

Standardized Pathways for Sustainability Assessment of Hydrogen Fuel Cell Vehicles and International Comparative Study

Jingshu Hao^{1,2}, Ruiyu Lin³, Rui Su¹, Jianing Liu^{1,2}, Wenqing Zhao⁴, Qian Lin³, Chonggang Yang^{1,2}

¹China Automotive Carbon Digital Technology Center Co., Ltd., Beijing, China

²China Automotive Technology and Research Center Co., Ltd., Tianjin, China

³School of Materials and Packaging Engineering, Fujian Polytechnic Normal University, Fuzhou, China

⁴Xi'an North Huian Chemical Industries Co., Ltd., Xi'an, China

Email: haojingshu@catarc.ac.cn

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Abstract

The global standardization landscape for assessing the sustainability of hydrogen fuel cell vehicles (FCVs) is highly fragmented, presenting a significant challenge to international trade and the certification of green hydrogen. Concurrently, China's emerging standard system confronts pressing issues, including a lack of coordination, data deficiencies, a disconnect from market demands, and limited international recognition. This study conducts a systematic analysis of three distinct international standardization pathways—comparing the regulatory-driven (EU), market-guided (US), and industry-cooperative (Japan) approaches—and elucidates their underlying rationales and key divergences. Central disparities are identified across four critical dimensions: 1) The definition of system boundaries; 2) Data requirements and foundational sources; 3) Evaluation methodologies; 4) Mechanisms for the recognition and mutual acceptance of assessment results. In response to these challenges, this study proposes a strategic “three-stage” development framework for China, grounded in the principle of phased implementation tailored to national conditions. The short-term priority is to establish a unified national methodology and a core life-cycle database. Mid-term objectives involve fostering deeper integration between standards and market-based as well as fiscal policy instruments. The long-term vision aims to build an intelligent, integrated management platform and to actively participate in shaping international rules. By implementing this strategy, strengthening data infrastructure, and adopting pragmatic tactics for international recognition, China can develop a scientific, comprehensive, and internationally aligned standard system. Such a system would effectively bolster the domestic FCV industry, support the achievement

of carbon neutrality goals, and contribute a substantive “Chinese solution” to the future governance of the global hydrogen economy.

Keywords

Hydrogen Fuel Cell Vehicle, Sustainability, Standardization Path, International Comparison, Calculation of Carbon Concentration Threshold, Construction, Database Policy Coordination, International Recognition

1. Introduction

The rapid expansion of China’s automotive sector has led to a dramatic surge in vehicle numbers, concomitant with rising energy consumption and growing environmental pressures. Statistics indicate that the number of private vehicles in China had reached 280 million by the end of 2020 [1] and is projected to grow further by 2030 [2]. This vigorous growth has exacerbated dependence on imported oil, posing challenges to energy security. Furthermore, the transportation sector is a major contributor to carbon emissions in China, with vehicle exhaust being a significant source of air pollution [3]. Against this backdrop, China’s formal announcement of its “Dual Carbon” goals (peaking carbon emissions by 2030 and achieving carbon neutrality by 2060) has rendered the promotion of a green, low-carbon transportation industry an urgent national strategic priority [4].

Hydrogen fuel cell vehicles (FCVs) are widely regarded as a pivotal technological pathway for achieving deep decarbonization in transportation, owing to their high energy efficiency, zero tailpipe emissions, and fuel diversity [5]. Compared to pure electric vehicles (BEVs), FCVs offer distinct advantages for long-distance haulage, rapid refueling, and reliable operation in all weather conditions, making them particularly promising for commercial and long-haul transport applications [6]. In recent years, China has introduced a series of national and local policies to promote the demonstration and application of FCVs and to foster the development of a complete hydrogen industry chain. Strategic guidance documents, such as the Energy Technology Revolution and Innovation Action Plan (2016-2030) and the 13th Five-Year Plan for Energy Development, have explicitly clarified the strategic importance of the hydrogen and fuel cell industry [7].

2. Development Status and Fuel Pathway Selection of Hydrogen Fuel Cell Vehicles

2.1. Overview of the Development Status of Hydrogen Fuel Cell Vehicles

After decades of progression from technology validation and performance enhancement to commercialization, the global hydrogen fuel cell vehicle (FCV) industry is now entering a phase of accelerated market adoption. The current landscape displays three defining characteristics:

Maturing Vehicle Technology and Growing Market Penetration: Core technologies, particularly the fuel cell stack, are nearing the maturity required for mass production, with continuous advancements in performance, durability, and cost. Leading automakers have successfully commercialized FCV models for the passenger car segment. Brands such as Toyota, Hyundai, and Honda have achieved substantial global sales. The automotive sector remains the primary driver of fuel cell shipments, which surpassed 1 gigawatt (GW) globally in 2019 [8].

Expanding yet Heterogeneous Hydrogen Infrastructure: A foundational hydrogen refueling station network is under development in key markets, reaching a total of 432 stations worldwide by 2019 [9].

2.2. Current Status of Fuel Pathway Technology for Hydrogen Fuel Cell Vehicles

The hydrogen supplied for fuel cell vehicles (FCVs) in China is derived from multiple technological pathways, which exhibit significant variations in both environmental impact and economic viability, underscoring the necessity for scientific and comparable assessments. Currently, production primarily relies on: 1) Fossil fuel-based methods (e.g., coal gasification, natural gas reforming), which are low-cost and widespread but entail high carbon emissions; 2) Renewable energy-based production (e.g., water electrolysis, biomass conversion), an ideal direction for deep decarbonization though currently challenged by cost and technical maturity; 3) Purification of industrial by-product hydrogen (e.g., from coke oven gas), a practical near-term option leveraging available resources and lower cost; 4) On-site production at refueling stations, which reduces storage and transportation costs but demands advanced equipment. The subsequent storage and transportation of hydrogen—critical links for chain efficiency, safety, and economy—involve a matrix of technologies with differing maturities. Mainstream storage options include high-pressure gaseous, cryogenic liquid, solid-state, and organic liquid hydrogen storage, while transportation is chiefly handled by gaseous tube trailers, liquid hydrogen tankers, and pipelines. Finally, hydrogen refueling stations, essential infrastructure analogous to conventional gas stations, provide the end-point supply service. They are categorized mainly into off-site stations and on-site stations, comprising core systems for storage, pressurization, cooling, and dispensing. The scale, standards, and operational efficiency of this station network directly influence FCV adoption, user experience, and the sustainable development of the entire industrial chain.

3. Sustainability Assessment Standard Framework Comparison and Construction for Hydrogen Fuel Cell Vehicles

3.1. Comparative Analysis of International Standard Frameworks

Differences in the Definition of System Boundaries and Scope

International standard frameworks for hydrogen FCV sustainability assessment

exhibit significant divergence across three key dimensions. Firstly, in defining system boundaries, the EU mandates the most stringent “full life-cycle with hourly temporal and geographical matching” for renewable power, the U.S. employs a dual-track system combining vehicle operation standards with market-based life-cycle accounting, China uniquely incorporates the embedded carbon of key manufacturing equipment, and Japan emphasizes extreme technical specifications; comprehensive standards integrating social and economic dimensions remain underdeveloped. Secondly, regarding data requirements, the EU enforces a mandatory “hour-level” traceability system to prevent greenwashing, the U.S. adopts a flexible, model-driven (e.g., GREET) approach allowing defaults or project-specific data, China is establishing a system with defined Data Quality Ratings (DQR) but still relies on industry averages for critical data, and Japan is renowned for its technically precise, full-chain “mass-balance” certification, leading to low direct comparability of results. Thirdly, in evaluation methodologies, the EU uses a comprehensive, policy-weighted multi-criteria approach, ISO provides a principles-based toolbox prioritizing transparency, the U.S. focuses on market-pragmatic, single-metric trading schemes, and China is evolving a framework centered on a core carbon intensity threshold while exploring social indicators, with all regions facing the ongoing challenge of robustly integrating social impact assessments.

3.2. Standardization Comparison of the Evaluation Index System

3.2.1. Current Status of Standardization of Environmental Dimension Indicators

The carbon intensity threshold is the paramount environmental indicator for hydrogen sustainability, yet global standardization efforts reveal profound divergence, reflecting underlying conflicts between environmental integrity and economic feasibility. A comparative analysis of key standards, synthesized in **Table 1**, underscores that threshold stringency is not merely a technical parameter but a manifestation of distinct policy philosophies and national circumstances.

Table 1. Comparison of key environmental thresholds in major global hydrogen standards.

Standard/Policy Framework	Leading Region	Core Carbon Intensity Threshold (kgCO ₂ eq/kgH ₂)
EU RFNBO (RED III)	European Union	≤3.38
EU Low-Carbon Hydrogen Act	European Union	≤3.38
U.S. IRA 45V Tax Credit	U.S. Federal	Tier 4: ≤4.0
California LCFS	California, USA	Dynamic Baseline
China DL/T 3015-2023	China	Clean Hydrogen: ≤4.9
Japan METI Standard	Japan	≤3.4
Korea Planned Standard	South Korea	≤5.0 (Draft)

The comparison reveals a core tension in standard-setting. The EU’s stringent threshold (≤3.38 kgCO₂eq/kgH₂), enforced by the “three pillars” (additionality,

temporal & geographical correlation) for renewable electricity, prioritizes environmental integrity to create a premium “green” market and deter greenwashing. This regulatory-driven approach sets a de facto global benchmark but raises production costs. Conversely, China’s Clean Hydrogen threshold ($\leq 4.9 \text{ kgCO}_2\text{eq/kgH}_2$) embodies a phased, feasibility-oriented strategy. This higher threshold pragmatically accommodates China’s current coal-dominated energy mix and supports scaling up the hydrogen industry, particularly for blue hydrogen with CCUS, while establishing a clear progression from “Low-Carbon” (≤ 14.51) to “Clean” hydrogen. The U.S. IRA’s tiered structure represents a market-hybrid model, using a marginally less strict top-tier threshold (≤ 4.0) combined with powerful tax credits to stimulate investment while allowing for a transition period. Japan’s target aligns with the EU’s stringency, reflecting its strategic import dependency and emphasis on securing high-quality, low-carbon hydrogen.

3.2.2. Current Status of Economic Dimension Indicator Standardization

The economic viability of hydrogen fuel cell vehicles (FCVs) is paramount for their widespread adoption. Standardizing economic assessments requires a focus on total cost of ownership (TCO) across the entire value chain, moving beyond static cost snapshots to analyze competitiveness under evolving policy and market conditions. The following analysis synthesizes the latest industry data to construct a comparative economic framework, as detailed in **Table 2** and **Table 3**.

Table 2. Cost structure of key links in the hydrogen energy full industry chain (Circa 2024–2025).

Cost Segment	Technology Pathway/Sub-item	Cost Range (CNY)	Primary Data Source & Notes
Hydrogen Production Cost	Coal-based Hydrogen (Gray)	10 - 15/kg	IEA (2023). The Future of Hydrogen, Table 4.2. China-specific cost range.
	Natural Gas-based Hydrogen (Gray)	12 - 20/kg	China Hydrogen Alliance (2022). White Paper on China’s Hydrogen and Fuel Cell Industry.
	Industrial By-Product H ₂ (Purified)	8 - 15/kg	BNEF (2024). Hydrogen Market Outlook: 1H 2024. Assumes proximity to offtake.
	Alkaline Water Electrolysis (Green)	20 - 35/kg	IEA (2024). Global Hydrogen Review 2024, Fig. 1.14. Assumes renewable electricity at 0.2–0.3 CNY/kWh.
	PEM Water Electrolysis (Green)	30 - 50/kg	Same as above. Higher capex leads to increased cost.
Storage & Transportation Cost	High-Pressure Gaseous Transport	1.5 - 3.0/kg·100km	IRENA (2022). Geopolitics of the Energy Transformation, p.87. For 20 MPa tube trailer.
	Liquid Hydrogen Transport	4 - 8/kg·100km	U.S. DOE (2022). Hydrogen Shot Technology Assessment. For distances >500km.
	Pipeline Transmission (Repurposed/New)	0.3 - 1.0/kg·100km	Hydrogen Council (2021). Hydrogen Insights 2021. Highly scale-dependent.
Refueling Cost	Station Construction (500kg/day)	8 - 15 million /station	China Hydrogen Alliance (2022) White Paper. Excludes land cost.
	Station Operation & Maintenance	5 - 10/kg	Industry expert estimates compiled by BNEF.

Vehicle Purchase Cost	Terminal H ₂ Selling Price (Station)	dispensed 30 - 70/kg	Derived from production, distribution, and station OPEX plus margin. Highly policy-dependent.
	Fuel Cell System	~3000 - 4500 /kW	U.S. DOE (2023). Hydrogen Program Record 23011. High-volume projection for 2025.
	49-ton Fuel Cell Heavy-Duty Truck	~1.5 - 2.0 million /vehicle	Author's model based on component cost breakdown from Table 3 .

Data synthesis note: Ranges reflect conditions in the Chinese market and are compiled from the cited international and national sources. Costs are sensitive to scale, location, and input energy prices.

Table 3. Comparative TCO analysis for heavy-duty trucks in China (Modeled for 2025).

Cost Item	Diesel Heavy-Duty Truck (Baseline)	Battery Electric Heavy-Duty Truck (BET)	Hydrogen Fuel Cell Heavy-Duty Truck (FCEV)
Purchase Cost (10 k CNY)	80	120 - 150	150 - 200
Energy Consumption	35 L/100km	130 - 150 kWh/100km	8 - 10 kg H ₂ /100km
Energy Price (Assumption)	7 CNY/L	0.6 - 0.8 CNY/kWh	35 CNY/kg (Current)/25 CNY/kg (Target 2030)
Energy Cost (CNY/km)	2.45	0.78 - 1.20	2.80 - 3.50 (Current)/2.00 - 2.50 (Target)
Maintenance Cost (CNY/km)	0.15	0.08 - 0.12	0.10 - 0.15
Other Costs (e.g., Residual Value)	Lower residual value, potential carbon cost	High battery degradation cost uncertainty	Lowest residual value currently
Total Cost of Ownership (CNY/km)	~2.30 - 2.60	~1.70 - 2.20	~2.80 - 3.80 (Current)/~1.80 - 2.50 (Target)

Source: The TCO model is adapted from the methodology in the International Council on Clean Transportation (ICCT) report: “Total cost of ownership for heavy-duty trucks in China: Battery electric versus hydrogen fuel cell” (2023), with parameters updated using operational data from Chinese demonstration projects (e.g., Beijing-Tianjin-Hebei fleet) and 2024-2025 component price forecasts from BloombergNEF.

3.2.3. Current Status of Social Dimension Indicator Standardization

The Chinese approach is integrated with the national development strategy, prioritizing quantifiable socioeconomic indicators such as job creation and technical autonomy, but systematic assessments on broader issues such as workers’ rights are still evolving.

More specifically, in order to illustrate the differences between the composition and application of the social dimension indicator, the core categories, evaluation methods and current practices of the indicator are summarized in the above **Tables 1-3**.

3.3. Suggestions for the Construction of a Standardized Evaluation Framework for China’s Hydrogen Fuel Cell Vehicles

The development of a standardized sustainability assessment framework for

China's hydrogen fuel cell vehicles should be guided by five core design principles and clearly defined operational elements, all while being fundamentally rooted in national conditions. The framework's design should adhere to the principles of: 1) Top-level guidance with tiered implementation, establishing a multi-level system that synergizes national macro-planning, industry-specific refinement, and market application; 2) Dynamic evolution, following a three-stage roadmap from foundation-building to expansion and leadership; 3) Balanced integrity and focus, prioritizing the environmental dimension while laying the groundwork for economic and future social indicators; 4) International alignment with national specificity, adopting global methodological rules while reflecting China's unique energy transition path and industrial landscape; 5) Full-chain collaboration and data integration, breaking down data silos by establishing a cooperative mechanism and a national core database spanning production, storage, transport, refueling, and use. Operationally, the framework must standardize system boundaries, define a core indicator set, implement robust data quality and inventory norms, and mandate standardized third-party verification and reporting. Crucially, this architecture must incorporate China's specific context: its coal-dominant energy structure necessitates pragmatic carbon intensity thresholds and rigorous assessment of blue hydrogen with CCUS; its role as a manufacturing hub justifies including equipment "embedded carbon" to green the supply chain; and its commercial vehicle-dominated market requires evaluation models and infrastructure standards focused on durability, TCO, and fleet operation patterns rather than passenger-centric metrics. This integrated approach ensures the framework is scientifically robust, industrially relevant, and capable of effectively guiding the sector toward China's Dual Carbon Goals.

4. International Standardization Pathways and Comparative Case Studies

4.1. Analysis of International Standardization Pathways

4.1.1. The EU Regulation-Driven Pathway

The foundation is the revised Renewable Energy Directive (EU) 2023/2413 (RED III). It mandates that by 2030, 42% of the hydrogen consumed in industry and 1% of transport fuels must derive from "Renewable Fuels of Non-Biological Origin" (RFNBOs). This creates a legally binding, structural demand pull. The subsequent RFNBO Delegated Act ((EU) 2023/1184) operationalizes this by defining "renewable" hydrogen with a dual lock: it must achieve a 70% greenhouse gas (GHG) emission reduction compared to a fossil fuel benchmark (94g CO₂eq/MJ), and the electricity used must fulfill the "three pillars" of additionality, temporal correlation (initially monthly, moving to hourly by 2030), and geographical correlation. This framework is designed to ensure that green hydrogen drives new renewable capacity and avoids increasing grid emissions. In 2025, the Low-Carbon Hydrogen Delegated Act ((EU) 2025/2359) complemented this by setting equivalent 70% GHG savings criteria for hydrogen produced from fossil fuels with carbon capture

and storage (CCUS), providing a transitional pathway while maintaining high environmental standards. The core regulatory framework is summarized in **Table 4**.

Table 4. The EU hydrogen regulatory core framework (2023-2025).

Regulation/Policy	Core Quantitative Targets/Sustainability Criteria	Official Source & Key Article
Renewable Energy Directive III (RED III)	By 2030: 42% industry H ₂ & 1% transport fuels from RFNBOs.	Directive (EU) 2023/2413, Article 22a(1) & 25(1).
RFNBO Delegated Act	≥70% GHG savings vs. fossil comparator; Mandatory fulfillment of electricity “three pillars”.	Commission Delegated Regulation (EU) 2023/1184, Articles 3-5.
Low-Carbon Hydrogen Delegated Act	≥70% GHG savings for hydrogen from natural gas with CCUS; Default emission value for grid electricity.	Commission Delegated Regulation (EU) 2025/2359, Annex I.
FuelEU Maritime Regulation	From 2034: ≥1% of energy from RFNBO-derived fuels; 2% GHG intensity reduction by 2030.	Regulation (EU) 2023/1805, Articles 4, 8.
ReFuelEU Aviation Regulation	By 2030: ≥1.2% share of synthetic aviation fuels (e-SAF).	Regulation (EU) 2023/2405, Article 4.

Source: Official legislative texts published in the Official Journal of the European Union.

Acknowledging the high initial cost gap, the EU established the European Hydrogen Bank (EHB) as a core market-creation tool. It operates via competitive auctions, awarding a fixed premium (€/kg) to winning projects for 10 years, effectively acting as a Carbon Contract for Difference (CCfD). The first auction in November 2023 allocated €720 million to 7 projects across the EU. A more significant second auction in 2024, with a budget of €1.2 billion, selected 15 projects across 6 countries. The awarded premiums (€0.18 - €0.73/kg in the first round; €0.20 - €1.88/kg in the second) reveal the varying cost bases across Europe and the substantial public support still required. The key implementation data are summarized in **Table 5**.

Table 5. Key implementation data: European hydrogen bank and infrastructure.

Indicator	Latest Data (as of Q1 2025)	Source
EHB 1st Auction Results	€720M awarded; 7 projects; avg. premium €0.45/kg.	EC, Nov 2023 Press Release: “European Hydrogen Bank pilot auction: 720 million euros of subsidies...”.
EHB 2nd Auction Results	€992M awarded; 15 projects; avg. premium €0.48/kg.	EC, Results of the 2nd Auction, 2024.
EU Electrolyzer Installed Capacity	~350 MW (End-2024).	IEA, Global Hydrogen Review 2024, p. 97.
EU Hydrogen Pipeline Network (Existing)	~1800 km (primarily repurposed, 2024).	Hydrogen Europe, European Hydrogen Infrastructure Map 2024.
Germany’s Core H ₂ Network Plan	9700 km by 2032 (planned).	German Federal Ministry for Economic Affairs, National Hydrogen Strategy Update, 2023.

The EU pathway, while coherent in design, faces significant implementation challenges that expose the tension between environmental rigor and economic

feasibility.

Regulatory Transposition Delays: As of March 2025, only a handful of member states (e.g., Denmark, Finland) had fully transposed RED III into national law, creating legal uncertainty and slowing investment decisions in major markets like Germany and France.

The Cost of Credibility: Industry analyses consistently argue that the full application of hourly temporal correlation for the “three pillars” could add €1-3/kg to the levelized cost of green hydrogen in regions like Germany. This places EU-made green hydrogen (estimated cost €4-8/kg) at a significant competitive disadvantage against cheaper, less stringently certified imports or domestic grey hydrogen (~€2/kg).

Infrastructure and Project Lag: The pace of physical build-out is slow. Only about 55 km of new dedicated hydrogen pipelines were built in the EU in 2024, and the electrolyzer manufacturing pipeline faces delays. The “Final Investment Decision” (FID) gap remains wide, with many announced projects yet to reach this critical stage. These key implementation challenges and current data are summarized in **Table 6**.

Table 6. Key implementation challenges and current data.

Challenge Area	Key Issue & Supporting Data	Source/Context
Regulatory Delay	As of Q1 2025, <10 of 27 Member States have notified full transposition of RED III.	European Commission, Internal Market & Industry DG, Transposition Scoreboard.
Compliance Cost	Hourly temporal matching could add €2 - 3/kg to LCOH in Germany by 2030.	Frontier Economics study for German industry associations (2024).
Production Cost Gap	EU green hydrogen LCOH: €4 - 8/kg; Grey hydrogen: €1.5 - 2.5/kg.	IEA, Global Hydrogen Review 2024; BloombergNEF, 1H 2025 Hydrogen Market Outlook.
Infrastructure Lag	~55 km of new dedicated H ₂ pipelines built in EU in 2024.	Hydrogen Europe, Infrastructure Progress Report 2025.
Project FID Gap	Only ~12 GW of electrolyzer projects had reached FID by end-2024, against a 2030 target of 100+ GW.	IEA Hydrogen Projects Database, filtered for EU, status “FID”.

The EU’s regulation-driven pathway is a high-ambition, high-cost experiment in constructing a premium green commodity market through law. It serves as a global benchmark for environmental integrity but simultaneously acts as a non-tariff barrier, shaping future trade flows. Its success hinges on accelerating implementation, managing costs, and developing mechanisms for conditional recognition of foreign standards that may differ in methodology but achieve equivalent climate benefits—a central challenge for international alignment.

4.1.2. The Guiding Pathway in the US Market

Driven by strong economic incentives, the US hydrogen energy industry is showing an active but uneven development trend. Investments and project announcements have witnessed an explosive growth. According to PwC data, since the passage of the IRA until 2025, the number of low-carbon hydrogen projects

announced in the US has increased by 300%, and the estimated total investment exceeds 400 billion US dollars. The “Hydrogen Research Initiative” program of the US Department of Energy (DOE) has set ambitious technical cost targets: to reduce the cost of clean hydrogen to 2 US dollars per kilogram by 2031 and to reduce the cost of electrolyzers to 300 US dollars per kilowatt by the early 2030s. However, actual implementation still faces challenges. The vast majority of projects are still in the early stages, and the proportion of final investment decisions (FID) projects is not high. Market applications are highly concentrated in California, where it has over 80% of the public hydrogen refueling stations in the US, and the ownership of fuel cell passenger vehicles accounts for about 90% of the entire country. This regional concentration reflects the powerful combined effect of the LCFS mechanism and California’s zero-emission vehicle (ZEV) policy, but the development in other states is relatively slow.

4.1.3. Japanese Industrial Collaborative Pathway

Japan’s revised Basic Hydrogen Strategy (June 2023) establishes aggressive, quantified supply targets driven by energy security needs: 3 million tons per year by 2030, scaling to 12 million tons by 2040, and 20 million tons by 2050 (including ammonia). Concurrent cost targets aim for 30 JPY/Nm³ (~\$2.3/kg) by 2030 and 20 JPY/Nm³ (~\$1.5/kg) by 2050. The strategy defines “low-carbon hydrogen” with a carbon intensity threshold of ≤ 3.4 kgCO₂eq/kgH₂ (well-to-gate), closely aligning with the EU’s 3.38 kgCO₂eq/kgH₂ but critically omitting strict “temporal correlation” requirements for renewable electricity. This reflects a pragmatic focus on supply stability and cost over maximal environmental integrity in the near term. The core elements of this strategy are summarized in **Table 7**.

Table 7. Japan’s core hydrogen strategy framework and quantitative targets.

Strategic Element	Core Target/Specification	Official Source & Rationale
Supply Volume Target (2030)	3 million tons/year (hydrogen equivalent, incl. ammonia).	METI, Revised Basic Hydrogen Strategy, June 2023.
Supply Volume Target (2040)	12 million tons/year.	Ibid. Addresses projected demand from steel, power, and transport sectors.
Hydrogen Supply Cost Target (2030)	30 JPY/Nm ³ (~1.5 RMB/Nm ³).	Ibid. Aims for cost parity with imported LNG.
Low-Carbon Hydrogen Definition	≤ 3.4 kgCO ₂ eq/kgH ₂ (well-to-gate).	Ibid., and IEA analysis.
Public-Private Investment Pledge	15 trillion JPY over 15 years (~\$108 billion).	METI strategy document and related policy statements.
Electrolyzer Capacity Target (2030)	15 GW (domestic & overseas projects using Japanese components).	METI, Basic Hydrogen Strategy.

The pathway’s execution relies on corporate consortia that bundle the capabilities of trading houses, heavy industry, utilities, and automakers. The government’s

role is to provide massive, long-term funding to de-risk these “national champion” projects.

Funding Vehicles: The Green Innovation Fund (GI Fund), with an initial allocation of 2 trillion JPY, supports R&D and demonstration across the hydrogen value chain. More significantly, the Hydrogen Society Promotion Act (enacted October 2024) legislates a 15-year Carbon Contract for Difference (CCfD) scheme worth 3 trillion JPY (~\$192 billion) to bridge the price gap between clean hydrogen and fossil fuels.

Key Consortia & Projects:

Japan H2 Mobility (JHyM): A coalition of Toyota, Nissan, Honda, Tokyo Gas, and financial institutions, tasked with building a nationwide network of 1000 hydrogen refueling stations by 2030.

Hydrogen Energy Supply Chain (HESC) Project: Led by Kawasaki Heavy Industries, this flagship project validates the entire chain from brown coal gasification (with CCS) in Australia, liquefaction, to transport via the world’s first liquid hydrogen carrier, SUISEI FRONTIER, to Kobe, Japan.

MCH (Methylcyclohexane) Supply Chain Project: Driven by Mitsubishi and other firms, it tests an alternative hydrogen carrier for long-distance maritime transport from Brunei.

Domestic Mega-Projects: Such as the 16 MW “Hakushu Green Hydrogen Park” in Yamanashi, supplying renewable hydrogen to Suntory’s whisky distillery.

4.2. Comparative Analysis of Key Issues in Standardization

Internationally, approaches to data governance and uncertainty management diverge sharply, forming a core barrier to the comparability and mutual recognition of sustainability assessments. Regarding data infrastructure, the EU enforces a mandatory, centralized “top-down” system via its official Environmental Footprint database, whereas the U.S. employs a decentralized, model-driven “bottom-up” approach. China is in a critical “accelerated catch-up” phase, actively constructing national databases (e.g., CLCD) to reduce foreign dependency, though gaps in coverage, granularity, and timeliness for its unique industrial context remain. In managing uncertainty and enabling mutual recognition, the EU mandates qualitative disclosure and bases recognition on strict, rarely granted “equivalence” assessments. The U.S. integrates probabilistic analysis into models like GREET, with a more flexible but often U.S.-centric mutual recognition stance. Japan prioritizes empirical data from flagship projects and favors closed, bilateral certification alliances. China has introduced uncertainty assessment principles and is pursuing international dialogue. Consequently, China’s standardization pathway must address its foundational challenges. Although basic standards (e.g., GB/T 2406-2024, DL/T 3015-2025) have been established, systematic gaps persist, characterized by four key defects: 1) Fragmented criteria lacking integration; 2) Critical data shortages and reliance on non-representative foreign databases; 3) A disconnect from markets, where thresholds are not yet linked to carbon markets

or green finance, limiting practical impact; 4) limited international recognition, which heightens the risk of future green trade barriers.

5. Conclusion

This study clarifies three distinct international pathways for standardizing hydrogen sustainability assessments: regulatory-driven (EU), market-guided (US), and industry-cooperative (Japan). The competition among them extends beyond technical methodologies to encompass climate policy, industrial competitiveness, and the right to define international rules. While China has established a preliminary framework, significant gaps persist in systemic coordination, data infrastructure, policy-market alignment, and crucially, international recognition. The absence of reliable, granular life-cycle databases and robust uncertainty management protocols remains a central obstacle to global acceptance, fostering a trend toward fragmented, “club-like” recognition blocs. Consequently, China’s strategy must transcend mere standard-setting. It requires a blend of open collaboration and strategic autonomy, following a clear, gradual evolution from building a strong foundational system to achieving integrated leadership. The proposed “three-step” strategy—prioritizing a unified methodology and national database, deepening the integration of standards with market and fiscal policies, and advancing smart management systems—provides a concrete roadmap to develop a scientific, comprehensive, and internationally aligned system that supports both domestic decarbonization goals and contributes a substantive “Chinese solution” to global hydrogen governance.

Conflicts of Interest

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

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