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Research on the Development Status and Countermeasures of China's Integrated Energy Service Stations

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ABSTRACT

Against the backdrop of the global energy revolution and China's "dual carbon" goals, integrated energy service stations-new infrastructure combining multi-energy supply (oil, gas, electricity, hydrogen, storage) and smart services-have become key enablers of clean transportation energy transition and the new energy system. This paper systematically reviews the development landscape of China's integrated energy service stations. It finds that, driven by top-level policies and market exploration, the sector has entered a fast lane of large-scale and diversified growth, with co-located stations as the mainstream model and growing trends toward smart and eco-friendly operations. However, development is still constrained by weak planning and approval coordination, lagging technical integration and standards, severe early-stage economic challenges, and complex cross-energy safety management. Drawing on domestic and international best practices, this paper proposes systematic countermeasures: strengthening top-level design and "multi-plan integration," building an innovation system that pairs technology breakthroughs with standard leadership, creating "energy-plus" value-ecosystem business models, and erecting a full-chain smart safety defense, aiming to provide decision-making references for high-quality and sustainable development of China's integrated energy service stations.

KEYWORDS

Integrated Energy Service Station; Multi-energy Complementarity; Clean Energy; Standard System.

1. INTRODUCTION

The global energy landscape is undergoing a profound shift toward low-carbon, smart, and distributed models. China's "dual carbon" strategic goals represent not only a sweeping socio-economic transformation but also a reconstruction of energy production and consumption patterns. As transportation is a major carbon emitter, upgrading its energy-refueling infrastructure is critical to achieving these goals. Against this backdrop, integrated energy service stations have emerged. Far beyond traditional gas or charging stations, they are "energy complexes" and "urban service nodes" that integrate fossil fuels (oil, gas), green electricity (charging/battery swap), hydrogen, and storage systems, while also offering data services and retail functions.[1]

National strategic guidance is increasingly clear. In 2022, the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) encouraged traditional gas stations to build integrated oil-gas-electricity-hydrogen service stations. In 2025, the NEA further supported integrated projects in monetizing green value via green-power certificates and participating in electricity markets as virtual power plants, pointing to market-oriented solutions. Meanwhile, the industry standard Integrated Energy Service-Energy Efficiency Diagnosis Service Specification (DL/T 2861-2024) took effect, signaling a shift from policy guidance to standardized development.[2]

Driven by policy and market forces, China's integrated energy service stations have evolved from sporadic pilots to large-scale deployment, and business models have moved from simple facility stacking to deep integration and smart empowerment. Yet as a cross-sector, cross-technology, and cross-department novelty, the sector faces systemic challenges in institutional mechanisms, techno-economics, and safety standards. A comprehensive review of current development, in-depth analysis of core bottlenecks, and forward-looking solutions are therefore of vital theoretical and practical significance for guiding healthy industry growth and supporting national energy strategies.

2. DEVELOPMENT STATUS

2.1. Policy Framework

National policies form the top-level framework. Beyond macro encouragement, 2025 saw a flurry of documents: Opinions on Promoting High-quality Development of the Renewable Energy Green-power Certificate Market, Notice on Deepening Market-oriented Reform of New-energy Tariffs, and Guidelines on Accelerating Virtual Power Plant Development. Together they create a policy environment that rewards green value, distributed trading, and flexible resources, opening new revenue streams such as green-certificate income and ancillary-service earnings.

Local practices show diverse, context-specific innovation. Lüliang City-blessed with 400,000 t y^{-1} of low-cost (8–10 RMB kg^{-1}) coke-oven hydrogen-issued its 2025–2030 plan to build an integrated oil-gas-charge-hydrogen network and brand itself the "Hydrogen Capital." Xiong'an New Area, through State Grid's integrated energy subsidiary, has built the Jucun "1+5+X" smart energy fusion station, integrating energy facilities, eco-landscape, community services, and carbon management, showcasing a future urban energy node.[3]

2.2. Scale and Layout

By end-2024, over 100 integrated stations were operating nationwide. A core indicator-hydrogen refueling stations-reached 497 built (291 in operation), led by Guangdong (68) and Shandong (38).

"Co-located stations" dominate: 85 % of 2024 new hydrogen stations were built alongside existing fuel or charging facilities, validating the pragmatic "oil-feeds-new" logic that leverages mature sites, traffic, and operations to share high new-asset costs and lower market-entry risks.

State-owned enterprises (SOEs) act as ballast and vanguard: 65 % of 2024 new hydrogen stations are SOE-owned, with Sinopec and PetroChina leading, leveraging vast networks, capital, and brand trust to accelerate network transformation.[4]

2.3. Technology Models

2.3.1. Multi-energy Co-located Station

Most common baseline: spatially compact and full energy menu. Example: Sinopec Beijing Tengda station-fuel, hydrogen, retail-1,000 kg d^{-1} hydrogen. Qingyang "four-in-one" station adds oil, electricity, hydrogen, and non-fuel services.

2.3.2. PV-Storage-Charge-Discharge-Test Smart Microgrid

Deep integration: production-storage-consumption loop. Changzhou's large V2G station-620 kW PV, storage, 42 V2G bays, 660 kW reverse discharge-turns buses into mobile storage, shaving peaks and filling valleys, consuming 600 MWh yr^{-1} green power and cutting 550 t CO_2. It becomes a flexibility resource for the new power system.[5]

2.3.3. Regional Energy Interconnection & Carbon–Energy Synergy

Beyond single sites: Daxing Airport area system links 8 heating plants, 2 PV projects, 54 chargers, customizing heat supply and cutting public energy use by 10 %. Xiong'an's city-level "energy–carbon integration" platform connects 1.17 million data points for multi-energy dispatch and precise carbon monitoring, heralding city-scale optimization.[6]

2.4. Market Players

Traditional-energy SOEs (Sinopec, PetroChina)–"transformation leaders," leveraging vast terminals and capital.

Grid-based system integrators–State Grid provincial energy-service firms, building regional smart-energy platforms.

Cross-sector innovators–city-gas firms like Neijiang China Resources Gas, extending to distributed PV and district cooling/heating.

Tech & ecosystem enablers–CATL (storage), Huawei Digital Power (smart management), Nengliang (digital platforms), driving intelligent upgrades and interconnection.[7]

3. DEVELOPMENT CHALLENGES

3.1. Institutional Barriers

Involves NDRC, natural resources, housing-urban-rural, transport, emergency, fire, etc. No unified cross-agency approval mechanism; projects face lengthy "approval mazes," raising transaction costs. Composite land use lacks a clear urban-planning category; safety distances and fire codes still reference single-energy facilities, leaving projects "rule-less" or "mismatched."

Comprehensive safety standards for co-located oil-gas-electricity-hydrogen-storage are incomplete. Hydrogen flammability and Li-ion thermal runaway may create coupled chain risks, yet standards lag, leaving hidden dangers. Yingtan City has listed "new-format safety issues of storage-charge infrastructure" as a key regulatory task.

3.2. Techno-economic Hurdles

Many sites remain at the "physical stacking" stage; subsystems use heterogeneous interfaces/protocols, creating data silos and preventing global optimization. Advanced cases like Changzhou V2G station face high equipment costs, immature communication standards, and market mechanisms.

High upfront investment (hydrogen, high-power chargers, storage) collides with long market-penetration of downstream applications (e.g., fuel-cell vehicles). Most operators still rely on subsidies; returns are strained. Profit heavily depends on conventional fuel sales-"oil-feeds-new" is pragmatic but fragile, with single revenue structure and weak risk resilience. Unlocking value via energy-efficiency management, carbon-asset operation, and power-market participation (virtual power plant) is key.[8]

3.3. Safety & Talent Shortage

Co-existence of oil-electricity-hydrogen-storage, especially hydrogen leakage and Li-ion thermal runaway, imposes extreme demands on design, monitoring, and emergency response. Specialized and intelligent safety management needs upgrading.

The sector urgently needs inter-disciplinary talent fluent in conventional oil & gas, power electronics, hydrogen, digitalization, and carbon management. Current staff have narrow knowledge, constraining innovative design and refined operation.[错误!未找到引用源。]

4. COUNTERMEASURES & RECOMMENDATIONS

4.1. Strengthen Top-level Design & Institutional Innovation

Advance "multi-plan integration" and approval reform: issue national guidance recognizing integrated stations as an independent infrastructure category in territorial spatial planning. Locally, implement "one-stop joint approval" with cross-agency task forces and parallel processing, compressing lead times. Borrow "standard land" reform: pre-complete regional safety assessments.

Accelerate a full-chain standard system: lead agencies plus SOEs and research institutes to fast-track national standards covering site selection, design, construction, operation, safety, and smart management. Focus on safety distances, fire configuration, and risk co-control under multi-energy coupling, giving the industry rules to follow.

4.2. Focus on Core Technology R&D & Digital Empowerment

Break key-tech bottlenecks: launch national R&D programs targeting 70 MPa hydrogen nozzles, low-cost high-flow compressors, high-efficiency hydrogen production, and integrated oil-gas-electricity-hydrogen skid-mounted units to cut on-site work and land use.

Deepen digital twins and AI: mandate new stations deploy smart energy-management platforms integrating IoT, big data, AI, and digital twins. Enable predictive maintenance, real-time multi-energy dispatch (e.g., PV output and time-of-use tariffs to dynamically adjust charging/hydrogen strategies), and "virtual power plant" aggregation to turn stations from cost centers into profit centers.

4.3. Innovate Business Models & Market Mechanisms

Build an "energy-plus" value symbiosis: shift from energy commodity reseller to customer energy-solution provider. For logistics parks and bus fleets, bundle energy-saving retrofits, smart fleet management, green-power/green-certificate procurement, and carbon-footprint accounting. Explore "energy + retail/data" to create premium rest-stop experiences and data-value services.

Plug into market revenue streams: implement green certificates, virtual power plants, and behind-the-meter green-power trading. Help stations monetize green electricity, storage peak-shaving, and V2G discharge into tradable ancillary-service income, fundamentally improving cash flow.

4.4. Fortify Safety & Cultivate Talent

Deploy smart safety & full-chain supervision: adopt AI video, laser gas-leak detection, early thermal-runaway warning, and IoT-based real-time monitoring with automatic response. Build a three-tier (regulator, headquarters, site) smart safety platform enabling risk warning, traceability, and accountability.

Create inter-disciplinary talent pipelines: encourage universities to launch "integrated energy engineering" programs; SOEs and vocational colleges set up training bases for large-scale upskilling of existing staff to close talent gaps quickly.

5. CONCLUSION

Integrated energy service stations are pivotal to transport-energy transition. Current constraints are threefold: complex planning/approval and absent standards impede project rollout; insufficient tech integration and smart levels hurt efficiency and economics; single business models and early losses threaten sustainability. Synergistic advances are needed: strengthen top-level design and standards to remove institutional barriers; focus on tech breakthroughs and digital empowerment to boost smart operation; innovate business models and market mechanisms to unlock diversified value. This paper aims to provide reference for the healthy and orderly development of China’s integrated energy service stations.

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