From speculation to engineering

by Fitzwilliam Scott

A study by Lloyd's Register (LR) and LucidCatalyst for Seaspan shows that defining what shipowners need makes nuclear propulsion not only feasible but economically compelling. The headline numbers demand attention: approximately $68 million in potential annual savings in fuel and carbon costs per vessel, a 32% increase in annual cargo capacity, and increased speeds (in the case of this study – 25 knots). A nuclear-powered 15,000-TEU container ship would not merely match conventional vessels on economics; it would fundamentally outperform them.

But these figures only become meaningful within a rigorous engineering framework. The study's most significant contribution is establishing a comprehensive set of functional requirements that defines what a nuclear power system must physically achieve when integrated into a modern container carrier. This requirements-led approach transforms nuclear propulsion from an open-ended research question into a defined engineering challenge – and that shift changes everything.

Previous efforts to evaluate nuclear propulsion for merchant ships have suffered from an excessively broad design space. With no clear use cases or performance targets, assessments default to comparing reactor technologies on generic metrics such as levelised cost of energy, without first defining the actual performance thresholds required. Missing the requirements to filter against, every option must be evaluated, and the regulatory implications multiply accordingly. "The result of having requirements specified is that it begins to sort out what the technical design work would need to actually do," explains Eric Ingersoll, Managing Partner at LucidCatalyst. "One of the problems we've had is that there isn't this kind of broader framework and understanding. Without making decisions about what the requirements are, the problem becomes much, much harder than it needs to be."

Constraining a cascade of complexity – without compromising safety

The study addresses this directly by defining a specific use case – a 15,000-TEU Asia-to-Europe container ship operating at sustained high speed – and developing requirements across 17 categories, from technical design through decommissioning. The essential 'must-have' specifications, representing roughly 20% of total requirements but driving 80% of project risk, coalesce around three principles: operational competitiveness, technical maturity & modularity, and regulatory viability.

The nuclear system must deliver approximately 74 megawatts electric to sustain a cruise speed of 25 knots, enabling 6.3 Asia-Europe round-trips per year compared with five for slow-steaming conventional ships. The reactor module must fit within an approximately 25 m × 10 m × 10 m envelope at no more than 1,000 tonnes, ensuring integration using existing shipyard capacities without fundamentally altering standard container-ship hulls.

Given commercial staffing constraints, the reactor must achieve 'walk-away safe' operation, requiring no active crew intervention to maintain safety under all credible conditions. This aligns nuclear operations with commercial maritime norms, where engineering crews are not trained nuclear specialists.

But perhaps the most consequential single requirement is that each reactor operates as a sealed cartridge for five to seven years, with refuelling aligned to the vessel's standard dry-dock schedule. This eliminates the need for at-sea refuelling infrastructure, nuclear-trained port personnel, on-board spent fuel storage, and specialised bunkering operations. The regulatory scope narrows dramatically, and port state acceptance becomes significantly more viable. This single constraint eliminates a cascade of complexity.

The framework also treats safety not as a downstream verification step but as a core design requirement originating from stakeholder concerns about nuclear hazards. Safety-critical interfaces – including hazard monitoring, emergency shutdown, failure signalling, and damage control – are defined early in system design, ensuring that decisions protect the crew, the public, and the environment from the outset. By deriving safety requirements from rigorous risk scenarios, the framework links hazards directly to protective design features, supporting feasibility studies, risk assessments, and structured regulatory engagement.

This approach ensures that the nuclear system is engineered to be both intrinsically safe and operationally compatible with commercial shipping realities. As LR continues advancing regulatory readiness and technical assurance, this safety-driven foundation will serve as a durable framework guiding all subsequent engineering and risk evaluation.

More than just a new engine drop-in

Operating at 25 knots, a nuclear-powered container ship achieves a 39% speed increase over conventional slow-steaming vessels, driving up annual cargo capacity by 32-38%. Eliminating bunker fuel entirely delivers roughly $50 million in annual savings, while avoiding carbon penalties under projected regulatory regimes contributes an additional $18m. Crucially, conventional vessels must slow-steam to comply with the International Maritime Organization's Carbon Intensity Indicator thresholds, while nuclear vessels face no such penalty at higher speeds, a divergence that will only widen as carbon pricing intensifies.

Photo: Canva

The study also compares nuclear against the alternative fuels the industry is actively pursuing. E-methanol and e-ammonia face fundamental availability constraints. The current global production of the former stands at approximately 0.5 million tonnes annually, while a fleet of 250 vessels would require 34 million tonnes. Ammonia bunkering infrastructure does not exist at scale. The synthetic fuels promising zero-emission shipping require massive green hydrogen production, itself competing for limited renewable electricity across multiple industrial sectors.

Meg Dowling, Senior Engineer for Nuclear Technology and Alternative Fuels at LR, notes that the economic modelling reveals opportunities that static fuel-cost comparisons miss: "It's not just a drop-in new engine. You could potentially change your entire operating profile of a ship and your business case." An operator might redesign routes to exploit higher cruising speeds, bypass fuelling ports, or serve routes where alternative fuel infrastructure will remain sparse for the foreseeable future.

Modularity, manufacturing, and co-design

By defining a standardised physical envelope and operational specification prior to vendor selection, the framework creates a competitive environment where multiple reactor developers design against the same requirements. Propulsion modules can be factory-built, transported, and installed using predictable, repeatable procedures. The study envisions a cross-industry consortium with purchase commitments for 1,000+ reactor units over 10-15 years, spanning maritime, mining, chemical processing, and data centre applications. At this volume, reactor costs of $750-1,000/kWe become achievable – well below the $3,000-5,000/kWe typical of bespoke nuclear projects.

The study deliberately avoids specifying reactor technologies, defining instead the requirements any successful design must meet. Because reactor technology is not yet locked in, maritime requirements can still shape designs, and vice versa. As Dowling notes, the process is "a two-way street of technology development," where vessel requirements inform nuclear system configuration and reactor capabilities open new operational models. Ingersoll adds, "The longer we wait to bring these two parts of the process together, the longer it's going to take to get solutions in the water. You don't want someone to go through years of detailed testing and then have us say, 'Well, how does that work when the platform's moving around?'"

This work establishes the foundation for subsequent concept design, shipyard engagement, and a detailed supply chain strategy. Market modelling indicates potential uptake of 40-90GW of nuclear propulsion by 2050, with manufactured units potentially reaching commercial readiness within four years of an intensive programme launch.

More than an alternative

Through rigorous, functional engineering, LR and LucidCatalyst have created the first comprehensive technical foundation for nuclear-powered container ships, tied explicitly to real-world operations. By defining clear physical dimensions, power requirements, safety criteria, and life-cycle considerations, this work converts nuclear propulsion from a speculative proposition into an actionable engineering pathway.

As the maritime sector confronts rising carbon costs, fuel volatility, and intensifying regulation, nuclear-powered shipping – designed and evaluated through strict requirements – offers not merely an alternative but, at its core, a superior pathway for safe, reliable, zero-emission global trade. ■

Lloyd's Register (LR) is a global professional services group specialising in marine engineering, technology, and digital solutions. We were created more than 260 years ago as the world's first marine classification society to improve and set standards for the safety of ships. Today, we are a leading provider of classification and compliance services to the marine and offshore industries, helping our clients design, construct, and operate their assets to accepted levels of safety and environmental compliance. Head to **lr.org/en** to learn more.

LucidCatalyst is an international consultancy offering thought leadership, strategy development, and techno-economic expertise, specialising in interventions that deliver the critical strategic changes necessary to bring about deep and rapid cuts to carbon emissions worldwide while expanding affordable energy access. Go to **lucidcatalyst.com** to discover more.