The Potential of Next Generation Nuclear Power for Marine Propulsion of Commercial Vessels

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Paper The Potential of Next Generation Nuclear Power for Marine Propulsion of Commercial Vessels
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Context

The maritime industry saw an increase of emissions by 9.4% between 2019 and 2024, from 889 to 973 million tonnes of CO_2 [OECD, 2024]. This upward trend highlights the scale of the decarbonisation challenge facing the sector, particularly as global trade demand continues to grow. Against this backdrop, this research paper [de Vries et al., 2024] explores the evolution of shipping within the net-zero energy transition, with particular attention given to the role that nuclear propulsion could play in supporting this transformation. Rather than viewing propulsion as an isolated technical alternative, the project looks to consider it within the wider maritime industry shaped by increasing cargo flows, operational demands, infrastructure requirements, and policy pressures.

Abstract

The authors evaluate the economic and technical case for a next-generation nuclear propulsion on large commercial vessels. Using (Very) High Temperature Reactors and Molten Salt Reactors as reference technology, the study models speed-dependent total cost of ownership across four route cases (two container and two bulk carrier) and compares nuclear options against a conventional VLSFO baseline. The central finding is that nuclear-powered vessels are economically incentivised to operate at significantly higher speeds than their conventional counterparts, driven primarily by the near-flat fuel cost profile of nuclear power across the speed range.

Breakdown of Paper

The paper explores the following aspects of nuclear propulsion for ships:

1. **Power Generation and Propulsion:** Reviews reactor selection ((V)HTR and MSR), heat exchanger choice (helical coil), and turbine selection (open Brayton cycle). Full electric propulsion is adopted as a conservative baseline.
2. **Propulsion Configuration:** Evaluates turbine-direct, turbine-electric, and hybrid arrangements. Full electric is selected for flexibility and conservatism, with hybrid configurations noted as a promising direction for future work.
3. **Case Studies:**
   - 20,000 TEU containership sailing along 2 routes: (i) North Europe – China/East Asia; and (ii) Europe – North America East Coast
   - 300,000 dwt Bulker sailing along 2 routes: (i) Tubarao, Brazil to Qingdao, China; and (ii) West Australia to Qingdao China.
4. **Speed-Dependent Total Cost of Ownership:** Decomposes costs into CAPEX (reactor, electrical system, propulsion) and OPEX (nuclear fuel, O&M, voyage costs). Nuclear fuel cost works out to roughly $0.007/kWh versus $0.102/kWh for VLSFO, which is approximately 15 times cheaper on an energy basis.
5. **Shipping Income:** Freight rate ranges are drawn from the five years of Baltic Exchange data. Container rates of $1,000-$3,000/FEU and bulk ore rates of $5-$30/tonne are used. Three scenarios (A: high freight / low cost, B: average, C: low freight / high cost) are evaluated across all cases.

6. **Design Speed Calculation:** Resistance is estimated by scaling a reference vessel at constant Froude number. Profit is maximised across speed, freight rate, and reactor CAPEX simultaneously. Service lives of 25, 50, and 75 years are modelled to reflect the extended operational life of nuclear reactors relative to conventional vessels.
7. **Design Development Considerations:** Discusses dimensional constraints against port restrictions, and explores multi-propeller hybrid arrangements (up to three shafts) to manage the high thrust demands at elevated design speeds.
8. **Design Speed Results:** Outlines the results of the modelling conducted.
9. **Discussion:** The results are further reflected upon and an outlook assessment is made depending on the design development. Considerations for propulsion configurations are also discussed.

Key Findings

- Nuclear vessels are economically optimal at higher speeds than conventional vessels across nearly all scenarios. For containerships, the suggested design speed range is 28-31 knots (vs. roughly 16-23 knots conventionally); for bulk carriers, 18-19 knots (vs. 11–16 knots).
- Freight rate is the dominant driver of optimal speed, while reactor CAPEX, despite its wide uncertainty band of $3,000-$9,000/kWe, has comparatively little influence on the result. This is a counter-intuitive finding given how much attention reactor cost typically receives in nuclear economics debates.
- Longer reactor service life substantially improves the economics. Extending the SMR reactor lifetime from 25 to 75 years increases the optimal container speed by roughly 4 knots in the average scenario, as the high upfront CAPEX is depreciated over a longer revenue-generating period.
- Nuclear fuel is approximately 15 times cheaper per kWh than VLSFO at current prices, meaning that unlike conventional vessels, fuel cost does not meaningfully constrain speed choice. Instead, the economic ceiling is more often determined by the reactor's CAPEX and physical resistance.
- The study is deliberately modelled to be more conservative. Full electric propulsion with gearboxes are used, and wave-making resistance is not underestimated. The authors note that hybrid or turbine-direct configurations could improve the nuclear case further.

Discussion Questions

1. **Can a reactor outlive a ship?** Much of the economic case rests on a reactor service life being up to 75 years, compared to roughly 25 years for a conventional vessel. In practice, this would require either extending the ship's operating life substantially or transferring the reactor into one or more replacement hulls. How realistic would either option be once structural ageing, refitting costs, licensing, liability and public acceptance are considered?
2. **If freight rate dominates reactor CAPEX in the sensitivity analysis, what does this imply for investment decisions?** If a shipowner cannot reliably forecast freight rates over a 25-year vessel life, does the apparent insensitivity to reactor cost actually make nuclear a more or less attractive bet than the paper suggests?
3. **The paper excludes insurance, financing costs (WACC), and the time value of money.** Given that nuclear vessels carry a large upfront CAPEX relative to conventional ships, how significantly might a full discounted cash flow treatment shift the optimal speed or the break-even freight rate? This paper also fails to account for financing options for the reactor's CAPEX, which may shift the "optimal" strategy away from high-speed operation and towards a more conservative design.
4. **Are the higher optimal speeds commercially useful, or just mathematically optimal?** The paper finds that nuclear propulsion could support higher economic speeds due to its marginal increase in fuel cost with greater power output. However, would cargo owners or shipping companies be able to consistently pay enough for shorter transit times to justify these speeds? Route options, port congestion, fixed schedules, canal restrictions and landside logistics may also prevent faster ships from completing more voyages meaningfully.

5. **Does the model reward speed without fully capturing its consequences?** Higher speeds require much larger propulsion systems and may introduce additional technical, maintenance and safety challenges.The paper's cost assumptions may be insufficient to capture the consequences of operating very high-powered nuclear vessels, particularly when some of the proposed sailing speeds are far above typical present-day service speeds.

6. **Who carries the risk when an accident occurs?** Insurance, liability, security and accident-response costs are largely outside this particular analysis. Operating expenses could be much higher when considering additional contingency fees. This issue becomes more complicated if accidents occur at port of calls, and if nations fail to prepare for such nuclear risks accordingly.

7. **Zooming out: Where does nuclear sit in the broader decarbonisation roadmap?** Nuclear competes with ammonia, methanol, hydrogen, biofuels and efficiency improvements, but it may not need to suit every vessel type. Nuclear propulsion may play a more realistic role as a niche solution for large, energy-intensive vessels operating on long voyages with few stoppages at ports.

8. **Ultimately, who would be the first mover?** Would the first commercially viable nuclear vessel be ordered by a conventional shipowner, a cargo owner, a reactor developer, or a state-backed consortium? What combination of guaranteed cargo, public financing, regulatory support and long-term chartering would be needed to make the first project economically feasible and safe?

References

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