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# Technological Development Trends of Traditional and New Energy in China: A Comparative and Integrated Perspective

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## Abstract

As the world's largest energy consumer, China's energy technological trajectory profoundly influences global decarbonization efforts. This paper systematically analyzes the technological development trends of traditional (fossil-based) and new energy (renewables, nuclear, hydrogen) sectors in China, emphasizing their dynamic interactions, technological bottlenecks, and synergistic pathways. Through a review of policy frameworks, R&D investments, and industrial practices, we identify key trends—including the "dual-carbon" goal-driven transition, breakthroughs in next-generation energy technologies, and the integration of digital solutions. The findings suggest that while traditional energy remains pivotal for near-term stability, its technological evolution is increasingly oriented toward efficiency and carbon mitigation. Meanwhile, new energy technologies are advancing rapidly, with China emerging as a global leader in multiple domains. The convergence of these two sectors through hybrid systems and smart grids will define China's mid-to-long-term energy landscape.

**Keywords**: Traditional energy; New energy; Technological trends; China; Carbon neutrality; Energy transition

## 1. Introduction

China's energy sector stands at a critical juncture, balancing the imperatives of economic growth, energy security, and environmental sustainability. As the world's largest producer and consumer of coal, second-largest oil importer, and a global frontrunner in renewable energy deployment (IEA, 2023), China's energy technological choices carry global significance. The 2020 pledge to achieve carbon peak by 2030 and carbon neutrality by 2060 ("dual-carbon" goals) has further accelerated the reconfiguration of its energy technological roadmap (NDRC, 2021).

This paper investigates the technological development trends of China's traditional (primarily coal, oil, and natural gas) and new energy (renewables—solar, wind, hydro; nuclear; hydrogen;

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and emerging storage technologies) sectors. Unlike conventional analyses that treat these sectors in isolation, we adopt an integrated perspective, examining their co-evolution, technological complementarities, and transitional dynamics. Our research questions include: (1) What are the current technological trajectories and bottlenecks in China's traditional and new energy sectors? (2) How do policy incentives and market mechanisms shape these trends? (3) What are the prospects for their convergence toward a low-carbon energy system?

# 2. Traditional Energy: Efficiency, Clean Utilization, and Carbon Mitigation

## 2.1 Coal: From Volume to Quality-Oriented Transformation

Coal, which accounted for 55.3% of China's primary energy consumption in 2022 (NBSC, 2023), remains the backbone of the energy system due to its abundance (proven reserves of 162.2 billion tonnes) and grid stability functions (CEA, 2023). However, its technological development is shifting from sheer output expansion to efficiency enhancement and clean utilization.

**Key trends include:**

- **Advanced Combustion Technologies:** Ultra-supercritical (USC) and ultra-supercritical once-through (USC-OT) coal-fired power plants have become mainstream, with unit capacity exceeding 1,000 MW and thermal efficiency reaching 47–49% (vs. 30–35% for subcritical plants). The Huaneng Taizhou Phase II project (2022) achieved a world-record efficiency of 49.4%, reducing coal consumption by 10% compared to conventional USC units (Huadian, 2022). Research on 700°C advanced USC (A-USC) is ongoing, targeting efficiency gains of 5–8 percentage points through nickel-based superalloys.
- **Carbon Capture, Utilization, and Storage (CCUS):** China has launched over 50 CCUS pilot projects (Global CCS Institute, 2023), with the Yanchang Petroleum project (Shaanxi) capturing 500,000 tonnes $CO_2$/year and injecting it into depleted oil fields for enhanced oil recovery (EOR). The "Near-Zero Emission Coal-Based Power Plant" initiative (NDRC, 2022) aims to commercialize CCUS-integrated plants by 2030, with costs projected to decline from ~$60/tonne(current)to$30–40/tonne.
- **Coal-to-Chemicals (CTC) Optimization:** Traditional coal-to-liquids (CTL) and coal-to-gas (CTG) processes are being restructured to reduce water consumption and $CO_2$ emissions. The Shenhua Ningxia Coal Industry Group's direct coal liquefaction plant (annual output 4 million tonnes) has improved energy efficiency by 2% through process integration, while new routes like coal-to-aromatics (e.g., benzene, toluene) focus on

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high-value chemicals with lower carbon intensity.

## 2.2 Oil & Gas: Reserves Enhancement and Low-Carbon Upstream

China's oil self-sufficiency rate dropped to 28% in 2022 (NBS, 2023), necessitating technological breakthroughs in unconventional resources. Key advancements include:

- **Tight Oil/Gas and Shale Development:** The Sichuan Basin's Fuling shale gas field (operated by Sinopec) achieved annual output of 23 billion cubic meters (2022)—the world's largest—and utilizes horizontal drilling and staged fracturing technologies adapted to China's complex lithology (low porosity, high clay content). Offshore, the deepwater Lingshui 17-2 gas field (CNOOC) employs subsea production systems and floating LNG (FLNG) concepts to exploit reserves in waters >1,500 meters deep.
- **Refining & Petrochemical Upgrading:** The "Oil Refining Industry '14th Five-Year' Plan" (MIIT, 2021) mandates the reduction of fuel oil production and expansion of high-end petrochemicals (e.g., bio-based plastics, specialty chemicals). Catalytic cracking units now incorporate nanoscale zeolite catalysts to improve light olefin yields, while carbon capture is integrated into ethylene plants (e.g., the Maoming Petrochemical project captures 100,000 tonnes $CO_2$/year).

## 2.3 Bottlenecks and Transition Pressures

Despite progress, traditional energy faces inherent constraints: (1) Coal's high carbon intensity (820–950 g$CO_2$/kWh) makes it incompatible with long-term decarbonization; (2) Oil/gas import dependence (~72% for oil, 45% for gas in 2022) poses geopolitical risks; (3) CCUS remains costly, with current utilization rates <1% of total emissions. These factors drive the gradual "phasing down" of fossil fuels, even as they remain critical for grid stability and industrial feedstocks in the near term.

# 3. New Energy: Scaling Up and Technological Leadership

## 3.1 Renewable Energy: Solar, Wind, and Hydropower

China dominates global renewable energy deployment, with renewables accounting for 29.7% of total power generation in 2022 (NEA, 2023).

**Solar Power:**

- **Photovoltaic (PV) Technology:** China leads in both crystalline silicon (c-Si) and thin-film PV. PERC (Passivated Emitter and Rear Cell) modules dominate the market with efficiencies of 22–23%, while TOPCon (Tunnel Oxide Passivated Contact) and HJT (Heterojunction with Intrinsic Thin Layer) cells are entering mass production, targeting

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25–26% efficiency. The Longi Green Energy 26.81% efficiency HJT cell (2022) set a world record. BIPV (Building-Integrated PV) and floating solar (e.g., the 320 MW Dezhou project on a coal mining subsidence area) are expanding niche applications.

- **Grid Integration:** Challenges include curtailment (reduced to <5% in 2022 from 15% in 2015) and intermittency. Solutions involve ultra-high-voltage (UHV) DC transmission (e.g., the ±800 kV Jinping-Suzhou line delivering 10 GW of west-to-east solar power) and hybrid systems (solar + storage). The "Renewable Energy + Energy Storage" policy (NEA, 2021) requires new utility-scale solar farms to include ≥10% storage capacity by 2025.

**Wind Power:**

- **Onshore and Offshore Technologies:** Onshore turbines (e.g., Goldwind's GW171-8.0 MW) feature 100-meter+ blades and intelligent pitch control, achieving capacity factors of 30–35%. Offshore wind is booming, with installed capacity reaching 30 GW (2022) and the 16 MW Hailiuhang offshore turbine (MingYang Smart Energy) setting a global record for single-unit capacity. Floating wind (pilot projects in Fujian and Guangdong) targets deepwater zones (>50 meters) to unlock 700 GW of additional resources.
- **Supply Chain Localization:** China produces >70% of global wind turbine components, including rare-earth permanent magnets (for direct-drive generators) and composite blades. The "Whole-Industry-Chain Synergy" strategy (MIIT, 2022) aims to reduce offshore turbine costs from ¥6,000/kW (2015) to ¥3,500/kW by 2025.

## 3.2 Nuclear Energy: Advanced Reactors and Safety Innovations

China operates 57 nuclear reactors (2023) with 55.6 GW capacity, ranking third globally, but its technological focus is on next-generation designs:

- **Third-Generation (Gen III+) Reactors:** The Hualong One (designed by CNNC and CGN) features passive safety systems (gravity-driven coolant injection) and standardized construction, with units in Fuqing (Fujian) and Fangchenggang (Guangxi) achieving grid connection. The AP1000 (Westinghouse technology, localized by SNPTC) has also entered commercial operation.
- **Fourth-Generation (Gen IV) and Small Modular Reactors (SMRs):** China is developing sodium-cooled fast reactors (e.g., the 200 MW CFR600 prototype in Xiapu, Fujian), high-temperature gas-cooled reactors (HTGRs, e.g., the 200 MW HTR-PM demonstration plant in Shidao Bay), and molten salt reactors (MSRs). SMRs, such as the 125 MW ACP100 (floating design for islands), offer decentralized deployment advantages. The "Nuclear Energy Innovation 2035" plan (NEA, 2021) targets commercialization of

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Gen IV reactors by 2035.

### 3.3 Hydrogen Energy: Production, Storage, and Applications

Hydrogen is positioned as a key medium for long-term energy storage and industrial decarbonization. China's hydrogen production reached 33 million tonnes (2022), primarily via fossil-fuel-based steam methane reforming (SMR, ~60% grey hydrogen). Key trends include:

- **Green Hydrogen:** Electrolysis-based hydrogen (using renewable electricity) is scaling up, with alkaline electrolyzers (e.g., Longi's 1,000 $Nm^3/h$ units) and PEM (Proton Exchange Membrane) electrolyzers (e.g., SinoHytec's pilot projects) achieving costs of ¥30–40/kg (vs. ¥10–15/kg for grey hydrogen). The "Hydrogen Energy Industry Development Mid-to-Long-Term Plan (2021–2035)" (MIIT, 2022) sets a target of 100,000–200,000 tonnes/year green hydrogen by 2025.
- **Storage and Transport:** High-pressure gaseous hydrogen (35–70 MPa) dominates, but solid-state storage (e.g., metal hydrides) and liquid organic hydrogen carriers (LOHCs) are under R&D. The "Hydrogen Refueling Infrastructure" initiative aims to build 1,000 stations by 2030, supporting fuel-cell vehicles (FCVs) and heavy-duty trucks.

## 4. Convergence and Synergies: Hybrid Systems and Digitalization

The future energy system in China will not be a binary replacement of traditional by new energy, but a hybrid model leveraging their complementary strengths:

- **Coal + CCUS + Hydrogen:** Coal can serve as a feedstock for hydrogen production (via gasification) or be coupled with CCUS to generate "blue hydrogen." The Yankuang Group's project combines coal gasification with electrolytic hydrogen to produce synthetic ammonia (low-carbon fertilizer).
- **Renewables + Storage + Smart Grids:** Advanced batteries (e.g., lithium iron phosphate, LFP), pumped hydro (China has 45 GW capacity, with 60 GW planned), and vehicle-to-grid (V2G) technologies will address intermittency. The State Grid's "Digital Twin Grid" project uses AI to optimize real-time dispatch of diverse energy sources.
- **Nuclear + Hydrogen:** High-temperature reactors (HTGRs) can provide heat for hydrogen production via thermochemical cycles (e.g., sulfur-iodine process), offering a zero-carbon alternative to electrolysis.

## 5. Challenges and Policy Implications

Despite rapid progress, challenges persist: (1) **Technological bottlenecks**, such as high-cost

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CCUS, limited Gen IV reactor scalability, and green hydrogen competitiveness; (2) **Market mechanisms**, including the need for carbon pricing (China's ETS covers only the power sector currently) and subsidies for early-stage technologies; (3) **Global supply chain risks**, particularly for critical minerals (e.g., lithium, cobalt, rare earths) used in batteries and wind turbines.

Policy recommendations include: (1) Strengthening R&D funding for next-generation technologies (e.g., direct air capture, advanced nuclear fuels); (2) Designing phased carbon pricing to incentivize low-carbon transitions; (3) Promoting international collaboration on standards and supply chain resilience.

# 6. Conclusion

China's energy technological trajectory reflects a pragmatic yet ambitious approach: maintaining traditional energy's role for stability while accelerating new energy deployment to meet climate goals. The interplay between efficiency-enhanced fossil fuels, scalable renewables, and emerging technologies (nuclear, hydrogen) will shape a diversified, low-carbon energy mix. By 2030, we anticipate a "dual-dominance" landscape where renewables contribute >40% of power generation, and traditional energy is increasingly decarbonized via CCUS and clean utilization. The integration of digital tools and cross-sector synergies will be pivotal in realizing China's "dual-carbon" vision, with global implications for energy innovation and climate governance.

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