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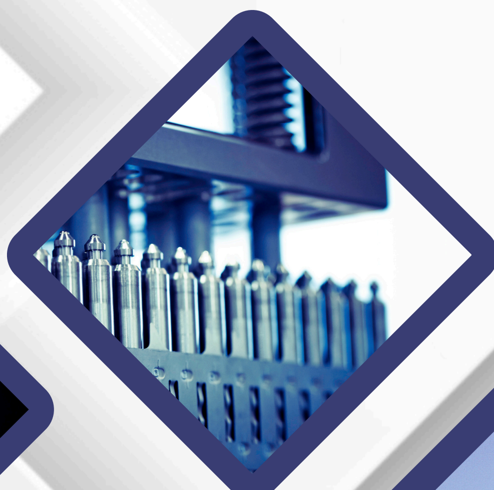
Securing Energy Leadership through SMR Innovation:

Strategic Insights for the U.S., Japan, and South Korea



Contributors

To inform this report, we conducted interviews with a diverse group of experts representing a range of sectors and all three countries central to this study, the United States, Japan, and South Korea. These contributors included:

- **Government/Regulatory Agents (3)**
- **Industry Professionals (16)**
- **Prominent Research Institute researchers (1)**

Their insights and perspectives were instrumental in shaping the analysis and recommendations presented in this report. We gratefully acknowledge their time and expertise.

Trilateral Energy Security Committee (TESC)

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Introduction

The global energy landscape is undergoing significant transformation, marked by an escalating demand for reliable and clean energy sources, particularly driven by the rapid expansion of artificial intelligence (AI) and data centers. In this context, Small Modular Reactors (SMRs) are emerging as a pivotal technology, offering a new pathway for nuclear energy deployment. As nations grapple with the dual challenge of meeting energy needs while ensuring sustainability, regulatory harmonization among key players, particularly the United States, South Korea, and Japan, becomes crucial. This white paper examines strategies to foster regulatory alignment, which is widely recognized as a vital lever to accelerate the global adoption and commercialization of SMRs.

While technological advancements in SMR design and safety have matured, regulatory fragmentation poses a significant barrier to timely deployment (Josephs et al. 2025). The United States, Japan, and South Korea face three systemic challenges: regulatory frameworks that evolved organically as part of licensing light-water reactor requirements, divergent safety standards that complicate design certification reciprocity, and asymmetric geopolitical priorities that prioritize domestic energy security over export markets. The success of SMRs hinges on the ability to achieve "economies of series," meaning mass production and widespread deployment, which is heavily influenced by how regulatory frameworks adapt and align across international borders.

Regulatory harmonization, while essential and should be undertaken first, cannot be meaningfully addressed in isolation. The deployment of SMRs is shaped by a complex ecosystem of interdependent factors, including financial viability, public perception, supply chain resilience, geopolitical dynamics, and technical readiness. Therefore, to ensure the relevance and utility of our findings, we include these systemic barriers and enabling conditions in the report. This holistic approach does not dilute the importance of regulatory harmonization; rather, it strengthens it by situating it within the broader context of SMR deployment challenges. By doing so, we aim to provide a more actionable and realistic foundation for trilateral cooperation and global market development.

Regulatory Landscape: Divergent Approaches Hinder Deployment

United States: The Litigation-Driven Model

The U.S. Nuclear Regulatory Commission (NRC) operates under a prescriptive framework codified in 10 CFR 50/52 regulations, a system that has grown from ten pages in 1960 to several thousand pages today. This approach is largely an organic outcome of public participation and administrative litigation under the Administrative Procedure Act. This extensive, primarily large-reactor-focused framework presents significant complexity, requiring applicants for SMRs to grapple with a dense and layered set of compliance factors, as regulations designed for large light water reactors often do not directly apply, necessitating numerous exemptions, prolonging licensing timelines, and increasing costs.

This regulatory rigor, while essential for ensuring transparency and public participation, can present challenges for SMR innovation. The extensive requirements originally designed for large light-water reactors, may lead to slower review timelines, increased project costs, and the need for frequent exemptions (EPRI 2022). Moreover, regulatory agencies often emphasize risk elimination over risk-informed management, which can inadvertently create barriers for emerging technologies like SMRs. This shift, especially pronounced post-Fukushima, means that new requirements can quickly become barriers for SMR technologies not envisioned by earlier laws (Danish et al. 2024). Additionally, nuclear licensing and safety requirements vary substantially from one jurisdiction to another, requiring developers to tailor compliance strategies for each market (OECD/NEA 2021). Mature regulators, cite accountability and public trust, and rarely rely on mutual recognition of foreign design approvals; instead, they require full repeat reviews, compounding redundancy, documentation, and first-of-a-kind (FOAK) engineering cost (EPRI 2022; OECD/NEA 2021). Legal systems complicate matters by enabling prolonged litigation and favoring bureaucratic caution, which in turn broadens and intensifies review requirements. For example, the NRC's 10 CFR Parts 50 and 52 add significant upfront costs and compliance burdens (NRC 2025).

Despite this, there is a push towards change. Recent U.S. legislation, such as the Nuclear Energy Innovation and Modernization Act of 2019 (NEMA) and the ADVANCE Act (enacted in 2024), mandates the NRC to adopt risk-informed and performance-based approaches. This legislative shift aims to make the framework "technology inclusive," capable of accommodating SMRs, large reactors, and micro-reactors of various technologies and applications. The core idea is to focus on high-level safety objectives, such as protecting the reactor, safeguarding people from radiation, and nuclear material from sabotage, theft, and diversion. If all regulatory bodies agree on these objectives, the methods for achieving them can be left to the applicants, fostering harmonization and flexibility. Historically, the NRC's mission was broader, aiming to enable and facilitate civilian nuclear use for societal benefit, but it became heavily fixated on public health and safety at the expense of considering the societal benefits of clean and affordable energy. The current administration is committed to expanding advanced nuclear technologies, streamlining regulation, and quadrupling U.S. nuclear capacity by 2050 (Nakano and Abrahams 2025).

The design certification of NuScale's VOYGR (US460) reactor marked a regulatory milestone, as it received multiple exemptions from legacy NRC regulations and set a precedent for reduced emergency planning zones tailored to its passive safety features. Notably, the NRC completed its technical review of the US460 in less than two years, issuing the Standard Design Approval ahead of schedule and under budget (Martucci 2025). The current U.S. SMR development landscape includes a diverse portfolio of advanced reactor projects spanning multiple technologies and stages. Table 1 summarizes the U.S. SMR project pipeline, highlighting the diversity of reactor technologies under development, their capacities, and current licensing or deployment status.

Developer	Technology	Capacity (MWe)	Status
Oklo	Liquid metal fast reactor	50–75	Siting and borehole drilling complete; NRC pre-application review; commercialization prioritized
GE Hitachi	BWRX-300 (boiling water)	300	Filed NRC construction permit (May 2025); first unit expected to begin construction late 2025
X-Energy	Xe-100 (high-temp gas)	320 (4 × 80)	NRC construction permit accepted (May 2025); first deployment targeted early 2030s
NuScale	VOYGR-6 (integral PWR)	462	U.S. deployment canceled (2023); design available for other markets
TerraPower	Natrium (sodium fast reactor + molten salt storage)	345 (up to 500 peak)	Construction underway at Kemmerer, Wyoming; NRC permit review accelerated (completion targeted end 2025); operational launch by 2030; DOE ARDP and major new investment; first-of-a-kind advanced deployment
Pipeline Various	Mixed (multiple early-stage)	~3,000+	Announced, in pre-development, or seeking permits

Table 1 U.S. Project Pipeline

Japan: Post-Fukushima Reforms

In response to the 2011 Fukushima disaster, Japan established the NRA to overhaul its nuclear safety framework. While these reforms were driven by technical considerations, they were also shaped by strong public opposition to nuclear energy. The NRA implemented stringent regulations, including enhanced tsunami defenses, mandatory hydrogen venting systems for boiling water reactors (BWRs), and stricter conditions for reactor restarts to restore public trust and ensure long-term safety (NRA 2013).

The NRA also mandates a full approval process for every new facility, covering all stages from design and construction to detailed safety plans - now explicitly including provisions for potential terrorist threats. Additionally, nuclear operators in Japan are subject to an unlimited liability framework in the event of a reactor failure. This legal and financial structure significantly increases the cost of investment and creates substantial challenges in securing financing. Combined with the lengthy and complex licensing procedures, these factors contribute to a constrained investment climate and diminish industry incentives to pursue the deployment of innovative nuclear technologies, such as SMRs.

Following the 2022 global energy security crisis, which exposed energy security vulnerabilities, and in consideration of policy goals for carbon reduction, Japan has (re)committed to increasing nuclear power’s role in its energy profile. However, Japan's current nuclear regulations were established and primarily designed for restarting existing conventional light water reactors, not for new construction or SMRs, creating a regulatory vacuum for SMRs in Japan. In our interviews we found that Japanese experts acknowledge that the U.S. NRC is ahead of Japan in establishing regulatory responses to new SMR technology and therefore regulatory collaboration could be path forward for SMR progress in Japan. Furthermore, Japan's Seventh Strategic Energy Plan acknowledges the regulatory and technological gaps in deploying SMRs and calls for the development of new regulatory frameworks tailored to these technologies (METI 2025).

As a model state under the global nuclear non-proliferation regime, Japan maintains a comprehensive safeguards system under the International Atomic Energy Agency (IAEA). It has developed operational nuclear fuel cycle capabilities, including uranium enrichment using centrifuge technology developed by Japan Nuclear Fuel Limited, and the pluthermal program to recycle uranium as mixed oxide (MOX) fuel, supported by the construction of a dedicated MOX fuel fabrication plant, all operating under comprehensive international safeguards. By contrast, South Korea has not developed these technologies and the United States only possesses them with limited commercial application. Therefore, Japan’s operational experience offers a complementary foundation for advancing trilateral collaboration on nuclear fuel cycle technologies.

South Korea: Export-Oriented Framework

South Korea's independent nuclear regulator, the Nuclear Safety and Security Commission (NSSC), oversees the safety licensing, inspections, and standards-setting for all civilian nuclear facilities, including SMRs. The Korean regulatory framework developed in close collaboration with the Korea Institute of Nuclear Safety (KINS), is recognized for its technical rigor and is broadly aligned with the U.S. NRC framework in terms of prescriptive depth and comprehensive design review processes (Shin et al. 2024).

Korea Hydro & Nuclear Power (KHNP) has aggressively pursued global expansion, positioning its reactors, most notably the SMART SMR design, as technically mature, cost-effective, and reliably delivered on schedule (IAEA 2024a). A key factor for Korean export success has been strategic alignment with the U.S. on nuclear cooperation and the leveraging of internationally recognized regulatory standards (OECD/NEA 2025). However, a critical barrier to export efficiency is the multi-layered duplication of design reviews by different national authorities, which routinely adds 18–24 months to project timelines (Carson et al. 2023). As summarized in Table 2, the SMART reactor required a 60-month domestic certification process by KINS, despite reaching Technology Readiness Level 8 at an early stage. In contrast, the design's adaptation for deployment in the United Arab Emirates (UAE) completed its site-specific licensing review in only 18 months, as the UAE's Federal Authority for Nuclear Regulation (FANR) accepted KINS's prior evaluations with minor site-specific modifications (Nuclear Engineering International 2012). This experience highlights both the inefficiencies in certifying designs separately for each market regime and the value of regulatory reciprocity or mutual acceptance.

Phase	Duration	Key Achievement
Design Certification	~ 60 months	Technology Readiness Level 8 reached
UAE Adaptation	18 months	Site seismic/foundations
ASEAN Region Market Prep	Ongoing	Climate adaptation studies

Table 2 SMART Reactor Certification Milestones

Korea's SMR strategy reflects both opportunities and constraints in international regulatory cooperation. While the SMART reactor's export success demonstrates success of regulatory reciprocity, Korean regulatory agencies KINS and the Korea Institute of Nuclear Non-proliferation and Control (KINAC) remain primarily focused on their domestic i-SMART design, showing limited engagement with international SMR variants. This specialization enables deep expertise in Korean technology but may constrain broader regulatory harmonization efforts. Additionally, Korean SMR equipment manufacturers face significant challenges from U.S. trade and tariff policies, often finding these commercial barriers more substantial than regulatory ones. Success in international markets increasingly requires government-to-government cooperation on trade policy alongside regulatory alignment, with Korean companies seeking government-led support such as R&D subsidies and tax credits to compete effectively against state-backed international competitors.

Regulatory Inertia

Regulatory Inertia refers to the tendency of regulatory bodies to maintain existing rules and processes. This carries the risk of becoming ineffective or outdated but can also allow agencies to develop expertise and specialization. Table 3 highlights the regulatory inertia faced in harmonizing licensing frameworks for a number of major markets involved in the SMR landscape.

Country/Region	Prescriptive Elements	Performance-Based Progress
United States	NRC's 10 CFR framework (Parts 50, 52), requirements for design certification and safety analysis for SMRs, referencing traditional large reactor criteria.	Ongoing NRC initiatives on risk-informed, technology-neutral frameworks for advanced reactors (e.g., proposed Part 53, endorsement of passive/inherent safety features in SMRs); coordination with legislative mandates for regulatory modernization (e.g., the ADVANCE Act).
United Kingdom	Risk-informed, goal-setting regulatory framework managed by the Office for Nuclear Regulation (ONR), which eschews detailed prescriptive rules in favor of high-level safety objectives. While industry-specific codes exist, the framework is less rigid.	Strong emphasis on technology-neutral, outcomes-based regulation, facilitating flexibility and innovation in SMR licensing; active piloting of performance-based licensing and regulatory harmonization efforts with international partners.
European Union	National authorities use IAEA and WENRA safety standards, with strong reliance on prescriptive design-basis scenarios and deterministic safety requirements for SMRs.	NEA and EU projects stimulating probabilistic and performance-based review methods, pilot application to SMR designs focusing on modular deployment and inherent/passive safety claims.
Japan	High prescriptive emphasis on seismic provisions, siting, and	Incremental adoption of technology-neutral and risk-informed principles post-Fukushima, guided partly by

	detailed deterministic criteria in safety review of SMRs.	IAEA recommendations on passive safety demonstration in SMRs.
South Korea	KINS (Korea Institute of Nuclear Safety) applies prescriptive national codes tailored to legacy PWRs but now extended to SMRs.	Introduction of regulatory exemptions and targeted performance-based assessment for SMART reactor projects; participation in IAEA international review missions on advanced SMRs .
Canada	CNSC prescriptive licensing structure, extensive deterministic safety case requirements for SMRs.	CNSC's framework encourages technology-neutral, risk-informed review; early SMR applications have been used as testbeds for performance-based, graded approaches.

Table 3: Regulatory inertia for SMRs (IAEA 2024b) (OECD/NEA 2021)

The competitive landscape is further complicated by regulatory modernization challenges within allied nations. Korea's regulatory system, like Japan's, is considered outdated compared to the U.S., requiring urgent modernization to remain competitive. However, this modernization is increasingly driven by private sector demands rather than government initiative. Korean companies facing growing demand to build SMRs licensed abroad domestically are pushing regulators to align with U.S. standards, demonstrating how commercial pressures can accelerate regulatory reform more effectively than top-down international frameworks.

To take advantage of regulatory inertia while preventing it from becoming a roadblock, policymakers must actively confront inefficiencies and engage with multiple actors in the process to adopt best practices and streamline the entire supply chain. Table 3 shows that the United States exemplifies deep prescriptive frameworks now evolving into risk-informed approaches, that Japan maintains high seismic prescriptiveness but pilots' technology-neutral reviews, and that South Korea balances prescriptive rules with pragmatic performance-based exemptions. Canada similarly pioneers' risk-informed licensing as a best-practice model. If countries can harmonize across best practices such as these, SMR deployment can be rapidly accelerated. In the next section, we demonstrate this opportunity with an example from UAE.

Opportunity Costs

Prediction of regulatory costs is challenging, given the unforeseen issues with new technologies. However, initial estimates[1] indicate that opportunity costs from regulatory delay have far greater potential to make projects economically unsustainable than direct regulatory expenses. Using estimates from various sources, direct regulatory costs (licensing, compliance, and qualification) range from $20–50 million for light-water SMRs to $500 million–1.2 billion for FOAK advanced reactors for each year spent awaiting approval (which would rapidly decrease for NOAK). In contrast, Opportunity costs - the revenue forgone when regulatory delays postpone commercial operation, can cost $120–180 million for niche microreactors and $375–500 million for mid-scale SMRs reactors per year of delay. These indirect costs exceed direct expenses by one to two orders of magnitude and are more difficult to incorporate into budget projections and investment decisions. Regulatory harmonization can substantially reduce the risk of regulatory delay after FOAK projects are approved in one country, facilitating investment procurement for NOAK projects and creating an economically sustainable deployment model.

Strategic Lessons for Regulatory Harmonization

International Cooperation Models

The Barakah nuclear power project in the UAE offers concrete evidence of the economic and operational benefits achievable via regulatory harmonization and reciprocity. With the UAE's FANR leveraging technical assessments from South Korea's KINS, the following outcomes were realized:

- Reduction in redundant documentation and design reviews: Conventional nuclear projects generate thousands of pages of design documentation per certification cycle. The mutual acceptance of regulatory evaluations minimized duplication and improved efficiency.
- Lower FOAK engineering costs: Industry estimates suggest redundant regulatory reviews inflate FOAK engineering costs by up to 30% (EPRI 2022). The Barakah project demonstrated that coordination cuts these excessive costs significantly.
- Streamlined Regulation: The Barakah nuclear power plant came online within 8 years from first concrete to fuel load, a relatively fast timeline (Dalton 2024). This reduction in regulatory delays underscores the potential benefits of coordinated frameworks for

[1] Researchers Gal Blatman and Shon R. Hiatt at the Zage Business of Energy Initiative, USC Marshall School of Business have worked to produce these estimates. For more detail on the estimates and how they were produced, please see https://hamminstitute.org/site-files/documents/regulatoryharmonizationforsmrs.pdf

nuclear technology transfers, exemplified by the UAE's acceptance of Korean certification findings. This reduction in regulatory delay illustrates the tangible time-saving potential for technology transfers under coordinated frameworks.

These lessons underscore why the trilateral framework between the U.S., Japan, and South Korea must pursue “certify once, deploy anywhere” paradigms - a regulatory approach that entails mutual recognition or acceptance of reactor design certifications among multiple national regulatory authorities with exemptions only for necessary local adaptations. Such mutual recognition would streamline global SMR deployment, reduce engineering overheads, and enhance competitiveness of advanced nuclear vendors.

Notably, this concept is supported by international initiatives such as, International Atomic Energy Agency's (IAEA) Nuclear Harmonization and Standardization Initiative (NHSI), promoting common safety standards and collaborative regulatory capacity building. The success of regulatory cooperation is further demonstrated by the trilateral partnership between the United States, Canada, and the United Kingdom on SMR licensing. This collaboration enables coordinated design reviews, regulatory information sharing, and technical assessment coordination among three advanced nuclear regulators. The partnership benefits from shared language, comparable regulatory frameworks, and equivalent technical maturity, factors that Korean industry experts have identified as potentially applicable to Korea-U.S.-Japan cooperation. The model shows how advanced nuclear nations with sophisticated regulatory systems can achieve practical harmonization while maintaining regulatory independence and sovereignty.

Synthesis: Toward a Unified, Competitive SMR Market

Integrating the Regulatory Inertia Matrix with practical export lessons like Barakah shows that regulatory harmonization is both a technical and strategic imperative. While regulatory prescriptiveness and institutional differences drive inertia, coordinated efforts even if initially phased and pilot-driven can unlock a "one great market" across these key nuclear powers.

The U.S. NRC’s evolving frameworks provide a detailed prescriptive baseline enhanced by risk-informed modernization. Japan’s seismic and safety rigor complements its pioneering of technology-neutral review pilots. South Korea’s pragmatic use of exemptions and safety-by-design philosophies translates into export successes and regulatory innovations. Together, aligned through trilateral cooperation and supported by forums like IAEA, these countries can create a scalable regulatory ecosystem that efficiently certifies SMRs once and facilitates their deployment across borders. The challenge lies in balancing multilateral inclusivity with practical effectiveness. International frameworks like the IAEA's NHSI, while providing important baseline standards, face inherent limitations due to their broad membership and consensus-driven processes. Korean representatives participating in NHSI have noted the tension between the IAEA's focus on peaceful nuclear use and the industry's need for commercially viable regulatory pathways. This suggests that effective harmonization may require a layered approach: broad international standards through organizations like the IAEA, complemented by more focused partnerships among advanced nuclear nations with aligned commercial and security interests. This unified approach promises to reduce review time delays, cut engineering costs, eliminate redundant documentation, and accelerate SMR market growth addressing both industry demands and public safety mandates.

Market Dynamics and Competitive Pressures

The global SMR market is rapidly evolving, driven by a unique combination of economic promises, escalating energy demands and security challenges, geopolitical shifts, and intensifying international competition. Understanding these dynamics, particularly China's emergent technology leadership, highlights the strategic urgency for the United States, Japan, and South Korea to pursue trilateral regulatory harmonization to maintain competitiveness and accelerate deployment.

In terms of absolute scale, China currently leads the global SMR race and nuclear deployment, a position attained through strong government direction, extensive state investment, and a centralized deployment strategy:

- Gigawatt-Scale Operational Capacity: As of 2025, China operates 58 nuclear reactors, including advanced SMR variants like the high-temperature gas reactors (HTGRs) and thorium-fueled designs, and has 29 reactors under construction, a scale far surpassing other nations (IAEA 2025).
- Continuous Construction and "Nth-of-a-Kind" Production: China's government-directed, uninterrupted build programs foster rapid learning curves, cost reductions, and swift supply chain maturation. This "Nth-of-a-kind" philosophy contrasts sharply with the slower, fragmented deployment seen elsewhere, enabling China to build reactors faster and more economically.
- Technological Innovation: Chinese SMR technology portfolios emphasize novel reactor concepts, including thorium-based and pebble-bed reactors, positioning them not only as volume leaders but innovation trailblazers.

Table 4 summarizes key metrics reflecting operational reactors, SMR technical readiness, and regulatory approval timeframes across leading nuclear countries, highlighting varying levels of maturity and market momentum.

Metric	China	South Korea	U.S.	Japan
Operable Reactors	58	26	94	36

SMR Technical Readiness (TRL)	9 (HTGR)	8 (SMART)	7 (Natrium)	6 (HTR)
Regulatory Efficiency (Approval Time)	48 months	60 months	84 months	No framework established

Table 4 Current nuclear momentum and Technology Maturity

South Korea has also emerged as a strong contender in SMR deployment, building on its legacy as a reliable exporter of large reactors. KHNP has successfully demonstrated its export capabilities with the Barakah nuclear power project in the UAE, where four APR1400 reactors were delivered on schedule and budget. This project showcased South Korea's ability to execute large-scale nuclear projects internationally through effective regulatory cooperation between Korea's KINS and the UAE's FANR.

In addition to the APR1400, South Korea has developed the SMART reactor design, which completed domestic certification and has attracted international interest through cooperation agreements, including a memorandum of understanding with Saudi Arabia. However, SMART has not yet achieved commercial deployment and remains primarily at the development and partnership stage rather than operational implementation. Despite this, KHNP is actively pursuing European, Middle East and Southeast Asian markets, positioning itself as a challenger to incumbents based on its proven track record with conventional reactor exports.

The United States, despite its historical leadership in nuclear innovation, has seen slower SMR progress, with regulatory timelines averaging 84 months. However, federal funding and international partnerships are accelerating efforts around advanced designs like NuScale and TerraPower's Natrium. Japan remains focused post-Fukushima on restarting existing reactors and piloting HTGR projects. With no formal SMR framework and lower technology readiness levels, Japan's regulatory modernization is ongoing but not yet conducive to rapid deployment.

Regulatory harmonization improves efficiency, which in turn reduces costs and strengthens competitiveness. However, regulatory harmonization alone is insufficient. The systemic barriers examined in the following section reveal the interconnected challenges that must be addressed alongside regulatory reform to enable effective trilateral cooperation and maintain leadership in SMR deployment.

Systemic Barriers to Global SMR Deployment

In addition to regulatory and market factors, the global deployment of nuclear energy, and particularly SMRs, is impacted by a mix of financial, social, supply chain, geopolitical, and technical challenges. These barriers are interrelated and often reinforce one another, making coordinated solutions critical for global progress.

Financial and Economic Challenges

SMRs, while expected to reduce costs through modular and serial production methods, still entail high initial investment requirements (Shobeiri et al. 2023). The lack of transparency in regulatory review costs, and the unpredictability of timelines compounded by shifting tariff incentive structures, further deter investment (Sustainability Directory 2025). Competing against state-backed enterprises from China and Russia, which benefit from preferential financing and streamlined domestic regulation, Western firms rely disproportionately on government support (Gaster 2025). The competitive landscape is further complicated by regulatory modernization challenges within allied nations. Korea's regulatory system, like Japan's, is considered outdated compared to the U.S., requiring urgent modernization to remain competitive. However, this modernization is increasingly driven by private sector demands rather than government initiative. Korean companies facing growing demand to build SMRs licensed abroad domestically are pushing regulators to align with U.S. standards, demonstrating how commercial pressures can accelerate regulatory reform more effectively than top-down international frameworks.

Social and Public Perception Challenges

Public skepticism, often rooted in historical accidents, has led to persistent opposition and reduced political appetite for new projects and is particularly notable in Japan, where support has dropped to 39% as compared to 59% before the Fukushima Daiichi incident (JAIF 2024). Politicians, wary of backlash, are reluctant to champion new nuclear developments. Efforts to clearly communicate the safety improvements and benefits of SMRs, such as smaller emergency planning zones, have yet to convince many stakeholders.

Supply Chain and Workforce Challenges

The post-Fukushima environment resulted in the contraction of the global enrichment and fuel supply chain—especially for the HALEU fuel vital for many SMR designs—and the simultaneous decline in pipelines producing experienced workforces for reactor design and operation. Currently, Russia dominates global HALEU supply as the primary commercial supplier, creating a strategic vulnerability for U.S. and allied SMR deployment (ExchangeMonitor 2025; Third Way 2023). Manufacturing bottlenecks such as limited access to ultra-large forgings (predominantly in Asia) and a shrinking skilled workforce add to deployment difficulties. In the United States, regulatory screening requirements further exacerbate workforce challenges by disqualifying a substantial portion of potential candidates. This issue is particularly pressing as 38% of the current nuclear workforce is projected to retire by 2030 (Lochbaum 2017; ClearPath 2017). Conversely, Korea's relatively robust nuclear workforce and supply chain capabilities could provide solutions for U.S. workforce shortages and broken supply chains. Japan's strength in fuel fabrication similarly positions it as a valuable partner for addressing supply chain vulnerabilities. This complementarity suggests that regulatory harmonization should be pursued alongside workforce and supply chain partnerships to maximize mutual benefits.

Geopolitical and International Relations Challenges

China's rapid SMR deployment and relatively streamlined regulatory process have given it a clear technological and market lead, while Russia still dominates global fuel supply (IAEA 2025). The U.S. "gold standard" policy requiring strict nonproliferation compliance and limitations on enrichment has driven some partner countries to turn to Russian alternatives (U.S. congress 2025). National policy constraints such as Japan's post-Fukushima restrictions and South Korean enrichment restrictions under U.S. 123 agreements limit their engagement in multilateral markets and projects (U.S. Congress 2025).

Additionally, the significant role played by China and Russia in international nuclear bodies like the IAEA, where they hold voting rights and influence standard-setting processes, has motivated some Western governments to pursue alternative forums for nuclear policy coordination. The International Energy Agency (IEA), which comprises thirty-one advanced economies and excludes China and Russia from membership, has increasingly focused on nuclear energy policy, including SMR development strategies. This shift reflects Western preferences for setting nuclear standards and policies within forums dominated by allied nations, though such an approach, risks creating parallel governance structures in the global nuclear sector.

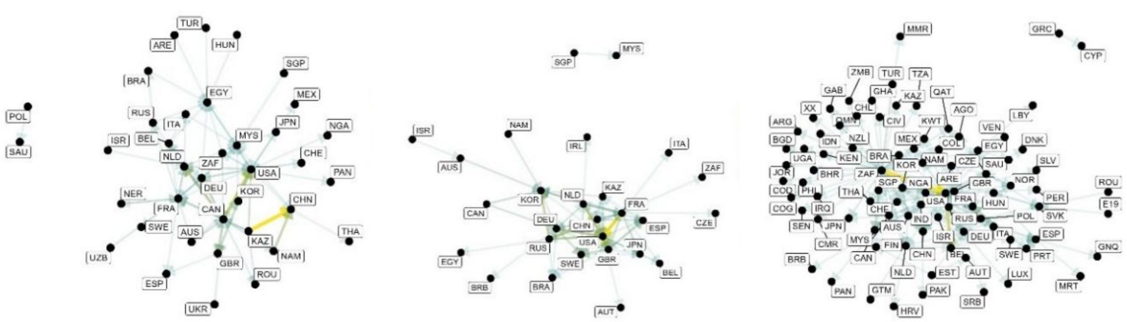
Technical and Design Challenges

The central challenge for global SMR deployment lies in the proliferation of reactor designs without standardization. The SMR field is characterized by 127 designs globally under 5 major reactor concept categories, most of which remain at early development stages (NEA 2025). The proliferation of designs directly slows down market adoption, requiring additional regulatory review. Furthermore, design standardization is necessary to leverage modularity and achieve economies of series. Many advanced designs are promoted aggressively despite lacking operational history, thorough regulatory vetting, or backing from experienced corporate sponsors, making them more marketing-driven than proven technology. It is difficult for startups and venture-funded companies to demonstrate a robust safety case for new reactor types because they demand significant, costly, and complex engineering R&D. Site-specific adaptation such as seismic, meteorological, or grid integration considerations can add significant costs in major markets like the U.S. and Japan (IAEA 2021). Additionally, innovative technologies often require novel operational and regulatory skillsets, compounding the workforce challenge. In short, design fragmentation amplifies costs and delays, making standardization and proven pathways essential for SMRs to scale.

Uranium Enrichment and Trade Vulnerabilities

Uranium enrichment capacity in allied nations has faced significant challenges over the past decade. In the wake of the Fukushima disaster, widespread reactor shutdowns depressed uranium prices, eliminating commercial incentives to sustain or expand western enrichment infrastructure (Son et al. 2023). This has resulted in a fragile "chicken-and-egg" environment, wherein suppliers hesitate to invest in new enrichment capacity absent firm reactor orders, and new reactor developers struggle to secure fuel contracts due to uncertain future supply. Market access and competition in this sector remain limited by strict nonproliferation controls, with only a small number of states authorized to operate commercial enrichment facilities. Historically, Russia became the leading global enrichment provider by leveraging scale and cost competitiveness, a dominance that discouraged Western investment. Following Russia's invasion of Ukraine in 2022, however, Western nations raced to reduce dependence on Russian supply, rapidly investing in enrichment plants in the U.S. and Europe though this surge has raised concerns about potential future oversupply and the need for sustained government support (Third Way 2023). China, meanwhile, is quickly building enrichment capabilities as part of a national strategy for supply self-sufficiency.

To better understand the risks in the uranium supply chain, we developed a visualization of unprocessed, enriched, and depleted uranium trade networks in 2024, presented in Figure 1. The structure of the networks and contrast between them lead to several interesting findings. The unprocessed uranium trade network has a relatively dense core and a clear periphery, with major traders such as South Korea, France, and the U.S. in the center. Enriched uranium has a similar structure but includes a much smaller number of countries. This highlights challenges to enriched uranium supply chains, as it increases the likelihood of being dependent on one or a few suppliers. The depleted uranium trade network is the most robust of the three, with two bifurcated cores and a large number of peripheral importers. This is likely due to the fact depleted uranium has a wider array of uses, such as manufacturing armor-piercing ammunition, is also purchased to recycle, and purchasing it is not hindered by as many policy restrictions.



Unprocessed Enriched Depleted

Figure 1: 2024 Uranium trade network

These vulnerabilities became particularly evident following Russia's invasion of Ukraine in 2022 and subsequent U.S. legislation in 2024 restricting Russian uranium imports, with full implementation planned by 2028 (Day 2024). Prior to these geopolitical disruptions, Russia supplied approximately 20% of U.S. uranium and dominated global enrichment capacity. The current network structure in 2024 still reflects this transition period, with Western nations working urgently to diversify supply chains and rebuild domestic enrichment capabilities. This shift has created both immediate supply challenges and longer-term opportunities for allied cooperation in fuel cycle security.

Regulatory and political restrictions further complicate enrichment strategies for U.S. allies. South Korea is expressly barred from domestic enrichment under its bilateral agreement with the U.S., forcing it to import all enriched uranium for its nuclear fleet (Baskaran and Schwartz 2025). Japan, while possessing enrichment capability, operates under extensive international oversight and nonproliferation commitments that limit its flexibility.

Alternative approaches such as fuel reprocessing are also under renewed discussion, primarily to address back-end fuel cycle concerns and supplement enrichment capacity. Japan, drawing on its established capabilities under IAEA safeguards, is already pursuing this strategy through its MOX fuel program, in line with its role as a model non-proliferation state and its efforts to close the nuclear fuel cycle. In the U.S., by contrast, the absence of a long-term waste management policy has spurred debate about the feasibility of commercial reprocessing as a route to reduce enrichment needs by recycling recovered plutonium into new fuel, a strategy already pursued by Japan. However, waste management remains unresolved in several countries, and this uncertainty undermines the long-term business case for new builds, adding another layer of complexity to fuel cycle planning and investment decisions (World Nuclear Association 2025).

In sum, the enrichment segment of the nuclear supply chain faces intertwined commercial, political, and strategic challenges that must be addressed to ensure a resilient and independent nuclear fuel cycle for advanced reactor deployment.

Policy Recommendations for Regulatory Harmonization and Reform

Foundations for Regulatory Harmony

Transitioning to Performance-Based Regulatory Approach

Current prescriptive, compliance-focused regulations create unnecessary barriers to nuclear deployment. A shift toward performance-based approaches that emphasize achieving core safety objectives regardless of specific technologies would significantly reduce licensing timelines and costs while maintaining robust protection. The UK's technology-neutral, outcomes-based framework provides a successful model that allows applicants flexibility in demonstrating safety, significantly reducing licensing timelines and regulatory costs while preserving robust protection (IAEA 2024b).

Leveraging U.S. Regulatory Leadership

The U.S. NRC is widely perceived as an international benchmark for nuclear regulation. It combines rigorous safety oversight with a flexible and pragmatic approach that is adaptable to emerging and diverse reactor technologies, including advanced SMRs. This adaptability, coupled with the NRC's reputation for transparency and independence, confers a significant competitive advantage. Supporting and preserving the independence and high standing of regulatory agencies such as the U.S. NRC is vital because their credibility underpins investor confidence and global design acceptance.

Modernizing Nuclear Legislation

Legislative reforms, including the Nuclear Energy Innovation and Modernization Act (NEMA) and the ADVANCE Act, represent important steps to modernize and streamline the licensing regime for advanced reactors, reducing uncertainty and facilitating market entry (Sen. Barrasso 2019; DOE 2024). Regular benchmarking of U.S. regulatory and deployment practices against leaders like China and South Korea can lead to continuous improvements (Gaster 2025).

International Coordination and Mutual Recognition

International coordination offers substantial benefits for reducing redundant licensing processes. Fostering mutual recognition of reactor certifications across jurisdictions is critical to eliminating redundant licensing, as exemplified by the UAE's acceptance of a Korean-designed reactor assessments for the Barakah project, which reduced duplication in regulatory reviews and contributed to greater efficiency (OECD/NEA 2021). Enhancing international collaboration through active participation in forums like the IAEA SMR Regulators' Forum promotes the development of shared safety standards and mutual trust.

Industry-Government Collaboration in Regulation

Achieving meaningful regulatory reform also benefits from recognizing the evolving role of private sector leadership in nuclear development. Industry-led initiatives, such as international conferences that facilitate regulatory dialogue, can complement traditional government frameworks by fostering practical cooperation and shared learning. Private sector engagement in regulatory modernization efforts can help identify implementation challenges and accelerate the adoption of performance-based approaches. While China currently leads in momentum through strong government direction and continuous construction models, the substantial regulatory strengths, transparent governance, and innovation culture of the U.S. and its allies can provide a powerful foundation for rapidly retaking nuclear leadership through coordinated policy and regulatory action.

Policy Interventions beyond Regulatory Harmonization

Regulatory harmonization is an important first step for accelerating SMR deployment and building US-led, alliance-supported leadership in the industry. However, regulatory harmonization alone will be insufficient. The following strategic interventions in fuel cycle security, financial frameworks, and workforce development must occur alongside regulatory harmonization to enable competitive acceleration and sustained nuclear deployment leadership.

Addressing Fuel Cycle and Supply Chain Vulnerabilities

Western reliance on Russian enrichment capacity and declining domestic capabilities expose critical strategic vulnerabilities. Governments must recognize enrichment capacity as a strategic national asset and actively support the expansion or maintenance of domestic enrichment infrastructure. The triad should also explore opportunities for enhanced allied cooperation in fuel cycle security, including potential adjustments to existing bilateral agreements where, if mutually beneficial; this could strengthen collective energy independence while maintaining robust nonproliferation standards. Additionally, the triad should encourage commercial reprocessing and plutonium recycling as another pathway to enhance fuel self-sufficiency and mitigate enrichment demand, especially since the lack of established waste management frameworks for new reactors pushes reconsideration of reprocessing policies.

Financial and Economic Support mechanisms

Regulatory complexity and overburdened processes remain principal contributors to high capital costs and uncertain returns, compromising nuclear competitiveness relative to other clean energy sources. Governments should deploy targeted financial incentives such as tax credits, grants, and federal loan guarantees and adopt innovative risk-sharing models similar to those used in other high-capital infrastructure sectors, to help offset the cost unpredictability associated with prolonged licensing processes. This can be completed in parallel paths. First, tariff structures that value consistent high-capacity output would further also enhance the investment attractiveness of nuclear power. Second, establishing specialized infrastructure financing vehicles, including potential international nuclear infrastructure banks, would create dedicated access to construction and commissioning capital for nuclear projects. Furthermore, policies emphasizing continuous fleet deployment and serial SMR construction, following China’s successful approach, will enable steep cost reductions through learning curves and more efficient industrial utilization.

Workforce Development

Addressing the worsening gap in skilled personnel entails significant investments in education, training, and up-skilling initiatives spanning all stages of the nuclear project lifecycle from conceptual design and licensing to construction, operation, and advanced maintenance. Concurrently, workforce screening practices–for example, non-safety critical drug testing and psychological assessments–should be periodically reviewed and, where appropriate, adjusted to broaden the talent pool and reduce escalating labor costs without compromising safety standards.

Final Thoughts

Without coordinated action, the three democratic allies risk ceding SMR market leadership to competitors who benefit from streamlined state-directed development and deployment processes. Regulatory harmonization stands as the imminent priority that will determine the success of global nuclear energy expansion. The coordinated achievement of performance-based regulatory approaches, international mutual recognition, and strategic regulatory leadership establishes the foundation upon which all other nuclear advancement depends. While fuel cycle security, financial frameworks, and workforce development remain critical, regulatory harmonization serves as the multiplying force that transforms isolated national efforts into a globally competitive nuclear renaissance. In summary, a holistic policy approach that integrates regulatory modernization, strategic fuel cycle support, robust financial frameworks, and proactive workforce planning is essential for unlocking the full potential of SMRs and ensuring the sustained growth of nuclear energy in the context of global energy demand expansion.

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