead. The third option, likely closest to market, is a helium gas-cooled reactor that uses a type of fuel called tristructural isotropic (TRISO), consisting of uranium particles encased in ultra tough carbide and carbon layers that can handle temperatures above 2,000°C.

Author's comment: Note that thorium is not directly usable as a fuel in a conventional nuclear fission reactor. Thus, it would either need to be mixed with a fissile fuel, and/or bred into U_{233} as described below before use in a molten salt reactor as described above.

The following text (with references) is from Bing's generative AI:

Thorium is a fertile material rather than a fissile one. Let me explain the difference:

Fertile Material: Thorium-232 (Th-232) is not directly usable as fuel in a thermal neutron reactor. However, it serves as a fertile material. When thorium-232 absorbs a neutron, it transmutes into uranium-233 (U-233), which is an excellent fissile fuel material. This process is similar to how uranium-238 transmutes into plutonium-239.[3]

Fissile Material: Fissile materials are directly usable as fuel in nuclear reactors. They can sustain a nuclear chain reaction. Examples of fissile materials include uranium-235 (U-235) and plutonium-239 (Pu-239).

Back to Reference 2.

All three reactor types operate at low pressures, making explosion extremely unlikely, Emblemsvåg notes. Also, a meltdown is so unlikely as to be irrelevant, in his view. For example, the melting temperature of TRISO fuel is so high that no realistic scenarios could result in the fuel becoming molten.

With the other reactor types, the molten fuel or coolant would solidify before an accident could become a disaster, according to their backers. Giulio Gennaro, technical director at Core Power, likens the molten-chloride-salt reactor the company is codeveloping with TerraPower to a simmering saucepan instead of a pressure cooker: "If you make caramel in a saucepan, it's extremely hot; you could burn your finger. But if the pan breaks, you have a leakage on the stove, and the molten caramel quickly solidifies…" So contamination would not get far from the reactor in a reactor failure, as opposed to a pressurized vessel explosion that could splatter fissile material kilometers away.

[3] World Nuclear Association, "Thorium," Dec 2020, https://www.world-nuclear.org/information-library/current-and-future-generation/thorium

Lead-cooled reactors have a similar advantage: The liquid lead would cool down and solidify in contact with cold water, encasing the reactor core and preventing nuclear material from being released into the environment, says Andrea Barbensi, engineering director at Newcleo. Launched in 2021, the company has designed a lead-cooled reactor that aims to produce its own fuel by recycling the by-products of conventional reactors, "offering a circular solution to nuclear waste," he says…

Last July, the American Bureau of Shipping and Herbert Engineering Corp. issued the results of a study addressing shipbuilders' concerns about nuclear reactors…

The study suggested that putting two 30-MW lead-cooled reactors on one of the largest container vessels would increase cargo capacity and speed, and eliminate refueling needs during its entire 25-year life-span. If there is sufficient industry interest, the ABS will identify the most promising reactor designs and assess risks and safety, Ryan says.

Even among supporters of nuclear ship propulsion, not everyone agrees that putting reactors on ships is the best way to go about it. In the near term, they argue, it makes more sense to use nuclear power as a source of electricity to produce alternative low-carbon fuels. "If you use nuclear electricity to electrolyze seawater to make hydrogen, and then you use that hydrogen as a feedstock to make ammonia or methanol, the carbon footprint of the production of fuel is effectively zero," says Ryan.

One potential snag for future nuclear-powered ships is the problem of fragmented nuclear regulation, says Emblemsvåg. Commercial ships traversing international borders will face different regulations at different ports. Right now, a reactor approved in the United States isn't automatically approved for use in France, for example. "The good news is that G7 countries with some E.U. countries and the International Energy Agency are working on harmonizing the rules," he says.

Meanwhile, Core Power is trying to harmonize support among stakeholders, including SMR makers, shipbuilders, and regulators. Besides selecting a nuclear technology appropriate for the marine environment, Gennaro says, the company is lobbying to create a market for the technologies. It helped organize an IAEA symposium on floating nuclear power plants this past November that brought together nuclear and maritime regulators, legal and policy experts, and industry leaders.

"It's not just about the technology; it's about the entire ecosystem," he adds. "If I have a technology ready for use, but the regulatory framework, market, financing possibility, and business model are not there, then the time to market, which for nuclear technology is already not extremely short, gets lengthened. Our goal is to make sure that once the technology is ready, the [ecosystem] is also ready to deploy."