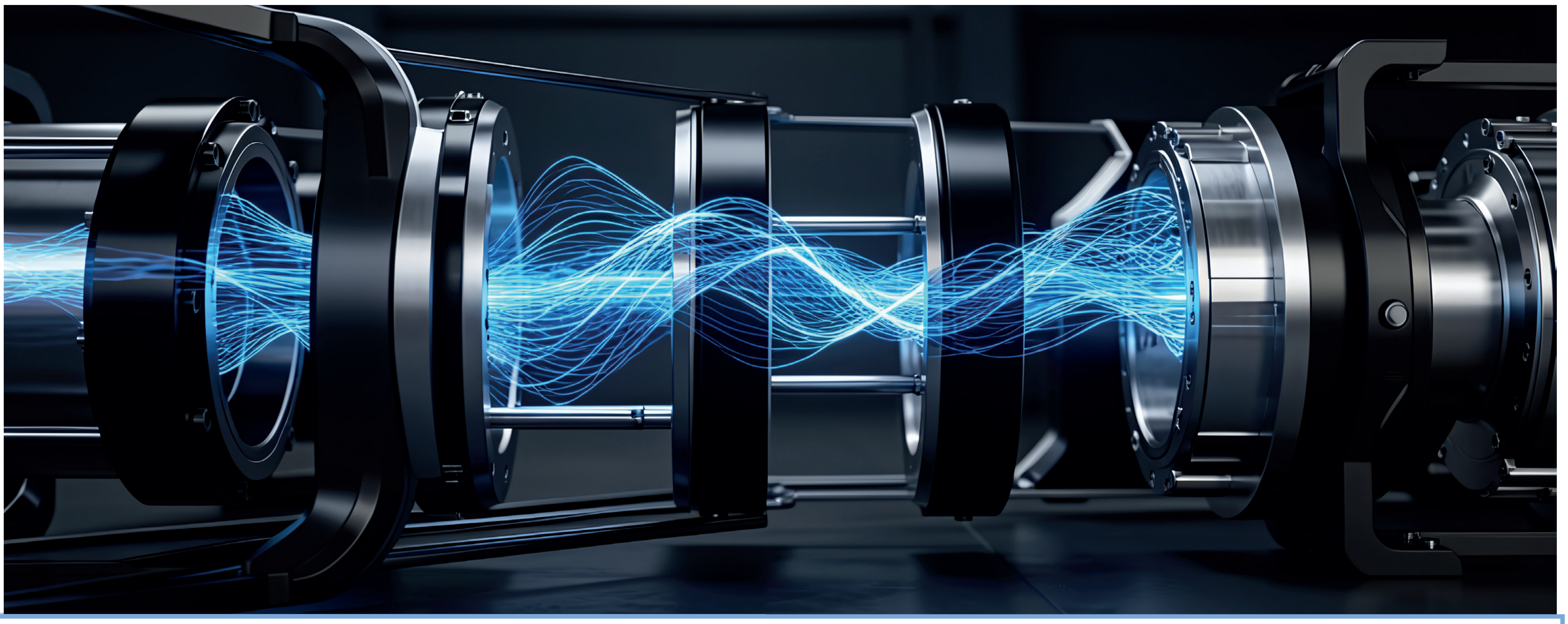

A SYNTHESIS OF ECONOMIC ARGUMENTS RELATED TO SMALL SCALE NUCLEAR MODULAR REACTORS

I. Introduction

Small modular reactors (SMRs) are often proposed as the next generation of nuclear energy technology, intended to address the economic and deployment challenges associated with conventional large-scale reactors. Traditional nuclear plants typically exceed 1,000 MW of electrical capacity, benefiting from economies of scale that reduce the average cost of electricity generation. In contrast, SMRs generally produce a few hundred megawatts per unit, which introduces a scaling penalty that can increase costs per unit of electricity. Recent estimates show that the levelized cost of electricity (LCOE) for large reactors ranges from $41.13/MWh to $95.08/MWh, while SMR estimates range from $47.24/MWh to $110.94/MWh under comparable discount rates. Despite this disadvantage, SMRs offer potential benefits through modular manufacturing, shorter construction timelines, and reduced upfront capital requirements. For example, cost structure comparisons show that SMRs allocate a larger share of total capital costs to indirect services (26.01% compared to 21.44% for large reactors), reflecting additional regulatory and logistical uncertainties associated with modular deployment. Real-world deployment efforts also highlight these uncertainties: the NuScale project's estimated cost increased from approximately $3 billion in 2015 to $9.3 billion by 2023, contributing to the project's cancellation.

This article synthesizes existing economic literature to evaluate the competing arguments surrounding SMR deployment. It finds that while SMRs may reduce financial risk and improve adaptability to smaller grids or phased deployment strategies, they remain economically uncertain and often less cost-efficient than conventional reactors. As a result, SMRs are unlikely to function as direct replacements for large nuclear plants but may instead serve as complementary technologies in specific institutional, financial, and energy-market contexts.

II. Conceptual Background: Why Economics Matter for SMRs

Since its conception, the nuclear power industry was built on the idea that larger plants would lead to more efficient outputs of energy. This philosophy led to the development of massive Generation III reactors, which are advanced light-water reactors that are distinguished by their significantly higher power capacities, typically reaching or exceeding 1000 MW. Compared to older versions, they represent the only currently viable option for large-scale investment, focusing on improved economies of scale to address modern energy demands and climate goals (Böse and Hirschhausen, 2023).

However, this fails to acknowledge outside factors such as risk and adaptability. In recent times, an increased struggle has been observed in large-scale nuclear reactors keeping up with small scale nuclear reactors in a changing economy and risk availability. As per Jeong Ik Lee, large-scale nuclear reactors using the conventional paradigm have faced several obstacles including high financial risks, strict safety regulations, a lack of adaptation to smaller electrical grids, and shifting energy markets making them increasingly lose out to small scale nuclear reactors (Lee, 2021).

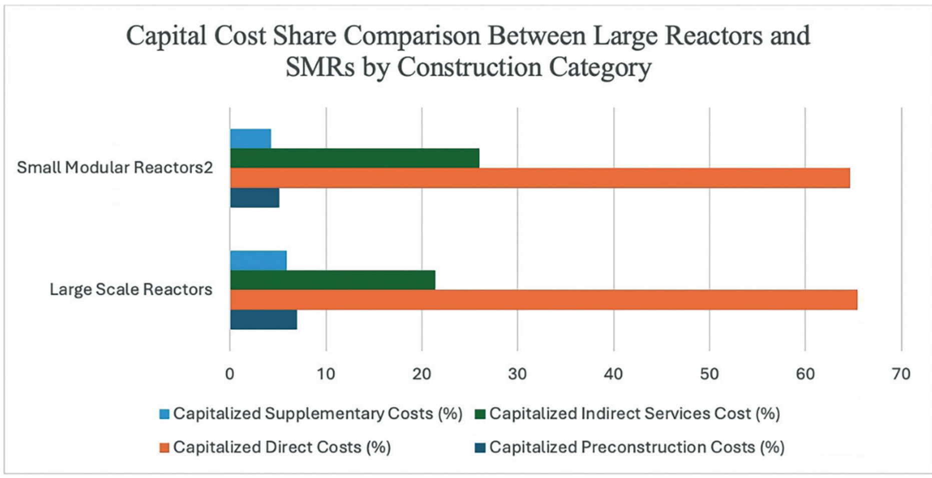

Figure 1: Percentage share of total overnight capital cost allocated to preconstruction, direct construction, and indirect services for a conventional large reactor and a representative SMR. While SMRs carry a lower preconstruction burden per unit, they incur notably higher indirect services costs (26.01% vs. 21.44%), driven largely by contingency reserves (6.59% vs. 0%) reflecting the unresolved regulatory and logistical requirements unique to modular deployment. Data from NREL Annual Technology Baseline (ATB) 2024.

Despite these initial advantages, small-scale nuclear technologies face further economic inefficiencies when compared to large reactors. As Ramana explains in his overview of SMRs, small reactors are expected to be more expensive per unit of output due to economies of scale. Since the capital and operating costs of power plants are not linear with generation capacity, larger reactors can spread material, labor, and regulatory costs over a much greater amount of electricity produced when compared to SMRs. As a result, large-scale nuclear plants are cheaper per Mega Watt (Ramana, 2021). Overall, while SMRs reduce some financial risks, they remain economically inefficient relative to large reactors due to scaling penalties and uncertain cost reductions.

III. The "Scaling Penalty": Why Smaller Isn't Necessarily Cheaper

Initially, estimates of the costs for SMR power plants argue that the reduced construction times, modular production, and learning effects may lower costs of electricity relative to more conventional nuclear reactors (Black et al., 2019). However, the authors also acknowledge that high initial costs remain the dominant driver of nuclear cost of electricity. Since SMRs produce less power per unit, their economic efficiency depends on these projected, but not confirmed, cost reductions. In a similar light, the ease of application and further adaptation possibilities of SMRs may come with their own issues. Another paper from Black et al. which addresses the prospects for nuclear microreactors states how SMRs come with their own problems. Specifically, unlike conventional large-scale nuclear plants, SMRs and microreactors require new licensing frameworks to address factory fabrication, transportation, and the deployment of fuel intact reactors (Black et al. 2023). Overall, as seen in figure 2, there is evidence that the economic viability that comes from the use of SMRs and microreactors in general depend highly on factors such as production and implementation. Factors that are not inherently concrete and can come with their own unique regulatory requirements leading to further inefficiency. Large-scale reactors demonstrate lower levelized costs, with LCOE ranging from $41.13/MWh to $95.08/MWh at discount rates of 3% to 10%, compared to SMR estimates of $47.24/MWh to $110.94/MWh under the same conditions (seen in Figure 1) (Alonso, 2025).

SMRs can have difficulty regarding the process of being installed as well. According to Rogalev et al., the unit cost is a main obstacle for large scale applications. They propose a solution to reduce dimensions and change the equipment necessary (such as heat exchange equipment and turbomachines) (Rogalev et al., 2023). However, these proposed design modifications are likely to introduce additional development and testing requirements, as well as regulatory review, which may extend the timeline for SMRs to achieve commercial viability compared to large-scale reactor alternatives.

	Large Reactor		Small Reactor
Power (MW)	1340		335
Overnight Cost (USD/kW)	4250		4505
			5355
Operation and Maintenance (USD/MWh)	14		14
Levelized Cost (USD/MWh) (3%)	4250	4505	5355
	41.13	47.24	51.81
Levelized Cost (USD/MWh) (10%)	95.08	96.98	110.94

Figure 2: Comparative levelized cost of electricity (LCOE) for large reactors versus SMRs at varying discount rates and overnight capital costs. Data from Alonso (2025).

IV. The Counter Argument: Economies of Mass Production and Learning Rates

Looking at arguments in support of SMRs, proponents argue that their smaller unit size, serial production, modular factory fabrication, and learning effects can reverse historical cost escalation trends observed in large reactors and ultimately deliver lower per-unit costs. SMRs are designed for repetition and economies of multiples (Van Hee et al., 2024; Steigerwald et al., 2023).

The use of modularization plays an important role. By shifting much of the construction process to factory environments, SMRs can reduce on-site labor requirements, shorten construction timelines, and allow for greater design standardization. This, in turn, creates opportunities for continuous process improvement across successive units, commonly referred to as the learning effect. Several studies attempt to formally capture these dynamics using production theory, comparing simple learning-curve models, such as exponential cost declines, with more flexible formulations that incorporate scaling exponents. These latter approaches allow costs to depend not only on cumulative production but also on unit size and manufacturing scale. When these proposed learning rates are met and scaling factors as well as projected costs, SMRs can sometimes approach or undercut equivalent large-reactor costs (Steigerwald et al., 2023). This sentiment of lower capital costs when compared to large-scale reactors is shared by Momin who also uses the argument of factory-based optimization and flexibility (Momin, 2023).

Further, SMRs provide similar effects as more traditional reactors in their decarbonizing potential which is also similar to that of other renewable energy resources. When looking at these arguments in support of SMRs one must also consider the viability of implementing SMRs (Vinoya et al., 2023). A further argument is presented of the ability to implement these systems as factors such as socio-political issues and overall public acceptance can impact proliferation of the technology (Vinoya et al., 2023). In the same light, many of the previous arguments depend heavily on the ability to produce SMRs at the predicted rate and capital and can easily become inefficient if unable to adhere to the estimates.

V. Financial Risk and Market Adaptability; Possible Use in Tandem

Arguments against the use of large-scale nuclear plants often cover the difference in costs, risk, and market structure between them and SMRs. As presented before, the scale of the large reactors allows them to more directly benefit from economies of scale but require high up-front investments. This is then contrasted by SMRs which are framed as a response to these financial constraints rather than as a strictly cost-competitive alternative. Alonso shows that although SMRs face higher costs of produced energy due to diseconomies of scale penalties, the unit size reduces capital requirements, altering their risk profile (Alonso, 2025). This brings up a possibility of SMRs functioning as a complement to large reactors rather than being direct competitors. This can particularly be applicable in markets where capital availability and risk tolerance are big factors and open up SMRs to markets beyond government and mega-corporation development.

The technical distinctions driving these financial profiles are illustrated in Figure 3, which compares a conventional large, pressurized water reactor (PWR12-BE) against various SMR designs. While the PWR12-BE demonstrates a massive single-reactor electrical output of 1144 MWe, the SMR designs—such as the LW-SMR, GC-SMR, and MS-SMR—show much lower individual capacities ranging from 77 to 262 MWe. However, the figure highlights that through co-siting multiple units, SMR installations can achieve a total electrical power (ranging from 924 to 1050 MWe) that approaches the scale of a single large-scale plant.

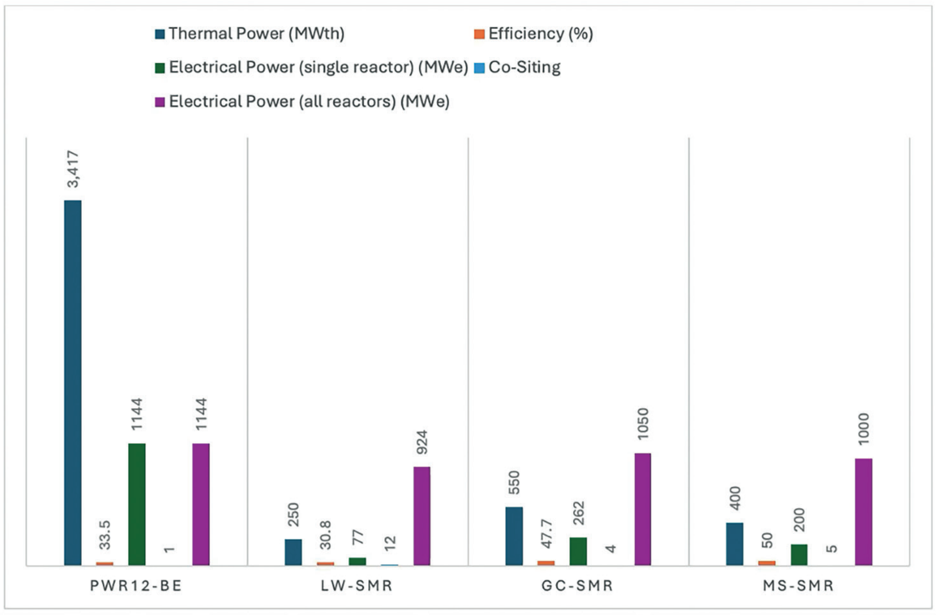

Figure 3: Comparative reactor scale characteristics for a conventional large, pressurized water reactor (PWR12-BE) and representative SMR (SMR) designs (LW-SMR, GC-SMR, MS-SMR), including thermal power (MWth), single-unit electrical output (MWe), total site electrical output under co-siting configurations (MWe), and thermal efficiency (%). Figure made from data compiled from Asuega, A., Limb, B. J., & Quinn, J. C. (2023).

Other market structures can affect the ability of SMR use. In environments where it would be more difficult to recover overruns for budget, it would be important to introduce more risk-averse and lower capital methods. Steigerwald et al. emphasize that a shorter construction timeline and deployment associated with SMRs can partially offset higher unit costs (Steigerwald et al., 2023). Wieser et al.'s study of coal-to-nuclear transitions in Texas offers a supporting example of this trend. Without largely increasing cost efficiency, SMRs can improve financial flexibility in other ways by using existing coal plant locations and grid linkages to lower entry costs and deployment issues (Wieser, 2025). Overall, these results imply that SMRs compromise long-term economic efficiency in favor of market adaptability and financial flexibility, making their competitiveness heavily dependent on institutional and market circumstances rather than solely on cost benefits. The flexibility of SMRs is further stated by Noland et al. who attests to how SMRs can provide load following services to the power grid. This highlights flexibility in being able to adjust and work with existing systems and competitiveness in energy transition scenarios (Noland et al., 2025).

VI. Case Studies: Real-World SMR Deployment

This is observed in real life examples and instances where these projects were implemented to see their viability. One of these such projects was NuScale's project which experienced an unprecedented cost increase due to required design modifications. This underscores previous arguments revolving around the viability of SMRs which depend on the implementation of such systems within a prespecified budget and plan. In 2015, the original design called for building 12 reactor modules with a combined capacity of 600 MW, at an estimated cost of USD 3 billion. To achieve a total output of 720 MW, NuScale raised the capacity of each module to 60 MW in 2018. They also predicted that the cost per kilowatt would decrease from USD 5000 to about USD 4200. However, because of growing expenses, the total capacity was lowered to 462 MW by 2021. The expected expenses increased to USD 4.2 billion in 2018 and USD 6.1 billion in 2020 and USD 9.3 billion in 2023 as a result. This led to uncertainties and an eventual cancelation of the project (Josephs et al., 2025).

The reason it becomes difficult to observe the possibilities of SMRs is due most information remaining claims. While large scale nuclear power has its own issues in that of cost overrun and delay in construction, that same can be said for SMRs, not necessarily posing them as an alternative. According to Testoni et al, there are technological challenges that need to be addressed such as development costs, licensing and cost per kWe comparisons (Testoni et al., 2021). This is a similar sentiment shared by Virgili who states that, new physical layouts, procedural design, and increased digitization of SMRs are likely to challenge traditional approaches to nuclear security, safety, and safeguards, as well as long-established regulatory regimes and procedural norms (Virgili, 2020)

VII. Conclusion

Overall, the notion of nuclear energy has often revolved around large scale nuclear power due to its advantages in economies of scale and therefore, more efficient production of energy in terms of cost. SMRs challenge this by addressing outside factors such as risk, adaptability, and low up-front costs. It is not lost upon us that large-scale nuclear reactors face issues of high financial risks, strict safety regulations, a lack of adaptation to smaller electrical grids, and shifting energy markets making them increasingly lose out to small scale nuclear reactors (Lee, 2021). This however fails to acknowledge the problems that SMRs face themselves. The highly speculative nature of SMR depends entirely on achieving anticipated production volumes and learning curves. SMRs have an increased ability to be used within pre-existing systems such as coal but bring up implementation risks of newfound permissions and policy requirements. This analysis suggests that SMRs may not be viable as entirely cost competitive alternatives to large reactors and can function more effectively as complements rather than competitors, offering distinct advantages in financial risk mitigation and market adaptability (Alonso, 2025). Overall, SMRs have economic inefficiencies despite their advantages in flexibility and implementation ability. Their viability depends on successfully being useful in markets where their characteristics of lower capital compared to large scale nuclear power, faster deployment, flexibility, and reduced financial risk from low upfront costs.

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