CHINA'S THORIUM REVOLUTION:

CHINA'S BREAKTHROUGH

AND WHAT IT MEANS FOR SINGAPORE

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Abstract

This report builds upon the earlier study titled Powering Asia's Energy Transition (2025), which introduced Thorium as a promising alternative nuclear fuel for emerging Asian economies. While the first version offered a regional overview, this updated edition narrows its focus to the People's Republic of China, which is now widely regarded as the global leader in Thorium-fuelled Molten Salt Reactor (MSR) development.

China's evolution, from Cold War-era experimentation through decades of institutional dormancy to the successful operation of the world's first Thorium MSR, carries significant technical, strategic, and commercial implications. The final section of this report will examine the downstream impact of China's Thorium program on Singapore and other small, energy-constrained nations.

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Foreword

As the global community intensifies its search for clean, secure, and scalable energy solutions, China's foray into Thorium fuelled Molten Salt Reactors (MSRs) offers valuable lessons, not only for major economies, but also for smaller, resource constrained states. China's trajectory in advanced nuclear development is instructive because it showcases what can be achieved through long term institutional commitment, integration of research and industry, and state coordination of innovation ecosystems.

The Chinese experience does not represent a universal model, nor should it be idealised. Rather, it is a real-world experiment unfolding at scale, with implications for countries at various stages of energy transition. For small states with limited land, high energy import dependence, and stringent safety needs, China's demonstration of modular, next generation nuclear systems, such as the Thorium Molten Salt Reactor-Liquid Fuel 1 (TMSR-LF1) prototype and the Gansu commercial project, opens a practical pathway worth watching. As this report builds on the broader regional framing in "Powering Asia's Energy Transition", the following report sharpens the lens on China's role in shaping the technological, commercial, and geopolitical contours of future nuclear energy.

Introduction

Thorium, long regarded as a promising yet underutilised nuclear fuel, is experiencing a quiet resurgence, and China is emerging as the key driver of this revival. While global attention has traditionally focused on Uranium-based technologies, China has pursued a multi-decade effort to master Thorium-fuelled molten salt reactors. This has culminated in the recent operational success of its prototype reactor, TMSR-LF1. This report explores how China moved from early experimentation in the 1970s to a strategically coordinated national programme that now positions it at the forefront of global Thorium development.

Thorium-232 is a well-recognised fertile radioactive substance capable of generating nuclear energy. When exposed to neutrons in a reactor, it converts into Uranium-233, which then undergoes fission to produce electricity. Like other fertile materials, Thorium-232 needs an external neutron source either from fissile materials such as Uranium-235 or Plutonium-239, or from spallation neutrons. A key advantage of Thorium-232 is its natural purity, eliminating the need for isotopic enrichment and simplifying its preparation for fuel through basic chemical separation (Schaffer, 2013). Although the concept of Thorium reactors dates back to the 1960s, only in recent years has Thorium started to gain traction as a potential alternative to conventional Uranium-fuelled nuclear power (Popular Mechanics, 2025).

Emerging Asia countries include large developing countries such as India and Indonesia, and other fast-growing Southeast Asian nations. These countries are witnessing rapid urbanisation and industrialisation, leading to surging electricity consumption that often outpaces current supply. Many still rely heavily on imported fossil fuels, which exposes them to price volatility and accounted for over 50% of global CO2 emissions in 2021 (NBP, 2024). Nuclear energy is being revisited as a viable solution especially in Asia, with 145 operable nuclear power reactors, 45 under construction, and firm plans to build about an additional 60 (WNA, 2025).

This second edition builds on the foundational research covered in Powering Asia's Energy Transition, shifting the lens from a regional overview to a focused case study of China's technical milestones, institutional leadership, and long-term ambitions. It offers a chronological narrative of China's Thorium journey, beginning with Project 728, followed by a pause in development, and later a revival in 2011 under the Chinese Academy of Sciences. It then tracks the design, construction, and commissioning of TMSR-LF1, paying particular attention to the changes in transparency, governance, and geopolitical signalling.

The report will examine the evolving institutional frameworks that have shaped China's Thorium strategy, evaluate the commercial pathways being explored, and assess the broader national objectives embedded within this nuclear endeavour. Finally, the conclusion will reflect on what this means for small, energy-constrained nations such as Singapore, especially in the context of energy diversification, nuclear research collaboration, and future deployment of Small Modular Reactors (SMRs).

In this context, Thorium is not simply a scientific curiosity. It is an energy technology with strategic implications. China's experience offers important insights into both the possibilities and constraints of Thorium energy and provides a valuable reference point for countries considering alternative nuclear pathways.

Industry Overview

Asia is experiencing a dramatic rise in energy demand, driven by rapid economic growth, urbanisation, and rising living standards. Electricity demand in Southeast Asia alone is projected to grow by 4% annually until 2035, surpassing 2,000 TWh, which is more than double Japan's current electricity consumption. This regional trend aligns with broader patterns across developing Asia, where total energy demand is expected to increase by more than 40% by 2050 (IEA, 2024).

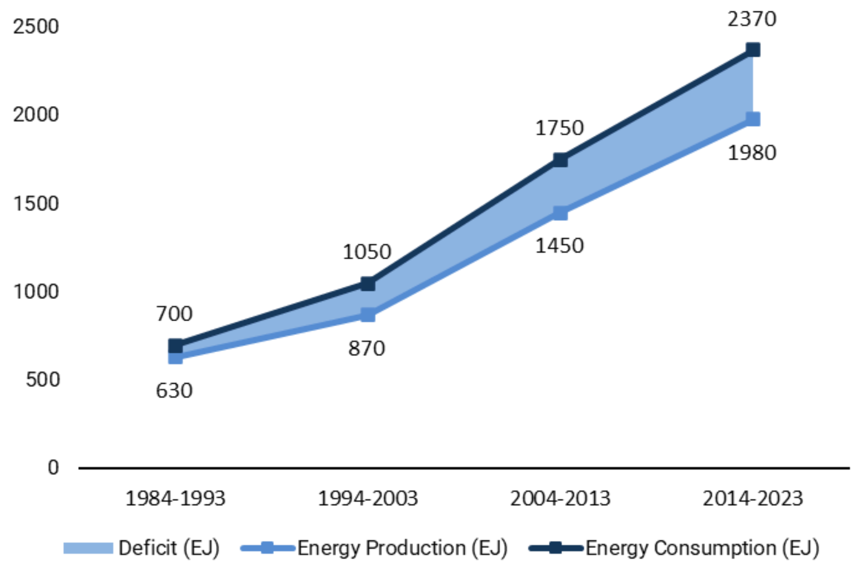

Figure 1 Energy Production vs Consumption in the Asia-Pacific (1984 – 2023). Source: Statista

Despite the growth of renewables, fossil fuels still dominate the energy mix. As of 2023, coal and gas account for nearly 80% of power generation in Southeast Asia, and their absolute use continues to increase. However, this reliance raises sustainability concerns, as these sources are highly carbon-intensive and subject to global price volatility and geopolitical disruptions (Asia News Monitor, 2024). In parallel, regional energy production has not kept pace with demand, contributing to widening supply-demand gaps in many fast-growing economies.

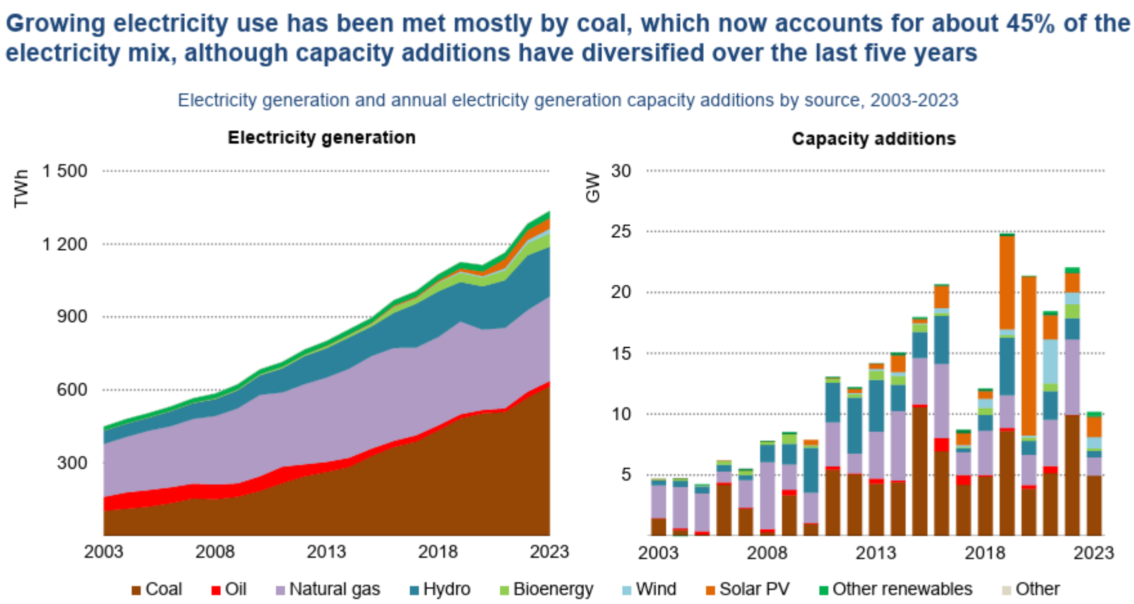

Figure 2 Electricity Generation & Capacity Additions in SEA (2003 - 2023). Source: IEA

To address these challenges, many Asian nations are strengthening their climate commitments. Countries such as Vietnam and Indonesia have announced commitments to achieve net-zero emissions and are aligning their energy strategies, including exploring or building nuclear power, in line with the Paris Agreement.

Nuclear energy is gaining renewed interest as part of this transition, particularly through scalable, low-carbon technologies such as SMRs. Thorium-fuelled SMRs, in particular, offer advantages including improved safety, reduced radioactive waste, and modular scalability suitable for decentralised grids (Hussein, 2020).

Globally, Thorium-based SMR research has gained traction in countries such as India and China. India's three-stage nuclear programme has identified Thorium as a long-term solution due to its abundance and fuel efficiency (Vijayan et al., 2016). China, meanwhile, has initiated the operation of experimental Thorium reactors (Xu, 2016). In Southeast Asia, Indonesia is preparing for SMR deployment by 2030 with floating reactor applications to supply remote islands (IEA, 2024).

In summary, the convergence of rising energy demand, unmet production capacity, climate policy shifts, and growing global interest in advanced nuclear technology positions Thorium as a promising candidate for clean baseload energy.

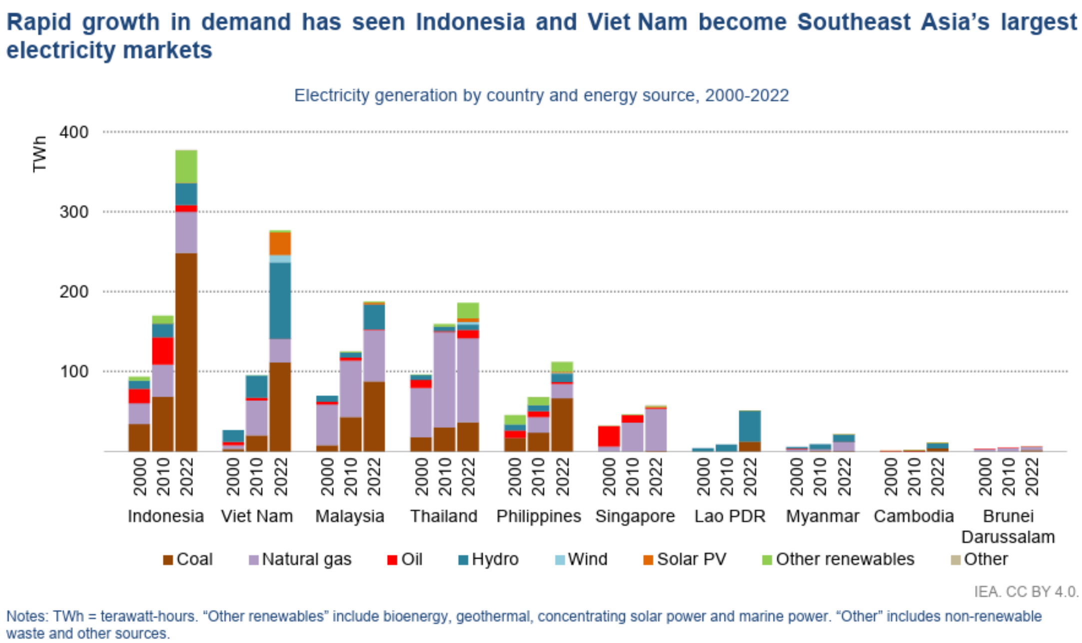

Figure 3 Electricity Generation by Country & Energy Source in SEA (2002 - 2022). Source: IEA

Thorium's Strategic Advantage

Thorium is gaining renewed global interest as a next-generation nuclear fuel due to its abundance, safety profile, reduced waste, and compatibility with SMR technologies. These characteristics align especially well with the needs of Emerging Asian economies, countries grappling with rising energy demand, reliance on imported fossil fuels, and increasing pressure to decarbonise. Thorium is approximately three times more abundant than Uranium in the Earth's crust and is particularly plentiful in countries such as India and China.

Critically, Thorium is often a by-product of rare earth element mining, which reduces both procurement costs and environmental impact (Lainetti, 2015). This positions Thorium as a strategic domestic resource for Asian nations aiming to enhance energy security and reduce reliance on external suppliers.

Unlike Uranium-fuelled reactors, Thorium systems produce significantly less long-lived radioactive waste and avoid generating Plutonium, which is a major proliferation concern (Lung & Gremm, 1999). The key fissile isotope produced from Thorium-232, Uranium-233, can be burned in situ, reducing the risk of diversion for weapons development (Selvam et al., 2025). Additionally, Thorium dioxide has a higher melting point than Uranium dioxide, offering improved thermal stability and a lower risk of meltdown (Schaffer, 2013).

When paired with molten salt or fast breeder designs, Thorium reactors achieve higher fuel efficiency and extended fuel cycles, translating to longer periods between refuelling and less maintenance, which is an essential feature for countries with developing technical capabilities (Moir & Teller, 2005). Thorium's integration with SMRs is especially promising for geographically dispersed and infrastructure-constrained regions. SMRs offer scalable, compact, and cost-effective alternatives to traditional gigawatt-scale nuclear plants, which often require USD 6 to 9 billion in upfront capital and over a decade to construct (World Nuclear Association, 2024). In contrast, Thorium SMRs are factory-built, deployable within 2 to 4 years, and can be installed incrementally which is often at a capital cost of USD 500 million to USD 1.5 billion, depending on scale (IAEA, 2022). This model aligns well with the needs of Southeast Asian markets such as Vietnam, Indonesia, and The Philippines, where infrastructure bottlenecks and constrained fiscal space hamper energy transition efforts (IEA, 2023).

Among these, Indonesia stands out as a regional leader in Thorium deployment. ThorCon International, a Singapore-based firm, is spearheading development of the TMSR-500, a 500 MWe Molten Salt Reactor (MSR) composed of two sealed 250 MWe modules, each designed for eight years of continuous operation before off-site refurbishment. In March 2025, ThorCon's Indonesian subsidiary made history by submitting the first-ever nuclear reactor licence application in the country (ThorCon International, 2025; NucNet, 2025a). The plant is slated for Kelasa Island, chosen in part for its Thorium-rich monazite residues from historical tin mining. With an estimated capital cost of just USD 1.1 billion (NeutronBytes, 2022).

Moreover, ThorCon's plans to establish a domestic reactor module manufacturing facility promise to create local jobs, accelerate technology transfer, and reduce costs through mass production (NucNet, 2025b). The initiative sets a strong precedent for how Thorium can deliver not just clean energy, but also industrial development and economic multipliers across Emerging Asia.

Competitive Positioning

Thorium vs. Conventional Nuclear and Other SMRs

Thorium-fuelled reactors offer distinct competitive advantages over both traditional large Uranium reactors and Uranium-fuelled SMRs. Conventional reactors typically generate 1 to 1.5 GW, requiring massive upfront capital and long lead times. In contrast, Thorium SMRs are modular and mid-sized (10 to 300 MWe per unit), enabling phased deployment, lower per-project investment, and suitability for smaller grids (IAEA, 2022). ThorCon's initiative in Indonesia is a strong validation of this model.

In safety and siting, Thorium Gen-IV designs such as MSRs offer inherent advantages. They operate at atmospheric pressure and include passive safety systems, reducing exclusion zones and enabling installation close to cities, industrial hubs, or even floating platforms which gives the flexibility that traditional Pressurised Water Reactor (PWR) / Boiling Water Reactor (BWR) plants lack (Reuters, 2025). Such adaptability shortens deployment timelines, improves public acceptance, and provides versatility across varied geographic contexts.

Thorium also outperforms in fuel cycle sustainability. Unlike conventional Uranium reactors, which use less than 1% of mined Uranium and generate long-lived transuranic waste, Thorium cycles breed U-233 more efficiently and dramatically reduce minor actinide production (Lung & Gremm, 1999). Some Thorium MSR configurations can even consume legacy Plutonium stockpiles, positioning them as not only effective means of power generation but also tools for responsible nuclear waste management (Schaffer, 2013).

Finally, Thorium's proliferation resistance enhances public and regulatory trust. While U-233 can be weaponised, its typical contamination with U-232, which emits intense gamma radiation makes diversion extremely difficult (Kang & von Hippel, 2001). This "clean slate" narrative can help countries overcome dual-use concerns and ease international partnerships and financing, setting Thorium apart from Uranium-based programmes.

Thorium vs. Renewable and Fossil Alternatives

Thorium reactors provide firm baseload power with high-capacity factors (80% to 90%), unlike solar and wind, which require costly and space-intensive storage to manage intermittency (IEA & OECD NEA, 2020). In densely populated regions such as Singapore or Manila, where land is scarce, SMRs can generate significant electricity on a compact footprint. For instance, a 500 MW SMR may require just 4 to 10 hectares of land, while an equivalent solar PV installation could need 400 to 4,000 hectares, making SMRs a compelling option when paired with renewables in land-constrained cities (Bryce, 2022; ITIF, 2025).

Moreover, the Levelised Cost of Electricity (LCOE), which represents the average total cost of building and operating a power plant over its entire lifetime, for newly built nuclear plants is projected to range between USD 40 to 80/MWh, depending on technology maturity and financing structures (IEA, 2020; OECD NEA, 2020). Advanced reactor designs, including Thorium-based MSRs, are estimated to achieve LCOEs as low as USD 45/MWh, due to passive safety features and simplified fuel cycles (World Nuclear Association, 2023). In comparison, combined-cycle gas turbines (CCGTs) typically incur capital costs of USD 1,000 to 2,000 per kW, but their competitiveness is sensitive to volatile fuel prices (IEA, 2020). Meanwhile, renewables coupled with battery storage often result in higher system-level costs due to intermittency and backup requirements, with storage-inclusive LCOEs frequently exceeding USD 90 to 120/MWh (Lazard, 2023).

Thorium thus joins the elite club of clean, dispatchable, and cost-effective energy solutions - uniquely targeting markets where large nuclear plants fail, and where renewables alone cannot guarantee reliability.

High Energy Density, Small Footprint for Urban Areas

Thorium SMRs offer a uniquely powerful combination of exceptional energy density and compact deployment, making them ideal for densely populated, space-constrained regions in Emerging Asia. A 100 to 200 MWe SMR can deliver continuous baseload power from just a few acres, dramatically less land than utility-scale solar or wind farms that produce equivalent output (Idaho National Laboratory, 2024).

For instance, meeting even 10% of Singapore's approximately 600 MWe demand via solar would require rooftops and offshore installations across nearly the entire island. In contrast, just two to three Thorium SMRs could supply the same energy footprint from a fraction of the land and be sited near demand centres, reducing grid expansion needs.

SMRs often achieve high-capacity factors typically between 90 to 95%, substantially higher than most solar PV and wind farms. This reliability is critical for powering energy-intensive urban infrastructure such as cooling systems, transit networks, and data centres. In contrast, solar and wind capacity factors generally stay under 40%, necessitating extensive battery storage or backup generation to maintain grid stability (ITIF, 2025).

In ASEAN nations, where infrastructure is varied and islands remain underserved, the modular, deployable nature of SMRs offers a strategic solution to expand electricity access while adhering to climate goals (ERIA, 2021). This aligns with studies in Energies, which conclude SMRs can match renewables on cost while offering the reliability demanded by urban grids in developing countries (Vinoya et al., 2023).

Inherent Safety and Public Acceptance

One of the most compelling attributes of modern Thorium MSRs is their inherent safety, directly addressing the primary barrier to nuclear deployment: public fear. MSRs operate at ambient pressure and utilise passive safety systems, notably freeze plugs that automatically drain molten fuel into a containment safe basin if temperatures rise or power is lost, eliminating core-meltdown risk and reliance on external systems (Hargraves & Moir, 2010). This design simplicity reduces emergency planning requirements, lowers insurance costs, and accelerates regulatory approval, especially important in high-density or island settings across Emerging Asia (Ho et al., 2023).

Fail-safe designs significantly lower project risk premiums by minimising the potential for accidents, public opposition, and costly regulatory delays. By emphasising transparent safety narratives that highlight the reactor's inability to explode, its automatic shutdown, and its production of significantly less long-lived waste, developers foster social license more effectively than conventional uranium plants. This rising public sentiment in favour of safer nuclear options is well-documented in stakeholder studies and public opinion analysis (Bisconti Research, Inc., 2023).

MSRs also excel in waste reduction and sustainability. Compared to traditional Uranium-fuelled systems, Thorium cycles generate much lower volumes of high-level, long-lived radioactive waste and avoid Plutonium production entirely (Wadjdi et al., 2021). Some designs enable in situ burning of existing actinides, effectively converting nuclear waste into usable fuel.

In combination, these features such as passive safety, public trust, and minimal waste position Thorium MSRs as not just technically advanced but as politically and socially viable. In contexts where regulatory environments are sensitive to public concerns, and where climate goals and circular economy principles are increasingly central, Thorium presents a credible opportunity especially for dense, rapidly growing urban regions in Emerging Asia.

Energy Security for Emerging Economies

Thorium presents a strategic path toward energy independence for countries endowed with significant domestic Thorium reserves. Nations such as India, Indonesia, and Malaysia, particularly regions such as Kerala and Odisha in India, and the Bangka-Belitung Islands in Indonesia, hold some of the world's most extensive Thorium deposits, embedded in monazite beach sands and tin mining by-products. India alone possesses a total of over one million tonnes of Thorium within an estimated 11.9 million tonnes of monazite resources, accounting for 25% to 30% of global Thorium reserves (Cosmos Magazine, 2024). Similarly, Indonesia's National Nuclear Energy Agency (BATAN) reports approximately 137,000 tonnes of recoverable Thorium, mainly in Bangka–Belitung, Kalimantan, and Sulawesi (KAI Putri et al., 2022).

Harnessing these resources could dramatically reduce reliance on imported fuels such as coal, LNG, or Uranium, which are subject to global price volatility and geopolitical constraints. For India, with limited domestic Uranium, Thorium has long been seen as a cornerstone of its three-stage nuclear programme to underpin long-term energy security (Cosmos Magazine, 2024). In Indonesia, Bangka–Belitung tailings, currently seen as environmental liabilities could be converted into valuable fuel assets, with pilot Thorium power plant studies already underway to support local electrification and energy autonomy.

Investments in Thorium-based energy are expected to attract strong government support via streamlined licensing and financial incentives aligned with national energy independence goals. Indonesia, for example, is planning a domestic Thorium reactor project on Kelasa Island as part of its decentralised energy strategy (Invest Indonesia, 2024; Indonesia Business Post, 2024). Similarly, international partnerships highlighted by the Thorium Energy Alliance's memorandum with El Salvador demonstrate rising global recognition of Thorium’s potential role in energy self-reliance (ANS Nuclear News, 2025; Thorium Energy Alliance, 2023).

Early engagement in Thorium development signifies participation in a national energy transformation, bearing reduced political risk, alignment with climate and energy security objectives, and co-benefits in local industrial supply chains. This positions Thorium not merely as a fuel source, but as a strategic lever for resource-rich countries to achieve autonomous, low-carbon, and politically resilient power systems.

Modular Deployment and Scalable Economics

A core strength of Thorium-based SMRs lies in their modular design, which enables standardised manufacturing, serial deployment, and scalable capacity expansion all while addressing the cost, schedule, and financing risks that have historically burdened conventional nuclear megaprojects (Locatelli et al., 2014; Ingersoll, 2009). Unlike traditional gigawatt-scale nuclear power plants, which often require USD 6 to 9 billion in upfront capital and over a decade to build, modular SMRs can be prefabricated in factories, transported to sites, and installed within 2 to 4 years, significantly accelerating time-to-revenue and reducing interest during construction (Zheng et al., 2020).

This approach offers clear advantages for emerging economies, particularly those with constrained fiscal space and fragmented demand growth. Rather than committing to a large-scale installation from the outset, policymakers and developers can begin with a single 50 to 100 MWe Thorium reactor to meet baseline energy needs and incrementally expand capacity by adding modules as demand grows. This phased deployment model mirrors successful practices from other industries such as aerospace and semiconductor manufacturing where unit costs fall along predictable learning curves due to design repetition and volume economies (Vinoya et al., 2023; Locatelli et al., 2014).

For instance, Southeast Asian nations such as Indonesia and the Philippines are especially well-positioned to adopt modular SMRs due to their archipelagic geographies, moderate demand centres, and logistical limitations that hinder centralised grid solutions (Nian, 2017). The ThorCon TMSR-500 model exemplifies this strategy: each 500 MWe plant comprises two 250 MWe molten salt modules, designed for factory production and sealed eight-year operation cycles. Plans to establish a manufacturing hub in Indonesia reflect the vision of regional self-sufficiency through mass production and local assembly, potentially lowering costs through domestic supply chains and repeatable construction workflows (NeutronBytes, 2022; ITIF, 2025).

Moreover, modularity directly improves investment viability. Shorter project cycles reduce financing risk and exposure to policy shifts, while incremental expansion allows capital to be deployed in stages, which improves capital efficiency and enables positive cash flows early in the asset life. This "deliberately small" reactor philosophy enables reactors to match regional load profiles more flexibly than traditional baseload plants, thus minimising the risk of stranded capacity and improving project internal rate of return (Ingersoll, 2009).

In summary, the modular deployment paradigm shifts nuclear from a bespoke, government-led undertaking to an infrastructure product that is standardised, financeable, and scalable. Thorium-fuelled SMRs stand out in this context, offering high safety, simplified fuel cycles, and a lower entry cost for emerging markets. As manufacturing processes mature and policy frameworks adapt, the modular Thorium SMR may form the backbone of a decentralised, low-carbon energy architecture across Asia.

Risk and Mitigations

Thorium-based nuclear systems, particularly MSRs and SMRs, offer compelling benefits, yet several risks remain when considering their deployment in Emerging Asian markets. Two central concerns are technological uncertainty and regulatory barriers, both of which must be addressed through structured mitigation strategies.

Technology Risk

Although Thorium MSRs promise higher efficiency and inherent safety, many designs remain at the experimental or pre-commercial stage. Material corrosion, especially the interaction between Fluoride-based molten salts and structural alloys is a major technical challenge (Wu et al., 2022). The Molten Salt Reactor Experiment (MSRE), for instance, encountered over 200 operational interruptions due to corrosion and control system instability (Lyman, 2022). Furthermore, the fabrication of Uranium-233 from Thorium and its reprocessing pose logistical and technical hurdles not yet industrially resolved (Daigle, DeCarlo, & Lotze, 2024).

These risks can be mitigated through phased demonstration projects, especially in collaboration with experienced nuclear research institutions (e.g., China's TMSR pilot in Wuwei). Recent developments in materials science, including high-throughput screening of corrosion-resistant nickel-chromium alloys using atomistic modelling, have shown promise in identifying stable reactor materials. Exposure can also be reduced by linking capital deployment to technical milestones, diversifying across Thorium SMR developers, and supporting shared R&D infrastructure.

Regulatory

Most countries lack dedicated frameworks for licensing advanced nuclear technologies. The absence of streamlined, SMR-specific licensing pathways could lead to multi-year delays and regulatory ambiguity (Caballero-Anthony & Trajano, 2017). As demonstrated by the lengthy regulatory review faced by SMRs in advanced economies such as The United Kingdom, emerging markets may face even longer timelines without targeted reforms.

Mitigating regulatory risk requires early and active engagement with national regulators and regional policy platforms such as the ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANATOM), which was established to foster regional cooperation in nuclear safety, security, and safeguards. Proposals for “graded approaches” and safeguards-by-design have gained traction and are being evaluated by the International Atomic Energy Agency (IAEA, 2022). Aligning projects with national decarbonisation goals, such as Indonesia’s commitment to net-zero and nuclear inclusion in its 2030 roadmap, can secure greater political backing (Murakami & Anbumozhi, 2022). Developers can also invest in public education and community engagement, as public sentiment has a demonstrable influence on nuclear policy in democracies (Vinoya et al., 2023).

China’s Motivations

China’s pursuit of Thorium-based nuclear energy is underpinned by a combination of strategic, economic, environmental, and geopolitical motivations. These motivations reflect both domestic priorities, such as energy security and industrial innovation, and global considerations, such as climate commitments and technological leadership.

Energy Security and Resource Independence

China’s rapidly increasing electricity consumption amplifies its urgency to secure reliable, long-term energy sources. Asia is expected to account for half of the world’s total electricity use, with China alone consuming one-third of global electricity (IEA, 2023). This growing demand, coupled with the nation’s ambition to sustain economic growth, makes energy security a strategic priority. Thorium offers a promising pathway to strengthen this security due to its abundance and domestic availability. Geologically, Thorium is 4 times more plentiful than Uranium, and China possesses significant reserves embedded in its rare earth mineral deposits (IAEA, 2023; World Nuclear Association, 2024). By investing in Thorium reactors, China can reduce its dependence on imported Uranium, which currently powers much of its expanding nuclear fleet (World Nuclear Association, 2024).

Moreover, the sheer scale of China’s energy needs magnifies the appeal of Thorium’s long-term potential. Studies suggest that a single Thorium-rich deposit, such as those in Inner Mongolia, could theoretically supply China’s energy needs for thousands of years (Hurst, 2011). While these estimates are ambitious, they underscore the strategic advantage of exploiting a fuel source that is both abundant and locally accessible. With electricity consumption continuing to surge due to urbanisation, industrialisation, and technological growth, Thorium represents a means for China to future-proof its energy mix while reducing vulnerability to global Uranium market fluctuations.

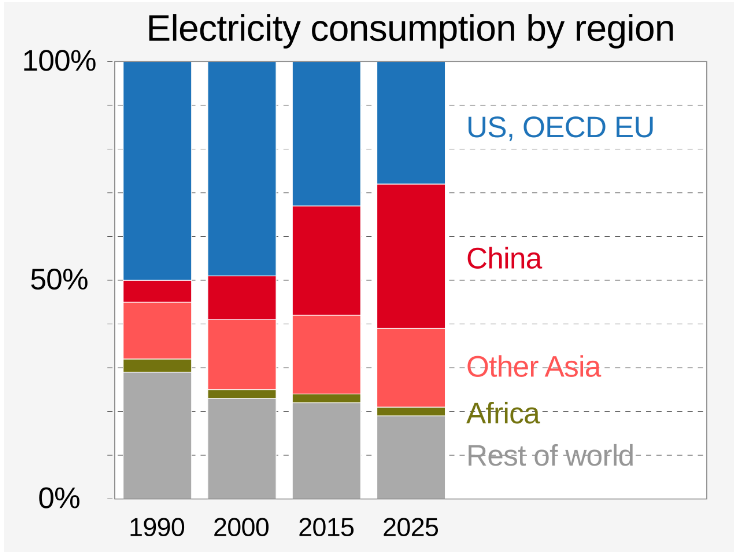

Figure 4 Electricity consumption by region (1990–2025). Source: International Energy Agency

Rare Earth Synergies and By-Product Utilisation

Thorium is among the most abundant actinides, with global reserves estimated to be 4 higher than Uranium (Jyothi, Santos, & Costa de Melo, 2023). In China, Thorium is commonly found alongside Rare Earth Elements (REEs) such as Neodymium and Lanthanum in Minerals like Monazite and Bastnaesite (IAEA, 2023; World Nuclear Association, 2024). China's dominance in REE extraction, accounting for more than 60% of global production, gives it a unique advantage in accessing Thorium at a low-cost by-product (Times of India, 2025). The extraction process of REEs naturally concentrates Thorium, which historically was treated as radioactive waste, incurring environmental and regulatory challenges (Su, Gao, Ni, Xu, & Sun, 2021). By repurposing this Thorium for use in molten salt reactors, China can transform a problematic waste stream into a high value energy resource (IAEA, 2023).

The abundance of Thorium through REE mining means that the material is already being extracted and stockpiled. Leveraging this co-production not only improves the economics of Thorium fuel but also enhances China's ability to scale reactor deployment without incurring significant additional mining costs. This synergy reinforces China's long-term strategy of integrated resource utilisation, ensuring that every component of its REE industry contributes to economic and strategic value. Moreover, Thorium's abundance positions it as a potential cornerstone of a sustainable nuclear fuel cycle, reducing resource constraints that have historically limited Uranium-based reactor programmes (World Nuclear Association, 2024). As global demand for REEs continues to grow for high-tech applications such as electric vehicles and wind turbines, Thorium availability in China will expand correspondingly, strengthening its potential for energy independence and innovation leadership (IAEA, 2023).

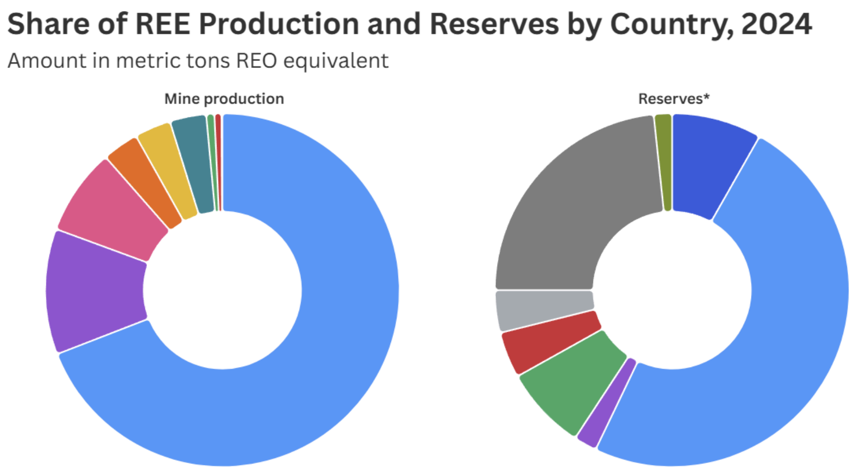

Figure 5 *REE Production and Reserves by Country (2024).* Source: US Geological Survey, Mineral Commodity Summaries

Climate, Sustainability, and Safety

China's pursuit of Thorium-fuelled MSRs is closely aligned with its national policy priorities, particularly those outlined in the 14th Five-Year Plan (2021 to 2025), and the carbon neutrality pledge for 2060. China is projected to consume one-third of the world's electricity by 2025, with electricity demand growing faster than any other region (IEA, 2023). Meeting this demand while reducing emissions requires low-carbon baseload power, and Thorium MSRs offer a pathway that aligns with Beijing's "dual carbon" strategy (carbon peaking and carbon neutrality). Projects like TMSR-LF1, which achieved criticality in 2023 and successfully operated at full power with Thorium fuel in 2024, are proof-of-concept milestones for clean nuclear technologies that aim to complement renewables and gradually phase out coal (Krepel, 2025). The planned 60 MW Thorium power station in Gansu's Gobi Desert, due to start construction by 2025, reflects China's commitment to scaling this technology for commercial deployment (Zadeh, 2025).

Unlike many Western countries where nuclear power faces public opposition, China's government has actively promoted nuclear innovation as part of its national energy security narrative. Thorium MSRs are particularly attractive to policymakers because they address both waste, and safety issues that can hinder public trust. The Chinese Academy of Sciences (CAS), through its Shanghai Institute of Applied Physics (SINAP), has emphasised that Thorium-based systems produce 80 to 90% less long-lived radioactive waste compared to Uranium reactors, reducing the need for expensive long-term geological disposal (IAEA, 2023).

Thorium MSRs also directly address the safety concerns raised by incidents such as Fukushima. China has more than 50 operational nuclear reactors, many of which are located near coastal or densely populated regions. A major accident could stall nuclear expansion and undermine clean energy plans. To counter this, China has invested in passive safety systems, such as those demonstrated in TMSR-LF1, where molten salt fuel can drain into a passive cooling tank and solidify in the event of overheating. Additionally, Thorium's proliferation resistance is strategically important for China, which seeks to position itself as a responsible nuclear technology exporter under the Belt and Road Initiative (BRI). By offering non-Plutonium-producing reactors with low proliferation risk, China can make its Thorium SMRs more attractive to countries that need energy solutions but lack nuclear infrastructure or face international regulatory scrutiny.

In summary, Thorium MSRs are not just a technical experiment for China; they are an integrated part of national climate, industrial, and geopolitical strategies. From the Gansu demonstration plant to the TMSR-400 small modular reactor designs, China is leveraging Thorium to reduce its carbon footprint, enhance energy self-sufficiency, and establish itself as a global leader in advanced nuclear exports. These reactors, by combining low-carbon baseload capability with enhanced safety and minimal waste, are central to China's vision of becoming the world's leader in clean, secure, and scalable nuclear energy technologies.

Commercial Benefits for China

Energy Independence

China’s pursuit of Thorium reactors is motivated by the potential to strengthen domestic energy independence. With its electricity demand continuing to grow at unprecedented levels, China currently imports significant amounts of Uranium to fuel its nuclear power plants, creating a strategic vulnerability in global energy markets. Thorium, however, is abundantly available within China’s borders, particularly as a by-product of rare earth element mining in provinces such as Inner Mongolia, Sichuan, and Jiangxi (Jyothi, De Melo, Santos, & Yoon, 2023). By exploiting these domestic reserves, China can significantly reduce its reliance on imported fuels and secure long-term access to a stable energy supply.

The potential energy yield of Thorium further enhances its strategic appeal. Studies suggest that a single Thorium-rich deposit in Inner Mongolia’s Bayan Obo rare earth belt could supply power for many decades, if not centuries, when used in advanced molten salt reactor systems (Interesting Engineering, 2023). This level of self-sufficiency would not only reduce the costs associated with fuel imports but also keep more economic value within China. Domestic mining companies and processing facilities involved in rare earth production, such as the Baotou Rare Earth Group, would benefit from the increased demand for Thorium, transforming what has historically been a waste product into a high-value resource.

In addition to energy security, the local economic benefits of Thorium utilisation are significant. Developing Thorium reactor infrastructure and the associated fuel cycle could boost domestic industries, from reactor manufacturing and chemical processing to high-temperature alloy production. This aligns with China’s broader industrial strategy under initiatives such as Made in China 2025, which emphasises self-sufficiency in advanced technologies and critical materials (NSI, 2024). By building a domestic Thorium supply chain, China is positioning itself not only as a global leader in clean energy technology but also as an economy that maximises the value of its natural resources while reducing exposure to external energy shocks.

First Mover Advantage

If China succeeds in being the first nation to commercialise MSR technology, it will achieve a decisive first mover advantage in a market that is expected to expand significantly over the next two decades (Jiang et al., 2022). China has already built a track record for exporting nuclear technology through projects such as the Hualong One reactors in Pakistan, including Karachi K-2 and K-3, as well as its agreement with Argentina to construct the Atucha III nuclear power plant (Madani, 2021). These projects demonstrate China's ability to offer a comprehensive package of financing, engineering, fuel supply, and long-term technical support (Zheng et al., 2021). If Thorium MSRs are successfully deployed at home, Chinese companies such as China National Nuclear Corporation (CNNC) and SINAP could replicate this export model on a larger scale, using Thorium technology as a unique selling point to differentiate themselves from Western and Russian competitors. (Hibbs, 2018)

China's Belt and Road Initiative (BRI) provides a strong platform for this expansion (Li, Liu, & Yu, 2023). Many BRI partner countries, including Bangladesh, Kenya, and Indonesia, are actively seeking affordable, clean energy solutions but face barriers to adopting conventional large-scale nuclear reactors due to cost, safety concerns, and infrastructure requirements. Thorium SMRs, which require less cooling water and feature enhanced safety systems, could be offered as turnkey solutions tailored to the needs of these emerging economies. The ongoing Gansu project, which will build a 60 MW commercial Thorium power station in the Gobi Desert by 2029, is intended to serve as a showcase of China's engineering and technological leadership. By perfecting the design and demonstrating operational success, China will be in a strong position to market its reactors abroad as proven, reliable, and safe.

The commercial benefits of this leadership go beyond construction contracts. Reactor exports involve long-term fuel supply agreements, operational training, maintenance, and technical services that can last for decades. For example, the Hualong One reactors exported to Pakistan have created enduring economic relationships through fuel supply contracts and operational support spanning their entire operational lifespan. Thorium reactors, with their advanced fuel cycle and unique safety features, could generate even greater revenues through licensing agreements and technology partnerships. China could also leverage its domestic intellectual property on Thorium MSRs to secure royalties from international reactor projects, further enhancing its earnings while establishing Chinese technical standards as the global benchmark (Valori, 2021).

In addition to energy exports, Thorium technology offers new opportunities for Chinese industries. Shipyards and maritime companies are already exploring Thorium-based nuclear propulsion for cargo vessels to achieve zero-emission shipping. If successful, China could dominate a lucrative new niche by exporting nuclear-propelled merchant ships or modular marine reactors (Interesting Engineering, 2023). This aligns with China's broader industrial and economic strategy to lead in green technologies, particularly in sectors like maritime transport, where the International Maritime Organization's decarbonisation rules are creating demand for innovative solutions.

The strategic value of Thorium reactor exports also extends to diplomacy and soft power. By offering BRI countries access to safe, low-cost, and proliferation-resistant nuclear power, China can strengthen bilateral ties and enhance its image as a global leader in clean energy. Unlike traditional Uranium reactors, Thorium MSRs produce negligible plutonium, which reduces international concerns over nuclear proliferation and makes these systems easier to export under global nuclear governance frameworks. This approach supports China's ambition, outlined in the 14th Five-Year Plan, to position itself as a leader in next-generation clean energy technologies and to expand its international influence through sustainable infrastructure partnerships.

As Southeast Asian nations explore Thorium-based energy, China's progress may set regulatory and technical benchmarks for the region. This opens space for China to assume a normative leadership role in shaping how thorium reactors are standardised, certified, and accepted across ASEAN, especially as others like Indonesia and Vietnam begin laying groundwork for future deployments.

Engineering the Next Energy Export

China is in an excellent position to replicate its industrial export playbook in Thorium MSRs, mirroring its success in the electric vehicle (EV) and solar photovoltaic (PV) sectors. From 2018 to 2023, Chinese EV exports surged by more than 1,000%, rising to nearly 1.6 million units, with export revenues soaring from USD 295 million in 2018 to USD 36.7 billion in 2023, with 70% of exports going to markets such as the EU (Zhou, 2023). China applied the same model in solar PV, scaling domestic capacity, driving down costs, consolidating supply chains, and exporting competitively to the world (Zou et al., 2017).

In the case of Thorium MSRs, China can use the same levers: large state-backed capital, vertically integrated supply chains from rare earth mining to high-performance salt chemistry, domestic factory standardisation of reactor modules, and Belt and Road strategic partnerships. The country already controls much of the global rare earth processing that produces Thorium byproducts, and has developed corrosion resistant Nickel Molybdenum alloys in collaboration with Australian Nuclear Science and Technology Organisation (ANSTO). With government coordination comparable to the “whole-of-government” approach seen in EVs and batteries (Graham, Belton, & Xia, 2021), China could package reactor technology, fuel supply, safety training, and licensing as turnkey solutions to partner countries. Memoranda of understanding with foreign governments, export finance via Chinese policy banks, and standardised licensing templates could lock importing states into Chinese technology systems for decades ahead (Li, Liu, & Yu, 2023).

Moreover, just as China helped set standards in solar panel certification and EV charging infrastructure, it could lead in establishing norms for Thorium reactor licensing, safety frameworks, and fuel reprocessing rules. Combined with its lead in materials, nuclear engineering, and operational experience, China is effectively positioning itself to dominate not only reactor sales, but also the broader global institutional architecture around next-generation nuclear power (Discovery Alert, 2024).

In parallel, neighbouring countries such as Indonesia are also pursuing Thorium-based MSRs, most notably through the privately-led ThorCon initiative. This effort, which aims to deploy barge-mounted MSRs offshore, illustrates the diversity of development models emerging across Asia. While China relies on a state-driven model, these regional projects create opportunities for China to position its technology as the default standard. By offering integrated support in reactor design, regulatory assistance, and operational training, China could anchor a broader Thorium ecosystem in Southeast Asia, underpinned by rising regional energy demand and the search for cleaner baseload alternatives.

Timeline and Progress of Thorium in China

China's interest in Thorium-fuelled reactors can be traced back to the 1970s, when the country launched "Project 728" in response to industrial energy shortages. Heavily influenced by the United States' Molten Salt Reactor Experiment (MSRE) at Oak Ridge National Laboratory, Chinese scientists constructed a test reactor at the Shanghai Institute of Nuclear Research, now SINAP that achieved criticality in 1971 (Chinese Nuclear Society, 2020; Liu et al., 2020).

However, faced with limitations in technology, industrial capacity, and economic resources, China made the pragmatic decision to prioritise pressurised water reactor (PWR) technology, leading to the commercial launch of the CNP-300 reactor in 1991 (Dai & Liu, 2013).

Despite this pivot, scientific interest in MSRs and Thorium fuel cycles never disappeared. In 2011, CAS formally revived the programme by initiating a RMB 3 billion research initiative dedicated to developing Thorium MSR systems. This project, led by Professor Xu Hongjie through SINAP, was divided into two main branches: one focusing on solid-fuel (SF) designs using TRISO particles, and the other on liquid-fuel (LF) designs inspired by the original United States of America's MSRE (Xu, 2018; Zou, 2019; Smriti, 2021).

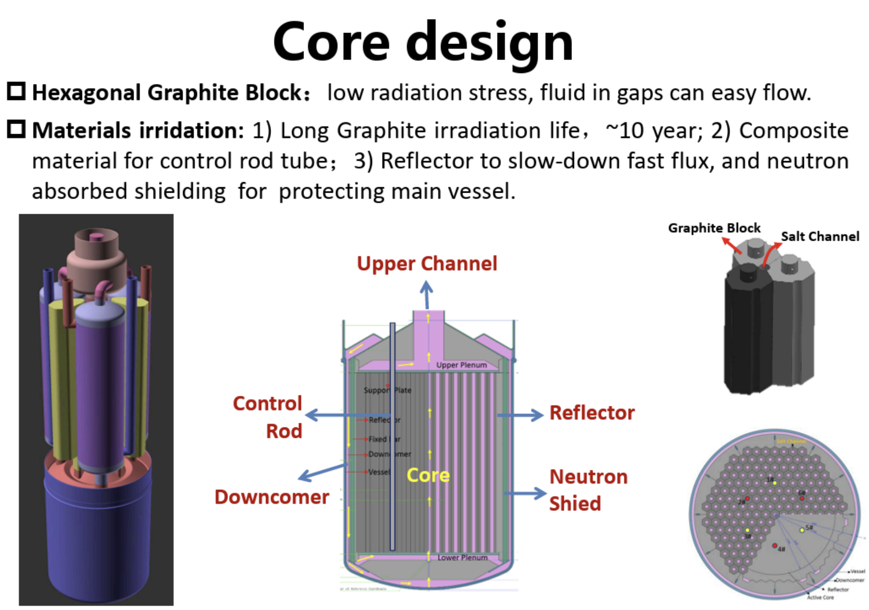

Figure 6 Core design of the TMSR-LF1 (2022). Source: TMSR Centre of CAS/SINAP

The most significant milestone of the LF branch is the TMSR-LF1 reactor, located in Minqin County, Gansu Province, within a dedicated low-carbon energy innovation zone (SINAP, 2022). Construction began in 2018, and the project progressed rapidly. A construction permit was granted in 2020 by the National Nuclear Safety Administration (NNSA), and a ten-year operating licence was issued in 2023 (World Nuclear News, 2022; Asian Nuclear Safety Network, 2023). TMSR-LF1 reached criticality on 11 October 2023 and achieved full-power operation using Thorium-based fuel on 8 October 2024. The successful detection of Protactinium-233 confirmed the breeding of Uranium-233, thereby validating the Thorium fuel cycle in a real reactor environment (Krepel, 2025).

As of 2024, China holds the distinction of operating the world's first Thorium-fuelled nuclear reactor. This achievement is not merely symbolic; it represents a technological and geopolitical breakthrough, particularly as the United States, which initially pioneered molten salt technology, abandoned Thorium research in the 1970s. The American withdrawal was largely due to shifting political priorities, the entrenchment of Uranium-based reactor infrastructure, and the military utility of Plutonium bred in Uranium reactors. Moreover, at the time, Thorium's fuel cycle presented engineering complexities that were deemed commercially unviable in a fossil fuel-dominant era (Martin, 2016).

In contrast, China has taken a long-term strategic view, identifying Thorium reactors as critical to decarbonisation and energy security, particularly in arid inland regions where conventional reactors requiring water cooling are impractical. The success of TMSR-LF1 has led directly to the development of the world's first Thorium-fuelled power station. Scheduled to begin construction in 2025 and to commence operations by 2029, this facility is expected to use a 60 MW thermal reactor to generate electricity and produce hydrogen via high-temperature electrolysis (ABC News, 2024). A 100 MW commercial small modular reactor is also planned for 2030, with potential deployment across central and western China, as well as BRI countries (IAEA, 2024).

While China’s Thorium research was initially shrouded in secrecy, the government has become increasingly open. Since 2021, China has released technical specifications, environmental reports, and performance data through platforms such as the International Atomic Energy Agency (IAEA), and the Generation IV International Forum (GIF), marking a significant departure from earlier opacity. This transparency reflects growing confidence in the technology’s maturity and a desire to shape global norms around next-generation nuclear energy.

Opportunities for Singapore

China's rapid progress in Thorium-based nuclear energy provides strategic lessons and concrete opportunities for Singapore, which seeks to strengthen energy security, diversify its fuel mix, and meet long-term decarbonisation goals. Singapore's power system is overwhelmingly gas dependent, with natural gas providing 95% of electricity generation, exposing the country to global price volatility and supply disruptions (Quah & Tan, 2022). Advanced nuclear technologies, particularly SMRs with improved safety characteristics and compact siting requirements, are increasingly discussed by policymakers as a viable complement to renewables in dense city states (Chew, 2025).

China's molten salt Thorium programme, from the TMSR-LF1 prototype to the planned 60 MW thermal commercial unit in Gansu, offers a living case study of how next generation reactors can simultaneously support energy security and deep decarbonisation (NEI Magazine, 2024).

Singapore could benefit directly in several ways. If China demonstrates commercially deployable 100 MW electric class Thorium reactors in the 2030s, Singapore could evaluate importing the technology, co-developing it with Chinese partners, or integrating it through regional power trade. Thorium MSRs are modular, occupy comparatively little land, and can be sited underground or offshore, characteristics that align well with Singapore's land constraints and stringent safety expectations (Murakami & Anbumozhi, 2022). A small fleet of such reactors could provide clean, reliable baseload power that complements solar generation and future renewable imports, reducing over reliance on natural gas while supporting Singapore's commitment to achieve net zero emissions by 2050 under the Singapore Green Plan.

China's success also opens investment and capability building pathways. Through sovereign wealth investors such as GIC and Temasek Holdings, Singapore could take equity positions in Chinese or international Thorium projects, securing returns, early technical visibility, and structured technology transfer. If institutions such as the SINAP or CNNC invite international partners into scale up phases, Singapore could negotiate participation that includes training for

Singaporean engineers, joint research programmes, and access to design data, much as it has done in aerospace and semiconductors (Aziz, n.d.).

The International Atomic Energy Agency's 2024 SMR compendium further notes that countries can accelerate readiness by partnering early on licensing, supply chain development, and safety case preparation (International Atomic Energy Agency, 2024).

Learning to construct or co-develop reactors would materially improve Singapore's energy independence profile. While Singapore currently imports almost all primary fuels, the capability to assemble and operate modular reactors domestically would create a secure, zero carbon baseload within its borders. A handful of 100 MW electric class Thorium units, comparable in electrical scale to the post TMSR-LF1 roadmap now planned in China, could meet a meaningful fraction of Singapore's round the clock demand, while avoiding greenhouse gas emissions during operation (World Energy Council, 2019). Singapore's established offshore and marine engineering ecosystem, including firms such as Keppel Offshore and Marine and Sembcorp Marine, could be adapted to assemble floating or near shore modular reactors, echoing China's own exploration of modular and air cooled advanced systems for remote or arid sites.

Industrial applications strengthen the case further. High temperature advanced reactors can co produce electricity, process heat, and hydrogen through high temperature steam electrolysis, enabling deep decarbonisation of petrochemicals, refining, and semiconductor manufacturing. Singapore could pilot a nuclear ready industrial cluster on Jurong Island that integrates small modular reactor heat and power, following the Chinese plan to pair its Gansu Thorium project with hydrogen production and Brayton cycle systems (IAEA, 2024; NEI Magazine, 2024). Academic and policy literature on ASEAN SMR deployment consistently highlights co-location with industry, hydrogen, and desalination as core value propositions for SMRs in dense or archipelagic settings (Seah, Len, & Chew, 2025).

Finally, regional cooperation can allow Singapore to benefit even without siting reactors domestically. ASEAN neighbours, including Indonesia, Malaysia, Vietnam, and the Philippines, are actively studying or re-opening the nuclear option, with Indonesia in particular assessing

SMRs for islands and industrial parks (Nuclear Business Platform, 2024) . If Chinese built Thorium SMRs are deployed in the region, Singapore could import carbon free electricity through enhanced regional grids, while positioning itself as a convenor for nuclear safety governance, emergency planning, regulatory harmonisation, and project finance.

Such a role is consistent with Singapore’s reputation for regulatory excellence, and would ensure that any regional deployment near its borders meets the highest safety and transparency standards.

Conclusion

China's evolution from early Thorium experiments in the 1970s to operating the world's first Thorium-fuelled MSRs marks a pivotal step in global nuclear innovation. Its success with TMSR-LF1, and plans for commercial-scale Thorium power plants, highlight the strategic importance of Thorium in achieving energy security, carbon neutrality, and technological leadership. By leveraging its abundant domestic Thorium reserves, rare earth mining synergies, and advanced reactor design, China is positioning itself as a first mover in next-generation nuclear technologies with significant commercial and geopolitical advantages.

For Singapore, China's Thorium programme offers both a blueprint and an opportunity. As a city-state heavily dependent on imported natural gas, Singapore can benefit from learning how Thorium-based SMRs deliver safe, reliable baseload power with a low-carbon footprint. Collaborations with Chinese institutions such as SINAP and CNNC could help Singapore build technical expertise, participate in joint research, and explore industrial applications like hydrogen production or nuclear-ready clusters on Jurong Island. Through its sovereign wealth funds, Singapore could also invest in Thorium projects, gaining both financial returns and strategic access to technology.

Regionally, Singapore could play a role as a hub for nuclear governance, safety standards, and project financing, even if it does not deploy reactors domestically. By engaging early and leveraging China's advancements, Singapore can position itself to diversify its energy mix, strengthen long-term energy security, and benefit from the emerging clean energy supply chains that Thorium reactors are likely to create.

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