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Research on the Key Pathways for Constructing an Ecological Transportation System Based on Hydrogen Energy in Larger Cities

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Abstract

This study explores the key pathways for constructing an ecological transportation system based on hydrogen energy in larger cities, with Jiaxing City, Zhejiang Province, as a representative case. The research investigates the strategic role of hydrogen as a clean energy source in promoting green transformation within the transportation sector. A comprehensive review is conducted on Jiaxing's innovative practices in the large-scale application of hydrogen-powered vehicles, construction of a "zero-carbon" transportation system, improvement of hydrogen energy-inclusive carbon benefit mechanisms, integration of diversified green travel modes, intelligent upgrading of slow transportation systems, and the development of smart transportation platforms. The study reveals the significant achievements of hydrogen-based transportation in reducing carbon emissions, enhancing transport efficiency, and optimizing travel structure. Moreover, this paper conducts an in-depth analysis of the core challenges currently facing the development of hydrogen transportation, including high costs, technological bottlenecks, weak hydrogen refueling infrastructure, insufficient policy incentives, imbalanced scenario adaptability, and data silos. Based on this analysis, five key pathways for building a hydrogen-based transportation ecosystem in larger cities are proposed: strengthening independent innovation in core technologies; improving the hydrogen infrastructure network; innovating policy incentives and carbon value systems; clarifying differentiated application scenarios; and promoting the construction of intelligent management platforms. The research concludes that the high-quality development of a hydrogen-based transportation system requires the synergistic advancement of technological innovation, institutional supply, scenario-oriented strategies, and digital empowerment to transition from pilot demonstrations to routine operations. This transformation will support

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the realization of a green, low-carbon, and intelligent transportation future in larger cities.

Keywords

Hydrogen Transportation, Green and Low-Carbon Transition, Ecological Transportation System, Hydrogen Refueling Infrastructure, Smart Transportation Management

1. Introduction

Zhejiang is a strong economic province in eastern China, committed to the goals of "common prosperity" and becoming a pioneer in Chinese-style modernization (Yao, Gao, & Yang, 2019). It is moving toward the center of the national economic map with a more open, efficient, and intelligent posture. In 2024, its permanent population reached 66.7 million, GDP exceeded 9 trillion yuan, and per capita GDP reached 135,267 yuan, demonstrating strong development momentum. Among them, Hangzhou and Jiaxing, as core drivers of the Yangtze River Delta integration strategy, have particularly outstanding performance. Hangzhou, with a permanent population of 12.62 million and GDP exceeding 2.2 trillion yuan, ranks steadily at the forefront of the province, with the digital economy and high-end manufacturing as key drivers of sustained growth; Jiaxing, with a population of 5.61 million and a GDP of 757 billion yuan, has achieved leapfrog development and become an important support for the regional economy (Zhejiang Provincial Bureau of Statistics, 2025). In terms of transportation construction, Hangzhou's expressway mileage has exceeded 900 kilometers, with an annual freight volume of 480 million tons, forming a "two-ring, thirteen-radiation" transportation framework, strengthening its status as a national smart logistics hub. Jiaxing has achieved "expressway access to every town", with expressway mileage exceeding 500 kilometers. Relying on the powerful collection and distribution system of the Ningbo-Zhoushan Port, the annual freight volume has reached 210 million tons, making it an important node in the Yangtze River Delta port cluster. By the 2023 Asian Games, Hangzhou's metro line had reached 516 kilometers in operation, with an average daily passenger flow of 4.3 million. The Hang-Hai Intercity Railway, which opened in 2021, has formed a stable intercity commuting channel from Hangzhou to Haining in Jiaxing. The opening of major projects such as the Hangzhou Bay Sea-Crossing Bridge and the Shanghai-Hangzhou-Ningbo expressway extension has enabled the two cities to achieve a "1-hour commuting circle" with other core cities in the Yangtze River Delta. The synergistic advancement of three major strategies—population agglomeration, industrial upgrading, and transportation leadership—has expanded the economic scale of Hangzhou and Jiaxing six to seven times over the past 20 years, making them models of high-quality development in Zhejiang and even across the country.

At the same time, traffic-related carbon emissions continue to rise, mainly due to a surge in the number of motor vehicles, the high frequency of freight logistics operations, and the diversification of travel demands. Larger cities across Zhejiang face similar challenges, with massive energy consumption and carbon emission pressures underlying the large transportation system. Under the "dual carbon" goal, how to achieve energy conservation and emissions reduction in urban transportation has become a critical issue in urban governance and industrial transformation. Therefore, it is urgent to promote a green transformation of the transportation sector from multiple dimensions. First, accelerate the application and promotion of new energy transportation, improve the coverage and convenience of public transport, and encourage citizens to adopt green travel methods. Second, rely on big data and artificial intelligence technology to optimize the allocation of transportation resources, enhance road network efficiency, and reduce ineffective energy consumption. Third, promote the integration of "rail + bus + slow mobility" in urban travel systems to reduce reliance on private cars. In addition, scientific urban planning should be strengthened to promote a balance between employment and residential areas, thereby reducing the carbon footprint caused by long-distance commuting (Wu, 2021).

Taking Jiaxing City as a case study, this paper explores how, as a pilot city for Yangtze River Delta integration, it can take the lead in exploring paths and accumulating experience in transportation green development based on hydrogen energy technology innovation, thereby providing strong support for the construction of sustainable transportation systems in larger cities across the country. The selection of Jiaxing primarily stems from its representativeness as a national hydrogen demonstration city. First, Jiaxing is located in the core of the Yangtze River Delta, with strong policy coordination and robust industrial foundations, featuring an advanced layout across the full hydrogen industrial chain. Second, its large-scale applications in areas like public transportation and freight have achieved significant carbon emission reduction effects; these experiences are quantifiable and highly efficient. Third, facing the common challenge of high-carbon commuting in large cities, Jiaxing's practices possess generality and can provide a replicable model for the entire nation. Furthermore, Jiaxing's moderate city size makes it an ideal testing platform that can reflect real-world challenges, thereby aiding the promotion of policies and technologies.

2. Strategies for Energy Conservation and Emission Reduction in Urban Transportation Based on Hydrogen Energy Technology Innovation

Under the "dual carbon" strategy, hydrogen energy, as a clean, efficient, and sustainable energy source, is gradually becoming a key breakthrough for promoting green and low-carbon urban transportation transformation (Zheng, Xu, Xie, Shao, Li, & Shi, 2025). As a pilot city for Yangtze River Delta integration, Jiaxing relies on its strong hydrogen energy industry foundation and well-developed transportation infrastructure to actively explore innovative applications of hydrogen energy in the transportation field (Zhang, 2025). This not only provides strong support for local transportation energy conservation and emission reduction but also offers replicable and scalable experience for green transformation of urban transportation across the country (Zeng et al., 2022). Jiaxing has established a systematic strategy covering six dimensions: hydrogen-powered vehicle upgrades, transportation system construction, inclusive carbon benefit mechanism improvement, diversified travel integration, slow-mobility upgrades, and smart platform construction.

2.1. Promoting the Large-Scale Application of Hydrogen Energy Vehicles to Build a Low-Carbon Transportation Equipment System

Jiaxing attaches great importance to the promotion and application of hydrogen-powered transportation, focusing on buses and freight vehicles to achieve large-scale implementation of hydrogen energy in urban transportation. Since 2019, Jiaxing has launched the province's first hydrogen-powered bus demonstration line and continuously expanded the deployment of hydrogen-powered buses. As of the end of 2024, the city had deployed 230 hydrogen-powered buses, leading the province. At the same time, leveraging its local hydrogen energy industry chain advantages, Jiaxing has accelerated the promotion of hydrogen-powered trucks, with 121 units deployed by 2024, accounting for 88.5% of total new energy freight vehicles, ranking first in the province. By building a low-carbon transportation equipment system centered on hydrogen buses and hydrogen-powered freight vehicles, Jiaxing has effectively replaced traditional fuel vehicles and significantly reduced carbon and pollutant emissions in the transportation sector. Moreover, hydrogen-powered vehicles have advantages over electric vehicles in terms of range, refueling time, and load capacity, making them particularly suitable for long-haul and heavy-load transportation scenarios, thus providing a new technological path for the green upgrading of urban logistics systems.

2.2. Creating a Zero-Carbon Transportation System and Promoting the Integrated Development of Hydrogen Transportation Routes and Logistics Parks

Another important exploration in Jiaxing's hydrogen transportation application is the establishment of a green transportation system integrating "zero-carbon fleet-zero-carbon route-zero-carbon logistics park". Among them, the Yemaodun Zero-Carbon Logistics Park at Jiaxing Port has been included in the first batch of pilot projects by the Ministry of Transport, becoming a typical demonstration of hydrogen application in port logistics scenarios. The park achieves full-process carbon reduction through multi-dimensional applications such as hydrogen-powered freight vehicles, hydrogen handling equipment, and hydrogen cold chain transportation. In addition, Jiaxing has built two distinctive zero-carbon transportation routes powered by hydrogen: "port short-haul + cross-regional transportation in the Yangtze River Delta". These routes have not only improved logistics efficiency but also achieved carbon neutrality in cross-regional transportation. Currently, related projects have entered the defense phase of the Ministry of Transport and are expected to become national demonstration projects. Through the deep integration of hydrogen with logistics parks and transportation routes, Jiaxing is exploring a new path for modern logistics development that combines green, intelligent, and efficient elements, providing innovative practices for the low-carbon transformation of urban logistics systems.

2.3. Improving the Hydrogen Inclusive Carbon Benefit Mechanism and Strengthening Green Transportation Economic Incentives

In promoting hydrogen transportation development, Jiaxing emphasizes institutional innovation and market mechanism building, actively advancing the formulation and implementation of hydrogen-inclusive carbon benefit mechanism methodologies. In 2024, Jiaxing completed and officially released the nation's first carbon reduction benefit assessment standard for hydrogen fuel cell freight vehicles—the "Hydrogen Freight Vehicle Inclusive Carbon Benefit Mechanism Methodology". The introduction of this methodology provides a scientific basis for carbon emission accounting and carbon asset trading of hydrogen vehicles and offers policy support for the sustainable promotion of hydrogen in the transportation field. Through the inclusive carbon benefit mechanism, Jiaxing encourages enterprises and individuals to participate in hydrogen transportation applications, promoting a virtuous cycle of "who reduces emissions, who benefits". At the same time, the city has incorporated inclusive carbon benefit mechanism results into the Yangtze River Delta regional cooperation framework, applying for the excellent case of "Hydrogen on the Move—Methods First, Promoting High-Quality Green Ecological Integration in the Yangtze River Delta". This initiative not only enhances the economic benefits of hydrogen transportation but also strengthens the public's participation and sense of gain in green travel (Wang, Sun, & Fan, 2025).

2.4. Constructing a Diversified Green Travel System to Achieve Synergistic Hydrogen Transportation under the "Three-Network Integration" Framework

While advancing hydrogen transportation development, Jiaxing focuses on the overall integration with urban green travel systems, building a "rail + bus + slow mobility" trinity green travel network. In 2023, Jiaxing compiled and implemented the "Three-Network Integration Plan for Trams, Buses, and Slow Mobility", improving the convenience and appeal of public transport through infrastructure integration, network integration, operational integration, and payment integration. In this system, hydrogen-powered buses serve as one of the backbone forces, complementing trams, shared electric bikes, and public bicycles. Currently, all 14 tram stations in Jiaxing that meet the conditions have achieved seamless connections with conventional public transport and slow mobility systems, forming a "Bike + Bus (B + R)" green transportation model. This multi-dimensional synergistic green travel system effectively reduces residents' reliance on private cars and further enhances the overall energy efficiency and environmental protection level of the transportation system (Nie & Li, 2025).

2.5. Promoting Intelligent Upgrading of Slow Mobility to Enhance Green Travel Service Experience

Slow mobility, as an important component of the green travel system, has also been systematically optimized and intelligently upgraded in Jiaxing. As of 2024, Jiaxing has deployed 17,500 shared electric bikes, with an average daily rental volume of 46,000 trips, greatly enhancing the convenience of short-distance travel for citizens. To strengthen industry management, Jiaxing has jointly issued the "Assessment and Management Measures for Shared Electric Bikes" with the Public Security Bureau and the Urban Management and Comprehensive Law Enforcement Bureau, and developed the "Smart Shared Electric Bike Platform", achieving intelligent monitoring of vehicle deployment, dispatching, and operations. At the same time, Jiaxing has accelerated the pile-free transformation of public bicycles, building 1085 pile-free service points, deploying 12,000 high-quality public bicycles, including 2000 family bikes, with an average daily rental volume exceeding 13,800 trips, a peak daily rental volume of 30,000 trips, and a turnover rate of 2.67 trips per bike. These initiatives have not only improved the accessibility and service quality of the slow mobility system but also enhanced citizens' willingness and habits to travel green, laying a solid social foundation for the widespread application of hydrogen transportation.

2.6. Deepening Intelligent Transportation Platform Construction to Achieve Precise Management and Optimization of Hydrogen Transportation

In the process of promoting hydrogen transportation development, Jiaxing attaches great importance to informatization and intelligent construction. As a model city for smart public transport construction in the province, Jiaxing was the first to build the "One Center, Three Platforms" (Data Resource Center, Enterprise Intelligent Dispatching Platform, Public Travel Service Platform, Industry Supervision Platform), achieving visual, measurable, and controllable management of bus operations. In 2023, the system was upgraded to version 3.0, accessing basic bus data across the entire city area, covering various transportation modes such as urban buses, trams, public bicycles, and shared electric bikes, constructing an integrated urban green travel monitoring platform. In addition, Jiaxing was the first in the country to open up public transport data resources in 2016, launching the "Bus Arriving" APP and pushing bus data to electronic station signs to achieve "on-time bus travel", greatly enhancing the passenger travel experience. The first national public transport big data analysis platform, launched in 2017, provides scientific decision-making support for optimizing bus networks, station planning, and scheduling. In the field of hydrogen transportation, the application of these intelligent platforms enables real-time monitoring and analysis of hydrogen-powered vehicle operation data, helping to optimize dispatching strategies, improve energy utilization efficiency, and reduce idle running rates and energy consumption. Through data-driven refined management, Jiaxing is building a new urban transportation pattern that is efficient, green, and intelligent.

3. Major Existing Problems in Energy Conservation and Emission Reduction of Megacity Transportation Based on Hydrogen Energy

Driven by global carbon neutrality goals, hydrogen, as a clean secondary energy source, has become a core pathway for decarbonizing transportation in major countries (Glenk & Reichelstein, 2019). Developed nations such as the United States, Japan, and the European Union have gained a first-mover advantage in hydrogen-powered transportation through systematic policy support, advanced technological accumulation, and large-scale infrastructure deployment (Zhang, 2025). For example, California's "Hydrogen Highway" initiative has established the densest hydrogen refueling network in North America; Toyota's Mirai fuel cell vehicles lead global sales; and the EU is accelerating the commercialization of hydrogen-powered heavy-duty trucks through the "Clean Hydrogen Partnership". These countries have accumulated rich experience in technology validation, business model exploration, and public awareness (Jin, Liu, & Chen, 2019). In China, hydrogen industry hubs centered in cities such as Xi'an, Shaanxi, and Changchun, Jilin, are rapidly emerging. Xi'an, leveraging the Xixian New Area, is building a "Western Hydrogen Capital" and has attracted leading electrolysis companies like Longi Hydrogen. Changchun, as a representative of traditional industrial bases, is developing the fuel cell vehicle industry chain through FAW Group, aiming to create a "Northern Hydrogen Valley" (Hou & Chen, 2025). However, during the deep integration of hydrogen technology into urban transportation systems, its promotion still faces numerous structural challenges, particularly in the following six key areas.

3.1. Dual Constraints of Cost and Technology Maturity

Countries like the U.S. and Japan have significantly lowered user barriers through substantial purchase subsidies (e.g., up to $12,000 per vehicle in the U.S.) and tax credits. Fuel cell system lifespans have generally exceeded 25,000 hours, with leading levels in stack power density. In China, however: First, acquisition costs remain high. Domestic fuel cell passenger vehicles are priced at more than twice that of comparable gasoline-powered vehicles. Although prices for commercial vehicles have dropped significantly, competitiveness remains weak. For example, FAW's fuel cell heavy trucks produced in Changchun cost over 1.5 million RMB, greatly limiting logistics companies' willingness to procure them. Second, critical components are still subject to supply bottlenecks. Core materials such as membrane electrode assemblies, proton exchange membranes, and carbon paper still rely heavily on imports (accounting for over 50% of stack costs), leading to high production costs for local stack manufacturers in Xi'an. Third, technological gaps in key areas. For instance, the severe winter cold in Changchun imposes stringent demands on the cold-start performance of fuel cell systems (startup time and efficiency at −30˚C). Although there have been breakthroughs in hydrogen-powered trains, practical test data for freight equipment (vehicles) still lag behind international advanced levels.

3.2. Weak Hydrogen Refueling Network and Mismatched Transport Scenarios

Germany and Japan have built extensive hydrogen refueling networks in larger cities—Germany has nearly 100 stations, and Japan has more than 160—and prioritized hydrogen-powered heavy trucks in closed environments like ports and mines. In China, however: First, hydrogen refueling stations are severely insufficient and unevenly distributed. Xi'an has only four operational stations (mostly concentrated in the Xixian New Area), and Changchun has only two. Sparse station coverage limits vehicle range and fails to support intercity freight demand. Second, there is a vicious cycle between vehicles and stations—low vehicle numbers lead to low utilization of refueling stations (generally below 30%), resulting in operational losses that discourage new station construction. Third, scenario adaptation is inadequate. While Xi'an has successfully promoted hydrogen in public transportation (over 100 buses in operation), large-scale deployment in hydrogen's advantageous areas—such as cold chain logistics and intercity freight—remains lacking. Changchun has pilot heavy truck lines, but lacks large-scale applications matching FAW's production capacity.

3.3. Insufficient Incentives and Lack of Accounting Standards

The Low Carbon Fuel Standard (LCFS) in California, USA, awards high carbon credits for hydrogen fuel (about $3 per kilogram of hydrogen), directly incentivizing fuel producers. The EU Emissions Trading System (EU ETS) is exploring the inclusion of transport emissions. In China, however: First, incentive efforts are weak. Existing local subsidies focus on vehicle purchases, with insufficient ongoing incentives for green hydrogen production and usage. No regional traffic-inclusive carbon benefit mechanism platforms have been established. Second, the accounting system is incomplete. There is no authoritative methodology for calculating carbon emissions reductions from hydrogen transportation, making quantification and trading difficult, and reducing companies' motivation to reduce emissions voluntarily. Third, green hydrogen traceability is challenging. The cost difference between green hydrogen (produced from renewable energy) and gray hydrogen (from fossil fuels) is significant, but there is a lack of a reliable certification system, hindering the realization of green premiums.

3.4. Ambiguous Hydrogen Positioning and Disconnected Intermodal Systems

Ideally, hydrogen fuel cell vehicles (buses, taxis, logistics vehicles) should seamlessly integrate with battery electric vehicles, rail transit, and shared bikes, forming a multi-level green mobility network. In China, however: First, hydrogen's role is unclear. While hydrogen has advantages in buses and heavy trucks, its differentiated positioning within the broader urban transportation system is not clearly defined, often leading to homogenized competition with battery electric vehicles. Second, intermodal infrastructure is lacking. For example, around Xi'an's subway stations, there are no dedicated hydrogen bus transfer lines; logistics routes from Changchun's high-speed rail stations to auto factories lack assort hydrogen refueling facilities. Third, policy coordination is weak. Urban planning, energy planning, and land use planning are not effectively integrated, causing difficulties in selecting locations for hydrogen refueling stations.

3.5. Marginalization of Hydrogen Micro-Mobility Tools

Europe has started piloting hydrogen-assisted bicycles and small shuttle vehicles for "last-mile" transportation in scenic areas and industrial parks. In China, however: First, there are no large-scale pilots of hydrogen bicycles or tricycles in cities like Jiaxing, Xi'an, or Changchun. Miniature fuel cells are expensive, and public awareness of their safety is low. Second, infrastructure does not support these vehicles. Current shared bike parking spots cannot accommodate hydrogen vehicle refueling or battery swapping needs. Third, policy attention is minimal. Local government planning focuses on large-scale vehicles, neglecting hydrogen's emission reduction potential in micro-mobility scenarios.

3.6. Data Silos and the Absence of Intelligent Dispatch Systems

In California, the "Hydrogen Digital Platform" monitors vehicle and refueling station status in real time to optimize dispatching. Germany has developed hydrogen logistics route planning algorithms. In China, however: First, transportation data is fragmented. Vehicle operation data, hydrogen station inventory, and grid green power information are managed by different entities, failing to create a coordinated "vehicle-station-energy grid" system. Second, intelligent dispatching capabilities are underdeveloped. There is no dynamic route planning system based on real-time hydrogen prices, station queue times, and vehicle range, leading to inefficient operations. Third, safety management relies on manual monitoring. AI-based predictive safety monitoring for hydrogen stations and vehicle failure warnings has not been implemented, posing potential risks.

The identified challenges exhibit significant coupling effects: High techno-economic costs (3.1) constrain the scale of hydrogen vehicle adoption, resulting in underutilized refueling stations (3.2); absent policy incentives (3.3) and data silos (3.6) hinder vehicle-station synergy, while inadequate infrastructure (3.2) further intensifies techno-economic constraints (3.1). Closed-loop blockages must be tackled through systemic thinking.

4. Key Pathways to Building a Hydrogen Transportation Ecosystem in Larger Cities

Under the guidance of the "Dual Carbon" strategic goals, hydrogen, as a clean energy source, has become a critical driver for promoting green and low-carbon transformation in urban transportation systems (Nie & Li, 2025). To establish hydrogen as the "green engine" for carbon reduction in urban transport, it is essential to advance systematically across multiple dimensions—technology innovation, infrastructure development, policy and mechanism innovation, application scenario orientation, and intelligent management—to create a sustainable, efficient, and synergistic hydrogen transportation ecosystem. This article proposes the following five key pathways.

4.1. Strengthen the Core Technology Innovation Chain and Build an Independent and Controllable Hydrogen Technology System

Core technologies form the foundation of hydrogen transportation development. Currently, China still faces "bottleneck" issues in key materials such as fuel cell stacks, membrane electrode assemblies, proton exchange membranes, and carbon paper, which severely restrict the large-scale application of hydrogen-powered vehicles. Therefore, it is crucial to strengthen core technology R&D across the hydrogen industry chain and establish a technology system with independent intellectual property rights. First, national-level science and technology projects should be established to focus resources on overcoming technical bottlenecks in key materials and components. For example, Changchun, leveraging research institutions such as the Changchun Institute of Applied Chemistry of the Chinese Academy of Sciences, can prioritize breakthroughs in fuel cell cold-start performance and low-temperature adaptability to enhance its suitability in extremely cold northern regions. Meanwhile, Xi'an, with leading enterprises like Longi Hydrogen Energy, can promote the iterative upgrading of electrolysis technology to improve green hydrogen production efficiency and economic viability. Mass production can reduce costs and provide a stable, low-cost hydrogen supply for future hydrogen transportation. Second, a collaborative innovation mechanism between industry, academia, and research should be strengthened. Universities, research institutes, and enterprises should jointly establish hydrogen technology R&D platforms to promote the deep integration of basic research and engineering applications. Jiaxing should continuously enhance its collaboration with Zhejiang University Hydrogen Energy Research Institute and Professor Zheng Jinyang—an expert in hydrogen storage, transportation, safety assessment, and standardization—and his International Hydrogen Association Standardization Committee to actively promote R&D and standardization in key hydrogen technologies. They are working closely with local governments and hydrogen enterprises in Jiaxing to advance diversified hydrogen storage technologies such as high-pressure hydrogen storage, liquid hydrogen storage, and solid-state hydrogen storage through demonstration applications. Additionally, Jiaxing can accelerate the transformation of scientific and technological achievements into real productivity by building hydrogen pilot bases and industrial demonstration parks. As a national-level hydrogen research platform, Zhejiang University Hydrogen Energy Research Institute is collaborating with local enterprises such as Edman and Fengyuan Hydrogen Energy to jointly develop core equipment like fuel cell systems and hydrogen power modules, forming a collaborative innovation model involving research institutions, local governments, and leading industries. Jiaxing can also actively participate in the national hydrogen standardization system. Leveraging Zhejiang University and other major research platforms' influence in international hydrogen standards, it can promote the formulation of key technical standards such as stack life, system efficiency, and hydrogen refueling interfaces, ensuring the uniformity and scalability of technological outcomes, thus laying a solid foundation for the large-scale application of hydrogen transportation (Zhang & Wang, 2025). The fundamental ecological value of green hydrogen lies in its full-life-cycle low-carbon attributes. Hydrogen produced via water electrolysis powered by renewable energy (green hydrogen) features near-zero carbon intensity, reducing full-cycle emissions by over 70% compared to hydrogen derived from fossil fuels (grey hydrogen). A stable supply of green hydrogen is foundational to sustaining the long-term ecological sustainability of hydrogen mobility systems—only through achieving "source greening" can the decarbonization chain of transportation be fully closed, aligning perfectly with the low-carbon essence of an "eco-transportation system".

4.2. Prioritize Infrastructure Development and Establish a Wide-Coverage, High-Efficiency Hydrogen Supply Network

The development of hydrogen transportation depends on an efficient, safe, and convenient hydrogen supply system (Wu, 2021). Currently, China has a limited number of hydrogen refueling stations that are unevenly distributed, significantly constraining the operational efficiency and popularity of hydrogen vehicles. Therefore, a "priority infrastructure" strategy must be adopted to build a hydrogen infrastructure network matched with transportation demand. First, hydrogen refueling stations should be rapidly deployed along key transportation routes—for example, prioritizing stations along major logistics corridors such as the Xi'an–Yulin expressway and the Changchun–Dalian port highway to form hydrogen transportation corridors. Simultaneously, integrated energy stations combining gasoline, hydrogen, natural gas, and electricity should be constructed at urban transportation hubs (such as high-speed railway stations, airports, and logistics parks) to improve infrastructure compatibility and service capability. Second, decentralized hydrogen supply models should be explored. In urban centers, advanced technologies such as liquid hydrogen storage and solid-state hydrogen storage should be promoted to overcome the spatial limitations of traditional high-pressure storage methods, enabling modular and compact deployment of hydrogen refueling stations and enhancing the flexibility and scalability of urban hydrogen networks. Third, the hydrogen transportation system should be optimized. Specialized hydrogen transportation vehicles and pipeline hydrogen delivery technologies should be developed to improve transportation efficiency and safety while reducing costs, thus ensuring stable hydrogen supply at the end-user level. Moreover, stronger coordination between hydrogen infrastructure and the broader energy system is needed. For instance, integrating hydrogen storage and transportation with renewable energy generation and grid dispatching can enable a closed-loop operation of "green electricity producing green hydrogen", further enhancing the environmental and economic value of hydrogen (Wang, Li, Fan, Yang, Ouyang, Cheng, & Liu, 2025).

4.3. Innovate Policy Instruments and Establish a Diversified Incentive Mechanism and Carbon Value System

Policy guidance is a vital driver for building a hydrogen transportation ecosystem. Currently, China's hydrogen transportation subsidy policies mainly focus on vehicle purchases, lacking systematic incentives for the entire hydrogen production and usage cycle. Therefore, a diversified and long-term policy support system should be established to stimulate market vitality (Zeng et al., 2022). First, a combined incentive mechanism of "green hydrogen subsidies + carbon credit points" should be introduced. Financial subsidies should be provided to transportation entities using green hydrogen, while the carbon reduction of hydrogen vehicles should be included in the carbon credit system, allowing enterprises or individuals to benefit from carbon trading. For example, the Low Carbon Fuel Standard (LCFS) mechanism in California, USA, can serve as a reference to establish a carbon reduction accounting methodology for hydrogen transportation and promote the quantification and tradability of carbon assets. Second, the carbon reduction accounting system for hydrogen transportation should be improved. China currently lacks a unified standard for hydrogen carbon reduction accounting, making it difficult for enterprises to benefit from carbon reduction. Therefore, a unified hydrogen transportation carbon accounting methodology should be developed and promoted, and integration with the national carbon market and regional carbon credit platforms should be accelerated to enhance the economic appeal of hydrogen transportation. In addition, policy coordination should be strengthened. Joint special plans for hydrogen transportation development should be formulated by multiple departments, including transportation, energy, and land resources, to overcome institutional barriers such as difficulties in hydrogen station site selection and land use approvals, thereby forming a joint policy force. As a pioneer in green and low-carbon development, Zhejiang Province can take the lead in introducing targeted fiscal support policies for hydrogen transportation at the provincial level, establishing a green hydrogen development fund, and promoting the deep integration of carbon credit platforms with transportation application scenarios to explore coordinated mechanisms for hydrogen in the Yangtze River Delta carbon trading system.

4.4. Clarify Scenario-Driven Strategies and Build a Differentiated and Synergistic Hydrogen Transportation Application System

Hydrogen transportation should not be developed in a scattered manner but should be based on urban transportation characteristics and industrial foundations to identify advantageous application scenarios and achieve differentiated development, avoiding homogeneous competition with pure electric vehicles. On one hand, hydrogen's strengths should be leveraged in specific scenarios such as cold chain logistics, port transportation, airport ground support, and heavy-duty truck transport. These scenarios demand high endurance, load capacity, and hydrogen refueling efficiency, where hydrogen vehicles demonstrate clear advantages. For example, the successful experience of the Yemaodun Zero-Carbon Logistics Park at Jiaxing Port can be replicated, promoting hydrogen-powered cold chain transportation and hydrogen handling equipment to create a green logistics model. On the other hand, strategies should be tailored to regional industrial characteristics. For instance, Changchun, leveraging FAW Group's advantages in vehicle manufacturing, can focus on hydrogen-powered heavy trucks and core component manufacturing, building a "Northern Hydrogen Valley". Xi'an, leveraging enterprises like Longi Hydrogen Energy, can emphasize green hydrogen production and hydrogen-powered bus applications, aiming to establish itself as the "Western Hydrogen Capital". Eastern coastal cities can leverage port economies to promote hydrogen-powered port machinery and container transportation. Moreover, hydrogen should be integrated with rail transit, shared mobility, and slow-travel systems to create a multi-layered green travel system combining "hydrogen + electric + rail + slow travel", achieving complementary transportation modes and improving overall travel efficiency and environmental performance.

4.5. Develop an Intelligent Hydrogen Cloud Brain and Achieve Digital and Smart Transformation of Hydrogen Transportation

With the rapid development of digital technology, the efficient operation of hydrogen transportation cannot be separated from data-driven intelligent management. Currently, China faces challenges such as data silos, low dispatch efficiency, and weak safety supervision in hydrogen transportation. Therefore, it is urgent to build an "Intelligent Hydrogen Cloud Brain" system to achieve comprehensive intelligent management of hydrogen transportation. First, a hydrogen big data center should be established. By integrating diverse data, including vehicle operation, hydrogen station inventory, energy supply, and traffic flow, a unified data platform should be built to enable full-chain visualization, analysis, and prediction of hydrogen transportation. Second, an intelligent dispatch system should be developed. Based on real-time hydrogen prices, station queue conditions, and vehicle range status, a dynamic route planning system should be constructed to improve dispatch efficiency, reduce idling and energy consumption, and optimize resource allocation.

Third, an intelligent safety supervision system should be built. Using technologies such as artificial intelligence and the Internet of Things (IoT), real-time monitoring and risk warnings should be implemented for hydrogen station operations, vehicle performance, and hydrogen storage and transportation to enhance safety and public confidence in hydrogen transportation. Furthermore, deeper integration between hydrogen transportation and the energy internet can be explored—for example, by connecting the hydrogen cloud platform with grid dispatch systems to enable coordinated scheduling of green hydrogen production and renewable energy generation, promoting the low-carbon and intelligent transformation of transportation energy systems (Wang, Sun, & Fan, 2025). Zhejiang Province has already piloted the integration of hydrogen cloud platforms with urban traffic brains, promoting intelligent applications of hydrogen in buses, logistics, and intercity transportation.

5. Conclusion

Building a hydrogen transportation ecosystem in larger cities is a key path to achieving the "Dual Carbon" strategic goals in the transportation sector and driving urban green and low-carbon transitions. From technology innovation to infrastructure layout, from policy mechanism design to application scenario expansion, and finally to digital and intelligent management, each link is closely interdependent, forming the core support system for high-quality hydrogen transportation development. Cities like Jiaxing have already begun exploring replicable and scalable practical experiences, offering valuable references for other larger cities across the country. In the future, as hydrogen production, storage, transportation, and utilization continue to break through technologically, and as the cost of large-scale green hydrogen production declines, the economic viability and sustainability of hydrogen transportation will further improve. Meanwhile, the maturation of policy incentive systems and the implementation of carbon credit mechanisms will effectively stimulate market vitality and social participation. More importantly, through intelligent platforms and data empowerment, hydrogen transportation will see significant improvements in operational efficiency and safety. Only by adhering to a systematic approach, coordinated promotion, scenario orientation, and innovation leadership can hydrogen transportation transition from demonstration to normalization, from localized efforts to systemic transformation, truly becoming the core engine of green urban mobility and propelling Chinese cities toward a cleaner, more efficient, and smarter transportation era.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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