

Economics of Cost to Design in Future Nuclear Energy: A Comparative Analysis of SMRs and Fusion Power

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Submitted: 16 October 2023 **Accepted:** 24 October 2023 **Published:** 31 October 2023

doi <https://doi.org/10.63620/MKSSJER.2023.1010>

Citation: Citation: Zohuri, B. (2023). *Economics of Cost to Design in Future Nuclear Energy: A Comparative Analysis of SMRs and Fusion Power*. *Sci Set J of Economics Res*, 2(3), 01-03.

Abstract

This article provides a comparative analysis of the economics of cost to design for two promising future nuclear energy technologies: Small Modular Reactors (SMRs) and Fusion power. Small Modular Reactors offer advantages such as lower initial capital costs, shorter construction times, enhanced safety features, and fuel efficiency. In contrast, fusion power, while holding great potential, faces significant challenges due to high research and development costs, complex engineering requirements, and stringent regulatory demands. The choice between SMRs and fusion power depends on regional energy demands, financial considerations, and sustainability goals. Ultimately, a blend of nuclear, renewable, and conventional energy sources may collectively address the global energy challenge and combat climate change effectively.

Keywords: Small Modular Reactors (SMRs), Fusion Power, Nuclear Energy, Cost to Design, Economics of Nuclear Energy, Energy Sustainability, Renewable Energy, Climate Change, Reactor Standardization, Future Energy Technologies

Introduction

As the world faces the dual challenge of reducing greenhouse gas emissions and meeting the growing global demand for energy, nuclear power has re-emerged as a potential solution. Two promising technologies, Small Modular Reactors (SMRs) and fusion power, hold the potential to revolutionize the energy landscape. This article conducts a comparative analysis of the economics of cost to design for both SMRs and fusion power, shedding light on the prospects of these technologies for a sustainable energy future.

The future of nuclear energy holds promise as a critical component of a sustainable, low-carbon energy mix. This article examines the economic aspects of designing nuclear power solutions, focusing on two distinct but interrelated prospects: Small Modular Reactors (SMRs) for the near term and Fusion Energy for the long-term future. We explore the design costs associated with both these technologies and their implications for the energy landscape.

Furthermore, a fusion confinement reactor is a cutting-edge technology designed to replicate the process that powers the sun, where hydrogen atoms are fused together to release enormous amounts of energy. Unlike traditional fission reactors, which split atoms, fusion reactors have the potential to provide a nearly limitless and cleaner source of power.

The key challenge in fusion power is achieving and maintaining the necessary conditions for controlled nuclear fusion, where the extreme heat and pressure generated inside the reactor allows atomic nuclei to collide and merge, releasing a vast amount of energy. Fusion power has several advantages, including an almost unlimited supply of fuel, minimal radioactive waste, and inherently safe operation since any operational malfunction would halt the fusion process. While significant research and development challenges remain, fusion confinement reactors hold the promise of revolutionizing the energy landscape by providing a sustainable and virtually inexhaustible source of power.

Small Modular Reactors (SMRs): SMRs are compact nuclear reactors designed to generate electrical power on a smaller scale than traditional nuclear power plants. They offer several advantages over large-scale reactors, including improved safety, scalability, and reduced capital costs. The economics of SMRs in terms of cost to design are influenced by several factors.

Initial Capital Costs: SMRs benefit from economies of scale due to their smaller size, which translates to lower initial capital costs. The cost to design and build an SMR is considerably lower than that of a conventional nuclear reactor.

Construction Time: SMRs typically have shorter construction timelines than large reactors. Reduced construction time contributes to lower financing costs and, therefore, a lower overall cost to design and build an SMR.

Safety Measures: Safety features are integrated into the design of SMRs, reducing the likelihood of accidents and the associated financial and reputational costs.

Standardization: Standardized designs of SMRs can further decrease design and construction costs. Repeating the design across multiple installations reduces the learning curve and improves efficiency.

Fuel Efficiency: SMRs are often more fuel-efficient than large reactors, leading to lower fuel costs over time.

Above lists are very high-level advantages of new generation of fission nuclear power plants known as Generation -IV for short as GEN-IV. [1-3]

Design Costs of Small Modular Reactors (SMRs)

SMRs are compact nuclear reactors with a capacity of under 300 megawatts. They offer advantages such as scalability, enhanced safety features, and shorter construction times. However, design costs remain a crucial factor:

Initial Capital Costs: SMRs' smaller size allows for potentially lower initial capital costs compared to traditional large reactors. The modularity of their design can reduce construction complexities, contributing to cost efficiency.

Regulatory Challenges: While SMRs offer promise, navigating regulatory frameworks tailored to larger reactors poses challenges. The cost of obtaining licenses and adhering to safety standards remains a significant consideration.

Standardization Benefits: Standardized SMR designs have the potential to drive down design costs through economies of scale, simplifying regulatory approval processes, and reducing uncertainties for investors.

In summary, the design costs of Small Modular Reactors (SMRs) represent a promising avenue in the pursuit of advanced and sustainable nuclear energy solutions. SMRs offer several distinct advantages, including reduced initial capital outlays, shorter construction timelines, enhanced safety features, potential for standardized designs, and improved fuel efficiency. These economic benefits make SMRs a competitive choice for regions seeking to diversify their energy portfolios and transition away from fossil fuels. While challenges related to regulatory approval, supply chain development, and public acceptance persist, the economic feasibility of SMRs places them at the forefront of efforts to meet the world's growing energy demands while mitigating environmental impact. As technology continues to advance and deployment becomes more widespread, SMRs may play a pivotal role in the transition to a cleaner, more sustainable energy future.

Fusion Nuclear Power

Fusion power, often considered the "holy grail" of energy, mimics the process that powers the sun by fusing hydrogen atoms to release massive amounts of energy. While fusion holds immense promise, it faces significant cost and design challenges.

Research and Development Costs Fusion power has been under development for decades, with significant investments required for research, testing, and prototyping. The upfront design costs for fusion reactors are substantial.

Complex Engineering: Fusion reactors are highly complex and require precision engineering. The intricate design of the reactors adds to the cost and design challenges.

Materials and Technology: Developing materials capable of withstanding the extreme conditions inside a fusion reactor is a costly and time-consuming endeavor.

Regulatory Hurdles: Fusion technology is subject to stringent safety and environmental regulations, leading to additional compliance costs.

Furthermore, Fusion nuclear power represents a transformative energy solution with the potential to revolutionize the world's energy landscape. By mimicking the process that powers the sun, fusion reactors could provide nearly limitless, clean, and sustainable energy. While the technology remains in the experimental stage and faces formidable research, engineering, and regulatory challenges, the promise of abundant fuel, minimal radioactive waste, and intrinsic safety makes fusion power a compelling candidate for addressing the pressing global energy and environmental issues. As ongoing research and development efforts advance, fusion nuclear power remains a beacon of hope for a cleaner, more energy-secure future. [4-6]

Design Costs of Fusion Energy

Fusion energy, often considered the long-term future of nuclear power, harnesses the energy produced when atomic nuclei combine. While fusion presents numerous benefits, including abundant fuel sources and minimal radioactive waste, the design costs are substantial:

Research and Development: Fusion energy is still in the experimental phase, requiring extensive research and development. Designing practical and efficient fusion reactors necessitates significant investment.

Technical Challenges: Fusion reactors require complex and innovative technologies to achieve and sustain controlled nuclear fusion. These technological challenges drive design costs up.

Long-Term Vision: Fusion energy represents a vision for the future. The transition from research to practical fusion power generation requires both public and private sector commitment.

In summary, the design costs of fusion energy represent a formidable challenge in the pursuit of this transformative technology. Fusion reactors, which replicate the sun's process of fusing hydrogen atoms, are highly complex and costly to develop due to intricate engineering, advanced materials requirements, and stringent safety regulations. Despite the substantial upfront investment, fusion energy offers the potential for nearly limitless, emission-free power generation once the technical and financial hurdles are overcome. As research and development continue, fusion energy remains an aspirational goal that, if realized, could revolutionize our energy landscape, providing a sustainable and virtually boundless source of clean power.

Comparative Analysis

While both SMRs and fusion power offer potential benefits, they have different economic profiles concerning the cost to design.

SMRs are relatively mature technologies, with some designs already in operation. They offer shorter construction times, lower upfront capital costs, and improved safety features. The standardization of SMRs can lead to cost savings as more units are built. This makes SMRs a viable and economically competitive option for addressing energy needs, especially in regions looking to transition away from fossil fuels.

Moreover, SMRs offer a more immediate solution to meet energy demands, given their advanced stage of development. While design costs for SMRs can be substantial, their modularity and established technologies make them an attractive choice for near-term energy needs.

On the other hand, Fusion power remains in the experimental stage, with ongoing research and development. The cost to design fusion reactors is considerably high due to the complexity of the technology, the need for cutting-edge materials, and regulatory requirements. However, fusion's potential for virtually limitless, clean energy makes it a worthy candidate for long-term investment.

Furthermore, Fusion energy, on the other hand, has the potential to revolutionize the energy sector in the long run. The design costs are significant, primarily due to ongoing research and the development of cutting-edge technologies. Fusion energy is seen as a sustainable, virtually limitless energy source with minimal environmental impact, which may outweigh its high initial costs.

Conclusion

In conclusion, the comparison of Small Modular Reactors (SMRs) and fusion power in terms of their design costs and potential economic viability reveals two distinct paths towards a sustainable energy future. SMRs, with their advantages of reduced initial capital costs, shorter construction timelines, enhanced safety features, and potential for standardized designs, offer a pragmatic and near-term solution for meeting the growing global energy demand while minimizing environmental impact. On the other hand, fusion power, while beset by high upfront design costs, regulatory challenges, and complex engineering requirements, holds the promise of almost limitless, clean energy generation. As research and development efforts continue, both technologies represent important steps toward achieving energy sustainability, and their long-term success may well depend

on regional energy needs, financial capabilities, and long-term environmental goals. The journey towards a cleaner and more secure energy future is one that may benefit from a combination of both SMRs and fusion power, as well as a diversified energy portfolio that addresses the complexities of a changing world. Furthermore, the economic evaluation of design costs in future nuclear energy involves a trade-off between short-term energy solutions and long-term sustainable energy prospects. SMRs offer a practical and cost-effective approach to addressing immediate energy needs, while fusion energy represents an ambitious vision for the future. Striking a balance between the two, along with addressing regulatory challenges and fostering innovation, will play a pivotal role in shaping the future of nuclear energy and the transition to cleaner, more sustainable power generation.

At the bottom of this conclusion, the economics of cost to design in future nuclear energy are a crucial aspect of determining the feasibility of Small Modular Reactors (SMRs) and fusion power. SMRs have the advantage of lower initial capital costs, faster construction times, and established safety records, making them attractive options for immediate energy needs. Fusion power, while promising, faces considerable challenges in terms of upfront design costs, complex engineering, and regulatory hurdles.

The choice between SMRs and fusion power will depend on regional energy demands, financial capabilities, and long-term sustainability goals. Ultimately, the synergy of various energy sources, including nuclear, renewable, and conventional, may provide a comprehensive solution to the world's growing energy needs while addressing climate change concerns.

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