

China at the forefront of energy innovations: From renewable energy to nuclear fusion

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Abstract

Over the past several years, the topic of energy sufficiency and security for states has once again come to the forefront in the context of the reconfiguration of primary energy resource flows due to the following: increasing geopolitical tensions, growing energy demand from developing countries, and the rapid rise in electricity consumption associated with the large-scale commissioning of data storage and processing centers, widespread use of artificial intelligence, expansion of electric vehicle adoption, active robotization of production, and other factors. As before, energy security remains a cornerstone of development and remains important for maintaining competitive economic positions, but in modern conditions of geo-economic and geopolitical uncertainty the requirements for energy security are significantly increasing in the context of growing energy deficit. At present, by developing and implementing a wide range of technologies across all subsectors of the energy industry China has built the world's largest energy infrastructure and continues to develop it thus reshaping the global energy landscape. This comprehensive approach is interesting in itself, as is the speed of its implementation.

This paper investigates China's pioneering role in energy innovations, starting from expansive renewable sources like solar, wind and hydro to cutting-edge technologies such as advanced energy storage, hydrogen technologies, smart grid infrastructures, and nuclear fusion.

Through a qualitative analysis of official documents, policy frameworks, and recent technological breakthroughs, we explore how these advancements shape the country's new energy profile through enhancing the resilience and competitiveness of the economy, as well as positively impacting the environment. At the heart of this transformation lies a state-coordinated approach: massive investments in fuel, the rapid deployment of non-fossil energy systems, supported by policies.

We highlight technological breakthroughs and innovations that enhance domestic resilience, reduce import dependencies (notably in oil and gas), and position China as a leader in global supply chains through vertical integration and state-guided R&D.

By examining these elements, the paper emphasizes how China's model – blending policy foresight, industrial capacities, and technological self-sufficiency – offers valuable lessons for industry development, while also raising questions about geopolitical implications and the feasibility of replication in other countries. This paper argues that China's energy trajectory is redefining competitiveness, which intertwines environmental goals with economic and strategic positioning.

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Introduction

Energy capacity and energy security are among the key components of successful socio-economic development of states and imperative in maintaining the competitiveness of their economies. This applies to both the industrial stage of development, where industry is the main consumer of energy, and the information and post-information eras, where computing power and data centers consume ever-increasing amounts of energy. For China, with its largest manufacturing base and dynamically developing new productive forces, energy innovation has become a cornerstone of the national development strategy through linking environmental considerations with industrial competitiveness and global technological leadership. The country's dual objectives of peaking carbon emissions before 2030 and achieving carbon neutrality by 2060 (Ye, 2025) serve not only as climate commitments but also as guiding principles for restructuring China's energy system.

These ambitions are codified in key planning documents including the 14th Five-Year Plan, the Action Plan for Carbon Dioxide Peaking Before 2030, and the forthcoming Energy Law 2025. Together, these frameworks promote rapid expansion of non-fossil energy sources and modernization of national energy infrastructure including digital grid systems, ultra-high-voltage transmission lines, and advanced storage technologies. They also provide targeted incentives for R&D, industrial upgrading, and market reforms (Xinhua News, 2023; China Energy Storage Alliance, 2025).

China's energy transformation is supported by record-level investments that reflect the government's long-term commitment to decarbonization and industrial modernization. In 2023, the country invested approximately 676 billion USD in energy transition initiatives, which ranks China as the largest investor globally in this domain (State Council Information Office of the People's Republic of China, 2024). This trend is expected to continue, with investment in power grid infrastructure projected to exceed 650 billion yuan (~90 billion USD) in 2025, marking the highest annual amount to date (Reuters, 2025). These investment figures highlight the scale of China's transition efforts and illustrate how financial planning, infrastructure development, and climate policy are strategically aligned.

China's energy transition is shaped by strong institutional coordination, long-term planning, and industrial policy. Government agencies play an active role in allocating investment, supporting domestic manufacturing, and connecting research with practical application. As a result, China has achieved large-scale deployment of advanced technologies ranging from high-efficiency solar panels to compressed air energy storage, green hydrogen systems, and nuclear fusion research. Together, this coordinated approach strengthens energy resilience and China's position in global energy markets, including clean energy supply chains.

This paper examines the most significant technological breakthroughs in five critical areas, namely: renewable energy, energy storage, hydrogen, smart grid systems, and nuclear fusion. It analyzes how these innovations contribute to decarbonization goals, strengthen industrial competitiveness, and enhance China's geopolitical positioning. The paper also offers insights into how policy, technology, and industrial capacity together shape China's path toward a low-carbon future.

Methodology

This paper uses a qualitative, document-based analytical approach to examine China's energy innovations. The research is structured around five key technological domains: renewable energy, energy storage, hydrogen technologies, smart grid infrastructure, and nuclear fusion. These domains were selected due to their strategic relevance to China's dual-carbon targets and their central role in national policy frameworks. The analysis draws on a range of publicly available primary and secondary sources, including official government documents, policy guidelines, industrial development plans, sector-specific datasets, and relevant news and technical reports. The study does not seek to establish causal relationships but rather wishes to identify patterns, strategic linkages, and institutional configurations that shape the direction and effectiveness of China's energy innovation model. In doing so, it contributes to a broader understanding of state-led technological transformation in the context of environmental policy and industrial competitiveness.

China's Strategic Energy Vision

China has positioned energy innovation as a foundational element of its national development strategy. The government frames technological leadership in the energy sector as both an environmental imperative and a pathway to long-term economic competitiveness. This ambition is operationalized through high-level policy goals, a robust regulatory architecture, and substantial industrial coordination.

The core of China's strategy is encapsulated in its dual-carbon targets: peak carbon emissions before 2030 and carbon neutrality by 2060 (Ye, 2025). These goals serve as organizing principles for the country's energy transformation and are anchored in key national planning documents such as the 14th Plan and the Action Plan for Carbon Dioxide Peaking Before 2030. The government promotes the rapid development of non-fossil energy sources – including hydro, solar, wind, and nuclear – and seeks to modernize the national energy infrastructure through digitized grid systems and ultra-high-voltage transmission networks. These efforts are supported by the forthcoming Energy Law 2025, which aims to standardize governance across energy production, transmission, and storage, and to formalize incentives for decarbonization and technological innovation.

Evidence from recent industrial activity confirms that the policy framework has translated into accelerated implementation. For example, China's total investments in grid infrastructure are projected to exceed 6 trillion yuan (approximately 885 billion USD) during the 14th Five-Year Plan period (Xinhua News, 2023). In 2025 alone, China aims to add 48 GW of energy storage capacity, accounting for over half of global additions that year (China Energy Storage Alliance, 2025). Mandatory storage requirements tied to new renewable installations, typically ranging from 5 to 20% of capacity, have catalyzed the commercialization of advanced storage systems, including compressed air energy storage (CAES) facilities and sodium-ion battery plants. Simultaneously, government-supported initiatives such as ultra high voltage (UHV) transmission corridors from western to eastern China are increasing energy transmission efficiency and expanding grid flexibility.

This transformation is further driven by China's integrated approach to industrial policy. Energy technology is prioritized as a pillar of "new productive forces", aligning macroeconomic planning with sectoral innovation. The state plays a proactive role by funding demonstration projects, supporting public-private R&D partnerships, and investing in the domestic processing of critical materials such as lithium, sodium, vanadium and others. Chinese manufacturers have

achieved vertical integration in several energy value chains, particularly in solar photovoltaics, battery production, and hydrogen electrolysis. This strategic structure enhances cost efficiency, insulates production from global market disruptions, and enables rapid scale-up of new technologies.

The deliberate coordination between policy, industry, and technology constitutes a distinct model of energy governance. China's approach aims to avoid fragmented innovation and to eliminate regulatory uncertainty by creating predictable, state-guided pathways for private sector participation. Through this model, the government actively cultivates global leadership in emerging energy domains. By 2024, China had already met its 2030 targets for renewable capacity, with over 1.2 billion kilowatt (kW) installed (Solarzoom, 2024). Such outcomes illustrate the effectiveness of a centrally coordinated strategy that combines political will, market design, and technological readiness.

In this regard, it is important to note that it would be difficult, if not impossible, to implement such an approach with such scalability in other countries, considering the need for resources, a manufacturing base, competencies, personnel, finances, and the coordination of this mix.

Energy security has also become one of China's key strategic priorities, particularly in the context of the escalation of various geopolitical tensions. In 2024, China remained heavily reliant on energy imports, with import dependence exceeding 70% for oil, 40% for natural gas, and 10% for coal (Tu, 2025). In response to this situation, the Chinese government has adopted a multi-faceted strategy aimed at reducing exposure to external supply disruptions. Core measures include advancing domestic energy innovation, expanding national infrastructure, and diversifying the country's energy portfolio. The increasing focus on renewables, nuclear power, hydrogen technologies, and large-scale energy storage reflects a dual objective: supporting long-term decarbonization targets and strengthening national energy self-sufficiency. At the same time, it should be noted that advanced domestic technologies for ultra-deep drilling, hydraulic fracturing, methane hydrate extraction, etc. are being implemented in the oil and gas industry, which allows for an annual increase in oil and gas production.

In strategic terms, China's energy vision enhances its resilience to external shocks and positions it as a norm-setter in global climate governance. The energy transition is framed not only as a climate obligation but as a competitive arena in which technological supremacy offers long-term geopolitical advantage. The coordinated deployment of advanced technologies within a supportive regulatory ecosystem strengthens China's capacity to define global standards, supply chains, and innovation trajectories. This orientation provides China with a sustainable, systemic advantage in shaping the future of energy.

Key Technological Breakthroughs in the Energy Sector

Renewable Energy Systems

Solar. China has positioned itself as the global leader in solar energy innovation as it made progress in technological development, manufacturing capacity, and rapid and large-scale deployment of photovoltaic infrastructure. In 2017, China surpassed the European Union and became the world's largest solar energy producer with of 130 gigawatts (GW) installed capacity. By 2023, China expanded its national capacity by 200 GW, while the United States only reached 130 GW (Washington Post, 2025). Such dynamics reflect not only heavy investment but also a strategic focus on industrial scalability and self-sufficiency.

Several factors explain China's dominance in the sector. Firstly, Chinese manufacturers have implemented advanced automated production techniques, which led to significant cost-reductions while maintaining quality level. Secondly, companies such as LONGi and JinkoSolar gained leadership in solar cell efficiency, with laboratory-tested conversion rates above 26%. Thirdly, Chinese research institutions have made significant contributions to emerging photovoltaics, including perovskite-based cells and tandem cell structures, which could potentially further increase efficiency. All of this has resulted in tangible economic advantages and reduced prices. For instance, China has succeeded in reducing solar power costs to below \$200 per kilowatt (kWh) compared to almost \$450 in the United States (Washington Post, 2025).

By combining cost advantages with a know-how, China has positioned itself as a major player in the global renewable energy supply chain. It has also provided China with a reputation and a strategic leverage in co-shaping those rules and standards that will govern energy markets in the coming decades. The importance of this leverage increases in the context of rising geopolitical tensions and the growing securitization of energy technologies.

Alongside an expansion in solar energy, China has also made significant progress in wind power sector. The focus on solar and wind power illustrates a broader commitment to scale multiple types of renewables, which is supported by consistent investment in research, innovation, infrastructure, and manufacturing.

By 2023, China's wind power capacity reached approximately 450 GW, which is more than double that of the European Union in the same year (Washington Post, 2025). This progress is tied to technological shifts that have made wind farms more efficient, scalable and resilient. For example, Chinese companies produce ultra-large offshore wind turbines with some models exceeding 16 megawatts (MW) per unit. Advances in blade design, particularly the use of new composite materials, have extended turbine lifespans and improved performance under variable wind conditions. At the same time, engineers are piloting floating platform technologies that make it possible to site wind farms in deeper, previously inaccessible waters. On the transmission side, grid operators are implementing integrated control and storage systems designed to offset fluctuations in wind generation, which thereby enhances the stability and predictability of large-scale electricity supply.

Simultaneously, China's dominance in renewable energy manufacturing is reinforced by structural advantages in supply chain coordination. The country benefits from economies of scale driven by its expansive industrial base, vertically integrated companies, and leadership in raw material processing, particularly in critical inputs such as silicon and rare earth elements. This combination of technological and supply-side capabilities underpins China's capacity to offer low-cost, high-output renewable energy solutions (Washington Post, 2025).

Recent projections confirm the continued acceleration of China's renewable deployment. In 2025, newly installed wind and solar photovoltaic capacity is expected to reach 396 gigawatts setting a new national record in China. As a result, wind and solar energy are forecast to account for 52% of total electricity generation for the year, highlighting their central role in China's energy mix and decarbonization pathway (Wang, 2025). These figures reinforce the structural shift underway in the Chinese power system and reflect the policy-driven scaling of low-carbon technologies.

The rapid expansion of China's wind energy sector illustrates the strategic interplay between innovation and industrial policy. The development of mega-scale offshore turbines has enabled the exploitation of deeper and wind-rich maritime zones thus expanding the geographic scope of viable wind installations. Floating platforms represent a critical leap in offshore potential allowing for deployment beyond shallow coastal areas, which tackles a limitation that has

constrained many other countries. These advances are embedded within an ecosystem of state-led investment, research collaboration, and export-oriented manufacturing strategy.

Vertical integration across companies facilitates rapid product iteration, cost reduction, and quality control. The centralized processing of raw material reduces supply volatility and allows to maintain a steady availability of inputs essential for manufacturing. Furthermore, by combining R&D capacity with large-scale manufacturing, China is able to mass produce at a faster pace than its competitors.

Advanced Energy Storage

China's rapid advancement in energy storage technologies plays a pivotal role in supporting the country's integration in large-scale renewable energy and maintaining grid stability. The capacity of a "new type" energy storage increased from 8.7GW in 2022 to 31.4GW in 2023 making China a world leader (Ye, 2025). This growth is the result of a technological leap in battery energy storage systems, including the development of advanced lithium-ion batteries with greater energy density and longevity that are optimized specifically for grid applications. Large battery installations in regions such as Inner Mongolia now make it possible to smooth out fluctuations in renewable generation, which demonstrates that storage can operate as a backbone for a variable energy mix. In addition, management systems enhance operational safety and performance, while large-scale production has driven notable cost reductions.

Besides batteries, China has also achieved a milestone in compressed air energy storage. The Nengchu-1 project, which is located in Yingcheng, Hubei Province, is the world's first 300MW facility of its kind. It sets new benchmarks for storage capacity, storage scale, and system efficiency. Operating at roughly 70% energy conversion efficiency, it can store energy for up to eight hours and discharge it over five hours each day (China Energy Engineering Group Co., Ltd., 2025). Designed using underground salt caverns reaching 600 meters in depth and totaling nearly 700,000 cubic meters in gas volume, the facility combines innovative engineering with environmental benefits. It is projected to save over 159,000 tons of standard coal annually, which translates into a reduction of 411,000 tons of carbon dioxide (CO₂) emissions. Crucially, this technological breakthrough was developed under China's full intellectual ownership through collaboration between China Energy Engineering Corporation and over one hundred domestic firms.

Beyond lithium and CAES, China continues to expand its energy storage portfolio. The country leads globally in pumped hydro storage, with over 50GW installed capacity forming the backbone of its system. Emerging technologies such as flywheel systems and thermal storage cater to short-duration and industrial needs respectively, while flow batteries (particularly vanadium redox types) are being scaled up for long-duration applications (Ye, 2025). These advancements collectively reinforce China's strategic energy resilience, thus enhancing system flexibility and decarbonization pathways across sectors.

China's acceleration in energy storage deployment represents a strategic inflection point with significant implications for the global energy value chain. From a systems perspective, large-scale energy storage plays a crucial role in using high levels of renewables in the energy mix without compromising on grid reliability and operational stability. This is particularly relevant for power systems that are increasingly shaped by variable energy generation. For example, solar and wind energy generation is inherently changeable due to weather conditions. As the share of renewables in an energy mix grows, so does the challenge of balancing supply and demand in real

time. Energy storage is a viable solution for variability and resilience as excess electricity is absorbed during periods of high generation and released during periods of low generation.

This diversified technology portfolio is a deliberate industrial policy move that reduces China's dependency on imported solutions, enhances technology sovereignty, and accelerates learning curves through deployment at scale. Projects such as Nengchu-1, with domestically developed intellectual property and collaboration across over 100 firms (China Energy Engineering Group Co., Ltd., 2025), reflect China's strategy to capture end-to-end value in emerging energy infrastructure segments.

From a global perspective, China's leadership could exert downward pricing pressure on storage hardware, influence standards in grid integration protocols, and crowd out competing suppliers in key export markets. For international firms, this raises critical questions about supply chain resilience, localization requirements, and the competitiveness of proprietary technologies. For governments, this highlights the strategic importance of scaling domestic energy storage capabilities as a component of industrial and energy security policy.

However, recent data also suggest emerging constraints in the pace of energy storage expansion. In 2025, the installation of new storage capacity is projected to decline by 17%. The absence of a profitable business model for large-scale storage remains a structural barrier to long-term commercial viability, which potentially limits deployment beyond short-term policy targets (Wang, 2025). This indicates that sustained regulatory and market support will be essential to ensuring the continued growth of the storage sector.

Hydrogen Technologies

China is accelerating the development of a diversified hydrogen energy ecosystem thus positioning hydrogen as a strategic pillar in its broader decarbonization and energy security agenda.

Major advances have occurred across production, storage, and utilization. In production, Sinopec's patented biomass-based hydrogen generation technology signals a shift toward low-carbon feedstocks, which allows for cleaner pathways for hydrogen synthesis (Fuel Cells Works, 2025a). Complementing this, Chinese researchers have improved solar-driven hydrogen production through photocatalytic water splitting using titanium dioxide, enhancing energy conversion efficiency in sunlight-only systems (Fuel Cells Works, 2025b). Furthermore, Sinopec's innovation in direct seawater electrolysis offers a sustainable production route for coastal regions, generating 20 cubic meters of green hydrogen per hour without requiring freshwater (Sinopec, 2024).

In storage and mobility, the deployment of a heavy-duty truck with a 100kg liquid hydrogen tank achieving a range over 1,000 km demonstrates feasibility in long-distance transport applications (FCW Team, 2025). Additional developments include solid-state storage technologies and the construction of three dedicated hydrogen pipelines, including the strategic "Baling-Changling" route.

These technological milestones are now accompanied by progress in cost reduction and energy system performance. The cost of hydrogen fuel cell systems is projected to fall below 1,000 yuan/kW by 2032 supported by ongoing innovation and economies of scale (Wang et al., 2025). A new tandem catalyst developed by Chinese researchers accelerates reaction rates and enhances energy efficiency in fuel cells thus offering significant performance gains and strengthening the case for broader adoption (Brown, 2025).

These developments demonstrate a coordinated approach to scaling hydrogen across both production and end-use segments. Innovations in biomass-based and solar-driven hydrogen

production contribute to lowering dependence on fossil-based hydrogen sources. Seawater electrolysis provides an alternative that addresses the issue of freshwater scarcity, which remains a critical barrier in densely populated or arid regions. Investments in storage and distribution infrastructure, including liquid hydrogen systems for transport and dedicated long-distance pipelines, indicate a shift from experimental deployment to commercial-scale implementation. The variety of technical solutions reflects a deliberate effort to manage risk by minimizing exposure to specific resource constraints and reducing reliance on any single technology. Integrating high-capacity hydrogen storage into heavy-duty transport applications further supports hydrogen's strategic value in decarbonizing sectors where battery-based solutions remain technically or economically limited.

Although China currently offers the lowest production costs for green hydrogen and its derivatives, commercial uptake remains limited. As of early 2025, only 12.6% of planned clean hydrogen projects had secured contracts, which reflects challenges in market readiness and regulatory alignment (Wang, 2025). These figures highlight a gap between technological potential and practical implementation suggesting that further institutional and policy coordination will be necessary to scale hydrogen adoption domestically.

China's hydrogen breakthroughs are not only technological milestones but foundational to building a resilient, low-carbon energy architecture. By addressing such challenges across the hydrogen value chain as production sustainability, logistical scalability, and end-use efficiency, China is laying the groundwork for hydrogen to serve as both a domestic energy carrier and a tradable commodity in future. These advancements enhance national energy independence, decarbonize high-emission sectors, and support China's ambition to become a global leader in hydrogen innovation.

Smart Grid and Infrastructure

The development of smart grid systems in China integrates advanced information and communication technologies to enhance energy efficiency, grid reliability, and renewable energy integration. Key technologies include bidirectional electricity transmission systems, large-scale smart metering infrastructure, and over 70 digital substations designed to improve data processing and grid security. The country also leads in UHV transmission equipment, enabling long-distance power transmission with minimal energy loss. In addition, automated demand response systems using artificial intelligence have demonstrated effectiveness in reducing peak loads by up to 30% during extreme weather conditions (Smart grid in China, 2024).

China's approach reflects a strategic alignment between technology development and energy policy objectives. The phases are as following: initially, standards development and pilot projects (2009-2010), followed by infrastructure deployment (2011-2015), and culminating in wide-scale integration (2016-2020) demonstrate long-term planning. The smart grid has enabled higher intra-regional transmission capacity (400 GW) contributing to improved grid reliability, especially in urban areas, where it now exceeds 99.915%. By supporting the integration of renewable energy and reducing emissions from inefficient coal-based systems, the grid infrastructure serves as a foundation for China's low-carbon transition (Smart grid in China, 2024).

In parallel with physical infrastructure upgrades, China is also advancing reforms in its electricity market. The government has announced that, beginning in 2025, all wind and photovoltaic power plants will be included in the liberalized electricity market. This timeline represents an acceleration of four years compared to the original plan. The reform is a significant

step toward integrating variable renewable sources into competitive market structures and toward improving the flexibility and responsiveness of China's power system (Wang, 2025).

The success of China's smart grid highlights the critical role of coordinated state planning and public investment in energy transition. For global policymakers and utilities, this reinforces the importance of integrating infrastructure, digital capabilities, and regulatory frameworks from the outset. As energy systems become more decentralized and variable, China's approach offers a replicable pathway, especially in rapidly urbanizing regions. The multi-billion-dollar grid modernization plan by China signals a maturing market with growing demand for software, automation, and grid cybersecurity.

The Role of Nuclear and Fusion Innovation

China has made remarkable progress in nuclear fusion technology, including several major projects testing the limits of what is currently possible in this field. A team from Shanghai Jiao Tong University and the Chinese Academy of Sciences has developed a novel hybrid particle-in-cell simulation tool known as LAPINS, designed to analyze the behavior of supra-thermal ions within burning plasma. This tool enabled the detection of supra-thermal deuterium ions with energies under 34 kilo-electronvolt and found a 24% increase in alpha particle density at the center of the hotspot thus enhancing core plasma reactivity. Tests also showed that large-angle collisions could improve efficiency through promotion of ignition reactions by an additional 10 picoseconds (Williams, 2025). These findings refine the understanding of particle dynamics in fusion environments and point toward ways to optimize future reactor designs. Therefore, LAPINS represents a critical leap in modeling capabilities, which is aligned with China's broader ambition to develop viable fusion energy solutions.

China is also expanding its physical fusion infrastructure. The Experimental Advanced Superconducting Tokamak (EAST) sustained plasma at over 100 million °C for more than 17 minutes. This is an unprecedented milestone in global fusion research. Other large-scale initiatives include the following: the X-shaped fusion facility in Mianyang, which is projected to exceed the size of the U.S. National Ignition Facility by 50%; the China Fusion Engineering Test Reactor (CFETR), which aims to bridge experimental research with commercial applications; the Comprehensive Research Facility for Fusion Technology (CRAFT), which develops the core technologies for future reactors. The Xinghuo Fusion-Fission Hybrid plant is scheduled to be connected to the grid by 2030, and it may become one of the first operational commercial fusion-based power sources (Clynes, 2025). The above-mentioned initiatives reflect China's strategic commitment to building a comprehensive and scalable fusion ecosystem from scientific experimentation to grid-ready deployment.

China's nuclear fusion leadership is driven not only by technological breakthroughs but also its systemic strategic advantages. The country's rapid construction capabilities enable it to build complex research facilities at a pace unmatched by many other counterparts thereby accelerating the fusion development timeline. China's investment in advanced technologies, including high-temperature superconducting magnets, allows for more efficient reactor designs with reduced size and increased magnetic confinement. Sustained and centralized government support with long-term financial commitment and alignment of policy objectives ensures continuity in fusion R&D despite the absence of short-term commercial returns. Additionally, the integration of multiple projects under a unified strategic framework allows for knowledge sharing and infrastructure synergies. Talent cultivation, both domestically and through international partnerships, further enhances the country's capacity for scientific innovation in this domain

(Clynes, 2025). Collectively, these advantages contribute to China's emerging status as a global front-runner in the commercialization of fusion energy.

Alongside its progress in fusion research, China is rapidly expanding its conventional nuclear power capabilities. As of April 2025, there are 102 nuclear power plants (NPPs) – either operational, under construction, or approved – with a combined installed capacity of 113 million kW. Of these, 28 NPPs are under construction, which gives China the world's largest pipeline of nuclear projects and secures its position as the global leader in nuclear capacity expansion for 18 consecutive years. In 2024, China's operating NPPs generated 444.7 billion kWh of electricity, which accounted for 4.72% of national electricity output. This helped to reduce standard coal consumption by an estimated 127 million tons and cut carbon dioxide emissions by approximately 334 million tons. Additionally, China has achieved full domestic production of all core nuclear power equipment, which reflects its growing technological self-sufficiency and reinforces the country's long-term energy security objectives (Zheng, 2025; Coelho, 2025).

As China faces growing energy demands, supply-side constraints and environmental pressures, fusion represents a next-generation solution that could deliver abundant, clean, and secure electricity with minimal fuel dependency or waste. Unlike traditional renewables, fusion offers high energy density and grid stability, which allows for industrial scalability and energy-intensive manufacturing. Strategically, investing early in fusion allows China to reduce long-term exposure to fossil fuel volatility and to avoid technology lock-in from foreign energy systems. Moreover, China views fusion as a dual-use innovation platform that drives spillovers across advanced materials, precision engineering, cryogenics, and computational physics, each of which supports broader national competitiveness in strategic sectors. By funding major projects such as EAST and CFETR, China signals its ambition to co-create international standards for reactor design, regulatory frameworks and commercial licensing. This aligns with its industrial policy objectives under strategies like “Made in China 2025” and its broader goal to shape global energy governance.

Conclusion

China has become a global leader in energy technology innovation across multiple sectors: China has changed from a country dominating renewable energy manufacturing and deployment to pioneering breakthroughs in fusion energy, advanced energy storage, hydrogen technology, and smart grid systems.

China is reshaping the global energy landscape. Its collective efforts are backed by strategic policy decisions, long-term vision and planning, substantial capital allocation, and a coordinated approach to research, development, and deployment. Some of the major advances such as compressed air storage, seawater electrolysis, and ultra-high-voltage transmission illustrate a strategic approach in order to reduce import dependence and strengthen resilience. The technological progress is also often accompanied by cost decline, which contributes to enhanced competitiveness, scalability and economic attractiveness.

While these achievements are significant, they also raise questions about international collaboration and how global governance structures will adapt to a more multipolar landscape for accommodating energy innovation and addressing climate challenges. When technologies mature and costs continue to decline, they will reshape current energy systems worldwide with profound implications for energy security, economic development, and environmental sustainability.

China's dual-carbon targets serve as a framework for climate action and as a mechanism to support industrial upgrading. This also has spillover effects on global supply chains and impact on

shaping technology standards. The resource-intensive fusion research supported by Chinese government indicates a long-term aim and intention to be prepared for engaging in formulating technical standards and regulatory structures governing future energy systems.

References

Brown, A. (2025, April 30). New tandem catalyst breakthrough from China promises leap in clean ammonia and fuel cell efficiency. *Hydrogen Fuel News*. <https://www.hydrogenfuelnews.com/new-tandem-catalyst-breakthrough-from-china-promises-leap-in-clean-ammonia-and-fuel-cell-efficiency/8570668/> (accessed May 13, 2025).

China Energy Engineering Group Co., Ltd. (2025, January 11). CEEC-built world's first 300 MW compressed air energy storage plant connected to grid at full capacity [Press release]. *Business Wire*. <https://www.businesswire.com/news/home/20250111706594/en/CEEC-built-Worlds-First-300-MW-Compressed-Air-Energy-Storage-Plant-Connected-to-Grid-at-Full-Capacity> (accessed March 28, 2025).

Clynes, T. (2025, April 29). China takes a bold leap in fusion energy. *IEEE Spectrum*. <https://spectrum.ieee.org/china-nuclear-fusion-reactor> (accessed May 13, 2025)

Coelho, Z. (2025, May 14). 500 GW by 2050? Inside China's massive nuclear expansion and its global power shift. *Nuclear Business Platform*. Retrieved from <https://www.nuclearbusinessplatform.com/media/insights/inside-china-massive-nuclear-expansion> (accessed June 18, 2025).

FCW Team. (2025, March 21). China unveils 'Track 1000' liquid hydrogen system for trucks, breaking 1,000km barrier without refueling. *Fuel Cells Works*. <https://fuelcellworks.com/2025/03/21/clean-energy/china-unveils-track-1000-liquid-hydrogen-system-for-trucks-breaking-1-000km-barrier-without-refueling> (accessed May 13, 2025).

Fuel Cells Works. (2025a, May 2). Sinopec awarded patent for hydrogen production using biomass technology. *Fuel Cells Works*. <https://fuelcellworks.com/2025/05/02/h2/sinopec-awarded-patent-for-hydrogen-production-using-biomass-technology> (accessed May 13, 2025).

Fuel Cells Works. (2025b, April 8). China focus: China achieves breakthrough in solar-powered water splitting for hydrogen production. *Fuel Cells Works*. <https://fuelcellworks.com/2025/04/08/clean-energy/china-focus-china-achieves-breakthrough-in-solar-powered-water-splitting-for-hydrogen-production> (accessed May 13, 2025).

Horizon Fuel Cell Technologies. (n.d.). Breaking news. *Horizon Fuel Cell Technologies*. <https://www.horizonfuelcell.com/news-1> (accessed May 13, 2025).

Reuters. (2025, January 15). China's State Grid outlays record \$88.7 bln investment for 2025. Reuters. Retrieved from <https://www.reuters.com/business/energy/chinas-state-grid-outlays-record-887-bln-investment-2025-2025-01-15/> (accessed March 28, 2025).

Sinopec. (2024, December 22). Sinopec achieves breakthrough in solar-powered water splitting for hydrogen production. *Green Car Congress*. <https://www.greencarcongress.com/2024/12/20241222-sinopec.html> (accessed May 6, 2025).

Smart grid in China. (2024, October 27). In Wikipedia. https://en.wikipedia.org/wiki/Smart_grid_in_China (accessed May 10, 2025).

State Council Information Office of the People's Republic of China. (2024, August 29). Title of the Article. State Council Information Office of the People's Republic of China. http://www.scio.gov.cn/zfbps/zfbps_2279/202408/t20240829_860523.html (accessed March 12, 2025).

Tu, K. J. (2025, March 7). Status and prospects of China's energy security: An update in March 2025. LinkedIn. Retrieved from <https://www.linkedin.com/pulse/status-prospects-chinas-energy-security-update-march-2025-kevin-j-tu-coawc> (accessed May 10, 2025).

Wang, X., Fan, L.-W., Zhang, H., & Zhou, P. (2025). Cost trajectory of hydrogen fuel cell technology in China. *iScience*, 28(5), 112359. <https://doi.org/10.1016/j.isci.2025.112359>

Wang, C. (2025). Monthly China energy update: May 2025. Climate Energy Finance. Retrieved from <https://climateenergyfinance.org/wp-content/uploads/2025/05/Monthly-China-Energy-Update-May-2025.pdf> (accessed May 30, 2025).

Washington Post. (2025, March 3). *China's renewable energy push aims to make it a green world leader*. The Washington Post. <https://www.washingtonpost.com/climate-solutions/2025/03/03/china-renewable-energy-green-world-leader/> (accessed March 29, 2025).

Williams, E. (2025, March 18). China's breakthrough in plasma technology – This seismic shift in physics could change energy forever. *Sustainability Times*. <https://www.sustainability-times.com/energy/chinas-breakthrough-in-plasma-technology-this-seismic-shift-in-physics-could-change-energy-forever/> (accessed April 15, 2025).

Ye, Y. (2025, January 23). Q&A: How China became the world's leading market for energy storage. *Carbon Brief*. <https://www.carbonbrief.org/qa-how-china-became-the-worlds-leading-market-for-energy-storage/> (accessed March 9, 2025).

Zheng, X. (2025, April 28). China tops global ranking of overall nuclear power capacity, report says. *China Daily*. Retrieved from <https://www.chinadaily.com.cn/a/202504/28/WS680f9880a310a04af22bcace.html> (accessed May 10, 2025).