Scientific and Social Research, 2025, Volume 7, Issue 6
https://ojs.bbwpublisher.com/index.php/SSR
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Research on the Development and Prospect of Hydrogen Energy Vehicles

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Abstract: With the increasing global attention to environmental protection and sustainable development, hydrogen energy vehicles, as an important development direction of clean energy vehicles, are receiving more and more attention. As a zero-emission or low-emission mode of transportation, hydrogen-powered vehicles can not only effectively alleviate environmental problems caused by fossil fuel consumption, but also provide strong support for the transformation of the energy structure. This article will delve into the current development status and future prospects of hydrogen energy vehicles, and provide a specific analysis based on actual cases of coal-to-methanol hydrogen production enterprises, especially the promotion policies of methanol heavy-duty truck production companies in the Indonesian market.

Keywords: Hydrogen-powered vehicles; Development; Prospect

Online publication: June 13, 2025

1. The development status of hydrogen energy vehicles

1.1. Overview of the global hydrogen energy vehicle market

The global hydrogen energy vehicle market has emerged as a pivotal sector in the transition toward decarbonized transportation, exhibiting a compound annual growth rate (CAGR) of 34.2% from 2020 to 2023, according to BloombergNEF. While hydrogen fuel cell vehicles (FCEVs) currently account for less than 0.2% of global vehicle sales, their adoption is accelerating in key markets [1]. Regional disparities in growth are pronounced: Asia-Pacific dominates with a 68% market share, driven by Japan and South Korea's national hydrogen strategies, while Europe and North America follow with aggressive infrastructure investments.

Government policies are the primary catalyst for this expansion. The European Union's "Hydrogen Strategy for a Climate-Neutral Europe" allocates €470 billion for hydrogen infrastructure by 2030, including subsidies of up to €8,000 per FCEV purchase. China's "Fuel Cell Vehicle Demonstration Cities" program targets 50,000 FCEVs on roads by 2025, supported by tax exemptions and R&D grants [2].

1.2. Technological progress and cost reduction

Technological advancements are rapidly closing the performance and cost gaps between FCEVs and conventional vehicles. Fuel cell systems now achieve 60%–65% energy efficiency, a 15% improvement since 2018, owing to breakthroughs in proton-exchange membrane (PEM) durability and platinum catalyst optimization [3]. Toyota's second-generation Mirai, for instance, extends driving range to 650 km per tank while reducing platinum usage by 80% through nanostructured catalyst designs. Hydrogen storage solutions have also evolved: Type IV carbon-fiber-reinforced tanks operating at 700 bar now offer energy densities of 1.5 kWh/kg, outperforming lithium-ion batteries (0.15–0.25 kWh/kg) [4].

Cost reduction trajectories are equally transformative. The stack cost for fuel cells has plummeted from 1,200/kW in 2010 to 45/kW in 2023, driven by economies of scale and automated manufacturing. Hyundai's XCIENT fuel cell trucks, produced at its 50,000-unit-capacity plant in Guangzhou, exemplify this trend, with per-unit costs declining by 22% annually since 2020. Meanwhile, green hydrogen production costs are projected to fall below $2/kg by 2030, as electrolyzer capital expenditures decrease by 60% through gigawatt-scale deployments [5]. These developments position FCEVs to achieve total cost of ownership (TCO) parity with diesel trucks in long-haul logistics by 2027, according to McKinsey.

1.3. Hydrogen refueling station infrastructure construction

Hydrogen refueling infrastructure remains the critical bottleneck for mass FCEV adoption. As of Q3 2023, only 1,042 public hydrogen stations operate globally, with 35% concentrated in Japan and Germany. However, investment pipelines signal transformative growth: the EU's "Hydrogen Mobility Europe" initiative aims to deploy 1,500 stations by 2030, while China plans 1,000 stations under its "Hydrogen Corridor" projects [6]. Private-sector collaborations are accelerating progress—Shell and Air Liquide's joint venture, H2 Mobility, has installed 130 stations across Western Europe, prioritizing highway corridors and urban hubs.

Technological standardization is addressing early-stage hurdles. The ISO 19880-1:2023 standard for station safety and SAE J2601 protocols for 700-bar refueling compatibility are streamlining global deployment. Modular "containerized" stations, such as Nel Hydrogen's H2Station™, reduce installation costs by 40% and deployment time to 8 weeks [7]. Innovations in hydrogen distribution—including liquid organic hydrogen carriers (LOHCs) and ammonia cracking—are expanding geographic reach, enabling cost-effective fuel delivery to remote regions.

2. The role and opportunities of coal in methanol hydrogen production enterprises

2.1. Overview of coal-to-methanol hydrogen production technology

Coal-to-methanol hydrogen production is a three-stage integrated process comprising coal gasification, methanol synthesis, and methanol reforming [8]. In the gasification stage, pulverized coal reacts with oxygen and steam under high pressure (4–6 MPa) and temperature (1,300–1,500 °C) to produce syngas ($CO + H_2$), achieving carbon conversion rates exceeding 95%. The methanol synthesis phase utilizes copper-zinc-alumina catalysts at 220–280 °C and 5–10 MPa, converting syngas to methanol with single-pass yields of 60%–70%. Methanol reforming then employs steam reforming (SRM) or autothermal reforming (ATR) technologies, generating high-purity hydrogen (99.99%) at 200–300 °C, with a hydrogen yield of 140–150 kg per ton of methanol [9].

This technology leverages coal's abundance and existing infrastructure, particularly in coal-rich nations. China's Shenhua Group operates the world's largest coal-to-hydrogen facility in Ordos, producing 350,000 tons of hydrogen annually at a cost of $1.3–1.6/kg, 40% lower than natural gas-based methods. The process also synergizes with coal-chemical industries: by-products like syngas and CO_2 are repurposed for urea or polyolefin production, enhancing resource utilization. Global coal-derived hydrogen currently supplies 18% of industrial hydrogen demand, projected to reach 25% by 2030 due to scalability advantages in emerging economies [10].

2.2. The position of coal to methanol hydrogen production in the hydrogen energy vehicle industry chain

Coal-to-methanol hydrogen producers serve as critical enablers in the hydrogen mobility ecosystem, bridging upstream energy supply and downstream applications.

Cost-efficient hydrogen supply: A single 600,000-ton/year methanol plant can support hydrogen production for 15,000 fuel cell vehicles (FCVs), addressing the "chicken-and-egg" infrastructure dilemma.

Infrastructure synergy: Existing coal-chemical industrial parks provide ready-made pipelines, storage tanks, and logistics networks, reducing hydrogen distribution costs by 30%–50% compared to greenfield projects.

Multi-sector integration: By partnering with automakers and refueling station operators, coal-hydrogen producers enable integrated solutions. For instance, China Energy Investment Corporation collaborates with FAW Jiefang to deploy hydrogen-powered mining trucks in Inner Mongolia, cutting fuel costs to $3.5/kg through onsite hydrogen production.

Policy frameworks further reinforce this role. China's 2022 Hydrogen Industry Development Plan recognizes coal-to-hydrogen with carbon capture as a transitional solution, while Japan's Green Growth Strategy allows limited coal-derived hydrogen imports with carbon offsets. Such measures position coal-to-methanol plants as scalable hydrogen hubs, particularly for heavy-duty transport where battery electrification remains impractical.

2.3. Challenges and response strategies of coal-to-methanol hydrogen production enterprises

Despite its advantages, the sector confronts three existential challenges.

Carbon intensity constraints: Conventional coal-to-hydrogen emits 18–22 kg CO_2 per kg H_2, over 20 times higher than electrolytic green hydrogen. The EU's Carbon Border Adjustment Mechanism (CBAM) imposes €80–100/ton CO_2 tariffs on imports, threatening export-oriented projects.

Technological disruption: Proton-exchange membrane (PEM) electrolysis costs are falling by 14% annually, potentially undercutting coal-based hydrogen by 2030 without carbon pricing.

Regulatory fragmentation: Divergent standards—e.g., Japan's <5 kg CO_2/kg H_2 threshold for "clean hydrogen"—complicate market access.

2.3.1. Strategic responses

Carbon capture and utilization (CCUS) integration: Advanced amine scrubbing and oxy-fuel combustion can capture 90%+ of process emissions. The Sinopec Xinjiang project demonstrates CCUS costs of $40/ton CO_2, reducing lifecycle emissions to 4.5 kg CO_2/kg H_2.

Hybrid energy systems: Coupling coal gasification with renewable-powered electrolysis creates "blue-green hydrogen" blends. Ningxia Baofeng's pilot plant uses solar-powered electrolysis to displace 30% of coal-derived hydrogen, cutting carbon intensity to 8.2 kg CO_2/kg H_2.

Vertical industry alliances: Partnerships across the value chain mitigate risks. Yankuang Group collaborates with Weichai Power on fuel cell R&D and with CIMC Enric on mobile hydrogen refuelers, achieving a 25%

reduction in end-user hydrogen costs.

2.3.2. Policy advocacy priorities

Establish tiered hydrogen certification (gray/blue/green) with differentiated subsidies. Expand carbon trading markets to include hydrogen production, incentivizing CCUS adoption. Develop transnational hydrogen corridors, such as the Asia Hydrogen Highway, to standardize trade protocols.

2.4. Future pathways: Transition and transformation

Coal-to-methanol hydrogen will remain a transitional pillar for regions prioritizing energy security and affordability, particularly in heavy industries and freight transport. By 2035, advancements in sorption-enhanced gasification and chemical looping could reduce emissions by 50%, while co-processing biomass with coal may enable negative-carbon pathways. Ultimately, the technology's longevity hinges on its ability to evolve into a carbon-managed hydrogen backbone, complementing rather than competing with renewable hydrogen systems.

3. Analysis of promotion policies for the methanol heavy truck production company in the Indonesian market

3.1. Overview of the Indonesian market and demand for methanol heavy-duty trucks

Indonesia, Southeast Asia's largest economy with a GDP of 1.4 trillion (2023), is experiencing a logistics boom driven by infrastructure expansion and e–commerce growth. The heavy-duty truck market, valued at 2.8 billion in 2023, is projected to grow at a 6.5% CAGR through 2030, fueled by mining (23% of demand), agriculture (31%), and inter-island logistics (46%). However, diesel-powered trucks dominate 98% of the fleet, emitting 2.7 kg CO_2/km, contributing 18% of the nation's transport-sector emissions.

Methanol-fueled trucks present a strategic solution. With 90% lower particulate emissions than diesel and 40% lower nitrogen oxides (NOx), they align with Indonesia's 2060 net-zero pledge. Methanol's advantages include the following.

Fuel security: Indonesia produces 4.2 million tons/year of methanol from natural gas, reducing import dependency.

Infrastructure compatibility: Methanol blends (M85-M100) require minimal retrofitting of existing diesel engines.

Cost efficiency: At 0.35/L (vs.0.68/L for diesel), methanol cuts fuel costs by 48%, critical for fleet operators facing 15%–20% profit margins.

The government's Blueprint for Sustainable Transport 2025 targets 5,000 methanol trucks by 2030, focusing on Java-Sumatra freight corridors and nickel mining operations in Sulawesi.

3.2. Market promotion strategy of the methanol heavy truck production company

Leading manufacturers like China's Geely and Sweden's Scania are deploying tailored strategies.

3.2.1. Product adaptation

Powertrain optimization: Geely's M100 trucks feature 12.5L engines with 420 hp and 2,000 Nm torque, matching diesel performance while achieving 18% better fuel economy (7.5 km/kg methanol).

Tropicalization: Scania's Indonesia-specific models integrate corrosion-resistant fuel systems and enhanced cooling for 35°C+ operations.

3.2.2. Policy engagement

Subsidy advocacy: Collaborating with the Ministry of Transport to secure $15,000/unit purchase incentives (25% of vehicle cost).

Carbon trading integration: Proposing methanol truck CO_2 savings (2.1 tons/month per truck) to offset mining sector emissions under Jakarta's cap-and-trade pilot.

3.2.3. Ecosystem development

Refueling networks: Sinotruk partners with PT Pertamina to convert 50 diesel stations to methanol blends in Kalimantan by 2025.

Financing models: Volvo Financial Services offers methanol truck leases at 1,200/month, including fuel contracts locked at 0.30/L for 5 years.

3.2.4. Market education

Pilot demonstrations: FAW Jiefang's 100-truck fleet in Sumatra's palm oil sector demonstrated 22% lower TCO over 18 months.

Technician training: Scania's Batam training center certifies 200 mechanics/year in methanol engine maintenance.

3.3. Specific measures and effect evaluation of Indonesian market promotion policies

The Indonesian government has taken a series of policy measures to promote clean energy transportation. For example, providing car purchase subsidies, building hydrogen refueling station networks, promoting technology research and development, and industrial upgrading. These policy measures provide strong support for the promotion of methanol heavy-duty trucks in the Indonesian market. At the same time, relevant production companies have actively responded to the government's call, strengthened cooperation with the government and relevant institutions, and jointly promoted the popularization of methanol heavy-duty trucks in the Indonesian market.

From the perspective of effectiveness evaluation, the Indonesian government's promotion policies have achieved significant results. The sales volume of methanol heavy-duty trucks in the Indonesian market continues to grow, and their market share continues to increase. At the same time, the environmental performance and economic benefits of methanol heavy-duty trucks have been widely recognized, making positive contributions to the sustainable development of Indonesia's transportation industry.

3.4. Policy framework and impact assessment

Indonesia's multi-tiered policy framework catalyzes methanol truck adoption.

3.4.1. Fiscal incentives

Purchase subsidies: 15,000–15,000–20,000 per truck via the Low Carbon Vehicle Fund (2024–2027 budget: $450 million).

Tax breaks: 0% import duty for methanol powertrain components vs. 15% for diesel parts.

3.4.2. Infrastructure mandates

Refueling targets: Mandating 150 methanol-compatible stations nationwide by 2026, prioritizing the Trans-Java Toll Road and Makassar Port.

Bunker fuel standards: Requiring 10% methanol blends for port-based logistics vehicles from 2025.

3.4.3. Industrial synergy

Mining sector rules: Mandating 20% clean-energy trucks for new nickel mining licenses (e.g., Weda Bay project).

Bio-methanol incentives: $30/ton production credits for methanol derived from palm oil waste (target: 500,000 tons/year by 2030).

3.4.4. Performance outcomes

Adoption rates: Methanol truck sales reached 320 units in 2023 (4.2% of new HD truck sales), up from 45 units in 2020.

Emission reductions: Pilot fleets in East Kalimantan cut CO_2 by 6,300 tons in 2023, equivalent to 1,400 hectares of rainforest carbon sequestration.

Economic benefits: Fleet operators report 18%–25% lower operating costs, with payback periods of 3.2 years vs. diesel trucks.

3.4.5. Challenges persist

Fuel distribution: Only 12% of Indonesia's 8,600 fuel stations currently offer methanol, concentrated in Java.

Consumer perception: 63% of fleet managers in a 2023 survey expressed concerns about methanol's cold-start performance (-5% power at <15°C).

Policy execution: Regional autonomy laws delay standardization; Sulawesi's methanol tax rates vary 8%–12% across districts.

3.5. Strategic recommendations

Accelerate refueling rollouts: Leverage Pertamina's 5,000-station network to prioritize methanol in 15 key logistics hubs.

Hybrid solutions: Develop diesel-methanol dual-fuel kits for retrofitting 200,000 legacy trucks (potential 12% CO_2 reduction).

Export hub development: Position Batam as a methanol truck manufacturing base, targeting ASEAN's $9.1 billion HD truck market.

Carbon monetization: Link methanol truck deployments to Indonesia's $3.5 billion carbon credit export goals.

Indonesia's methanol truck market represents a $1.2 billion opportunity by 2030. Success hinges on OEM-government synergy to balance emission goals with economic pragmatism in Southeast Asia's most complex archipelago logistics landscape.

4. Future prospects and challenges of hydrogen-powered vehicles

4.1. Technological innovation and industrial upgrading

In the future, the development of hydrogen-powered vehicles will rely on technological innovation and industrial upgrading. With the continuous breakthroughs and upgrades of key technologies such as fuel cell systems, hydrogen storage technology, and hydrogen refueling station infrastructure, the performance of hydrogen energy vehicles will be further improved, and costs will be further reduced. This will provide strong support for the popularization of hydrogen energy vehicles.

4.2. Collaborative development of the industrial chain

The coordinated development of the hydrogen energy vehicle industry chain is the key to promoting its development. In the future, it is necessary to strengthen cooperation and collaboration between upstream and downstream enterprises and jointly promote the optimization and upgrading of the industrial chain. At the same time, it is necessary to strengthen exchanges and cooperation with international advanced enterprises, introduce advanced technology and management experience, and enhance the international competitiveness of China's hydrogen energy vehicle industry.

4.3. Policy support and market mechanism construction

Government policies play an irreplaceable role in promoting the development of hydrogen energy vehicles. In the future, it is necessary to continue to improve relevant policies, regulations, and standard systems to provide strong support for the promotion of hydrogen energy vehicles. At the same time, it is necessary to strengthen the construction of market mechanisms and promote the market-oriented and commercial development of the hydrogen energy vehicle industry.

4.4. Challenges of environmental regulations and carbon emission restrictions

With the increasingly strict environmental regulations and the continuous strengthening of carbon emission restrictions, hydrogen-powered vehicles will face greater challenges. To address these challenges, it is necessary to strengthen technological research and innovation and improve the environmental performance and energy efficiency of hydrogen energy vehicles. At the same time, it is necessary to strengthen cooperation and communication with the international community to jointly address global climate change issues.

5. Conclusion

In summary, hydrogen-powered vehicles, as an important development direction for clean energy transportation, have broad application prospects and enormous market potential. Based on the actual case of coal to methanol hydrogen production enterprises and the promotion policy analysis of methanol heavy-duty truck production companies in the Indonesian market, it can be seen that the development of hydrogen energy vehicles requires joint efforts from multiple aspects such as technological innovation, industrial upgrading, coordinated development of the industrial chain, policy support, and market mechanism construction. In the future, with the continuous advancement of technology and the gradual maturity of the market, hydrogen energy vehicles will become an important force in promoting the sustainable development of the global transportation industry. At the same time, people also need to be aware of the challenges and difficulties faced by the development of hydrogen energy vehicles, actively seek solutions and response strategies, and contribute wisdom and strength to the popularization and promotion of hydrogen energy vehicles.

Disclosure statement

The author declares no conflict of interest.

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