The law of physics versus the law of economics: nuclear-powered oceangoing ships

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Overview

The international shipping industry is responsible for transporting around 90 percent global trade volume (UNCTAD, 2020), and the share of shipping emissions in global anthropogenic Greenhouse Gas (GHG) reached 2.89% in 2018 (Faber et al., 2021). The International Maritime Organization (IMO) has adopted the mandate to reduce carbon intensity (CO2 g/ton-mile) by 70% and total GHG emissions by 50% by 2050 from 2008 baseline, with the ultimate goal of reaching zero emissions (IMO 2018). To achieve the zero emission goal, drastic changes are required to transition the industry, which has been heavily dependent on huge diesel engines buring the residual fossil fuels for the past century, to true zero-emission power and propusion.

Most zero carbon technologies for shipping are hampered by the low energy densities of energy carriers compared to conventional fossil fuels. Proven battery-electric technologies as well as new hydrogen or ammonia technologies face this challenge. For established low emission technologies, energy density issues are somewhat smaller. The energy density of biodiesel is close to that of conventional diesel. Liquefied biogas has somewhat lower energy density than marine diesel – but for most shipping segments, the fuel volume of liquefied biogas is not a major obstacle (Handberg et al. 2019). The speed of technical innovation and industry and political acceptability have put hydrogen, ammonia, battery-electric and hybrids in the front seat as the future low- or zero carbon technologies of choice – especially for shorter distances. Biodiesel and liquefied biogas are less in vogue due to limited availability and expected increased future cost. LNG plays a key role in the early transition. (Bach et al. 2020, DNV 2021).

In this paper we explore the option of nuclear electric power for ocean-going vessels. Advanced atomic power from Molten Salt Reactors (MSRs) has promising potential for deepsea shipping in the transition to zero-emission with viable economics and societal benefits. Nuclear power is carbon-free, but the perception of nuclear energy source has been less favourable by governments and the public due to issues with waste management and safety concerns. As opposed to the conventional nuclear power systems of Pressurized Water Reactors (PWR), MSR-based small reactors that can be installed on ocean-going vessels are less powerful and consume less nuclear fuel, while produc stable heat for power generation.

Methods

A techno-economic study is conducted to comprehend the application of MSR small reactors on merchant vessels from various perspectives. A full shiplife fuel cycle fast spectrum MSR benefits are evaluated from the aspects of costs, storage volume, emission and risks.

The law of physics states conservation of energy, that is any extra energy must come from somewhere, and energy spreads out and dissipates. The thermal efficiency of diesel engines on ships is approaching the physical maximum level of 30-40 percent, and the lost energy is unrecoverable. To equipment a large container vessel of 18,000 twenty-foot-container equivalent unites (TEU), a two-stroke duel-fuel LNG engine with eight cylinders with an 800 mm bore can deliver their maximum efficiency at 70 rpm. The fuel consumption for such a vessel is about 300 tonne per day (tpd). If alternative fuels are used for engine combustion, the storage volume for the same energy amount will be substantially increased. For instance, ammonia would require 3.4 times of that of marine diesel oil (MAN, .

The law of economics, both monetary and environmental perspective, would require a solution that optimizes power output with true zero-emission at an investment cost level justifying vessel life-time fuel cost saved, at the same time no jeopardizing cargo space onboard. Above everything, safety ensurance for the crews and people involved is the top priority. MSR has substantial advantages over other reactor designs, and thorium offers superior physical and nuclear fuel properties, low weaponization potential, with reduced nuclear waste production.

Results

The results highlight the feasibility of MSR small reactors installation on ocean-going vessels to achieve zero-emission for the long-run.

Conclusions

Advanced nuclear propulsion system for deepsea vessels would require drastic mindset change in the industry and the wider society. The improvement in vessel construction and operation will need to be met by high level crew and management training. Regulation, port state control, insurance policies will all have to adapt. There are clear challenges in implementing the technological change in a mass scale.

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