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Motives in Motion: Low-Carbon Hydrogen Development in the Transportation Sector of China and Japan

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Konstantin Matveenkov

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Abstract (English)

This master's thesis addresses the research question: "How do China and Japan approach the development of low-carbon hydrogen in their transportation sectors in the context of promoting decarbonized mobility?", focusing on the period from 2015 to the present. Using a comparative case-study design and the "Motives in Motion" framework, the thesis evaluates governance, certification, supply strategy, incentives, infrastructure readiness, and market uptake.

The findings show two distinct development models. China scales hydrogen mobility primarily through a plan-led, multi-level governance system that bundles incentives to build domestic supply, refuelling corridors, and high-utilisation commercial fleets, leveraging industrial policy to deepen local value chains. Japan advances through a statute-centred approach that prioritises stable rules, eligibility and audit frameworks, and long-horizon de-risking instruments coordinated with industry, while remaining structurally import-oriented and organising hydrogen logistics around hubs and ports. Despite these different architectures, both countries share similar ambitions—positioning hydrogen as a solution for hard-to-electrify transport segments—yet progress is still constrained by the same bottlenecks: high costs, uncertain demand formation, and the challenge of sequencing supply, infrastructure, and uptake.

Abstract (Deutsch)

Diese Masterarbeit behandelt die Forschungsfrage: „Wie gehen China und Japan bei der Entwicklung von kohlenstoffarmem Wasserstoff in ihren Verkehrssektoren im Kontext der Förderung dekarbonisierter Mobilität vor?", mit Schwerpunkt auf dem Zeitraum von 2015 bis heute. Auf Basis eines vergleichenden Fallstudiendesigns und des Analysemodells „Motives in Motion" bewertet die Arbeit Governance, Zertifizierung, Versorgungsstrategie, Anreize, Infrastrukturreife und Marktaufnahme.

Die Ergebnisse zeigen zwei unterschiedliche Entwicklungsmodelle. China skaliert Wasserstoffmobilität vor allem über ein planungsgeleitetes, mehrstufiges

Governance-System, das Förderinstrumente bündelt, um inländische Versorgung, Betankungskorridore und hoch ausgelastete kommerzielle Flotten aufzubauen, und dabei industriepolitische Maßnahmen nutzt, um lokale Wertschöpfungsketten zu vertiefen. Japan entwickelt sich über einen gesetzeszentrierten Ansatz weiter, der stabile Regeln, Rahmenbedingungen für Förderfähigkeit und Audits sowie langfristige Instrumente zur Risikoabsicherung in Koordination mit der Industrie priorisiert, dabei jedoch strukturell importorientiert bleibt und die Wasserstofflogistik um Hubs und Häfen organisiert. Trotz dieser unterschiedlichen Architekturen verfolgen beide Länder ähnliche Ambitionen—Wasserstoff als Lösung für schwer zu elektrifizierende Verkehrssegmente zu positionieren—doch der Fortschritt wird weiterhin durch dieselben Engpässe begrenzt: hohe Kosten, eine unsichere Nachfrageentwicklung und die Herausforderung, Angebot, Infrastruktur und Markthochlauf sinnvoll zu sequenzieren.

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ABBREVIATIONS

ALK — Alkaline (alkaline electrolysis / alkaline electrolyser)

ANRE — Agency for Natural Resources and Energy (Japan)

APERC — Asia Pacific Energy Research Centre

CAB — China Association for the Promotion of Industry–Academia–Research Collaboration

CAPEX — Capital expenditure

CCS — Carbon capture and storage

CCUS — Carbon capture, utilisation and storage

CfD — Contracts for Difference

CJPT — Commercial Japan Partnership Technologies (Corporation)

CSIS — Center for Strategic and International Studies

DC — Direct current

DOE — (U.S.) Department of Energy

DOI — Digital object identifier

FC — Fuel cell

FCEV — Fuel cell electric vehicle

FCV — Fuel cell vehicle

FH2R — Fukushima Hydrogen Energy Research Field

FID — Final investment decision

FY — Fiscal year

GHG — Greenhouse gas

GIF — Green Innovation Fund

GW — Gigawatt

H2 — Hydrogen

HGP — Hydrogen gas pipeline (dedicated hydrogen pipeline)

HRS — Hydrogen refuelling station

ICCT — International Council on Clean Transportation

ICE — Internal combustion engine

IEA — International Energy Agency

IEEJ — The Institute of Energy Economics, Japan

IPCC — Intergovernmental Panel on Climate Change

IPHE — International Partnership for Hydrogen and Fuel Cells in the Economy

IRENA — International Renewable Energy Agency

ISO — International Organization for Standardization

JH2A — Japan Hydrogen Association

LBST — Ludwig-Bölkow-Systemtechnik

LCA — Life-cycle assessment

LCOH — Levelized cost of hydrogen

LHV — Lower heating value

LNG — Liquefied natural gas

LOHC — Liquid organic hydrogen carrier

METI — Ministry of Economy, Trade and Industry (Japan)

MCH — Methylcyclohexane

MIIT — Ministry of Industry and Information Technology (China)

MLIT — Ministry of Land, Infrastructure, Transport and Tourism (Japan)

MRV — Measurement, reporting and verification

MW — Megawatt

NDRC — National Development and Reform Commission (China)

NEA — National Energy Administration (China)

NEV — New energy vehicle

NEDO — New Energy and Industrial Technology Development Organization (Japan)

NHS —National Hydrogen Strategy

OPEX — Operating expenditure

PEM — Proton-exchange membrane

PV — Photovoltaic

REI — Renewable Energy Institute

RIETI — Research Institute of Economy, Trade and Industry (Japan)

RIFS — Research Institute for Sustainability

RMB — Renminbi

RMI — Rocky Mountain Institute

SAF — Sustainable aviation fuel

SAIC — Shanghai Automotive Industry Corporation (SAIC Motor)

SMR — Steam methane reforming

SOE — State-owned enterprise

TMG — Tokyo Metropolitan Government

US — United States

WIPO — World Intellectual Property Organization

WTG — Well-to-gate

ZEFI — Zero Emission Freight Initiative

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1. INTRODUCTION

1.1 Research Context

The global effort to limit anthropogenic climate change has brought about an unprecedented transformation in national energy and industrial systems. More than 149 countries, accounting for over 92% of global GDP and 88% of greenhouse gas emissions, have formally committed to achieving net-zero emissions by around mid-century. [1]

Decarbonizing the transportation sector is a critical component of global efforts to address climate change. In 2023 road, rail, aviation and shipping together accounted for ≈24 % of global energy-related CO_2 emissions (7.9 Gt) — a share that has barely fallen over the last decade despite rapid growth in electric cars. [2] International Energy Agency models show that even a fully electrified light-duty fleet leaves "hard-to-abate" segments such as heavy trucks, long-distance buses, shipping and aviation dependent on high-energy-density fuels well beyond 2040. [3] Low-carbon hydrogen offers a technology pathway for those segments: produced via water electrolysis powered by renewables or from fossil fuels with carbon capture, hydrogen can be used directly in fuel-cell electric vehicles (FCEVs), blended into internal-combustion engines, or converted into ammonia / e-fuels for maritime and aviation use. [4]

The global push to develop hydrogen has intensified since the mid-2010s. In 2017, Japan became the first country to publish a comprehensive national hydrogen strategy, positioning hydrogen as a central technology for achieving its long-term energy transition and decarbonisation goals.[5] Since then, more than 40 countries have followed with national roadmaps, and international institutions have begun

[1] Net Zero Tracker. 2023. "*Net Zero Stocktake 2023: Assessing the Status and Trends of Net Zero Target Setting"*. P. 4.
[2] International Transport Forum. 2023. "*ITF Transport Outlook 2023"*. OECD/ITF. P. 10.
[3] International Energy Agency. 2024. "*Global Hydrogen Review 2024"*. IEA. P. 54
[4] International Renewable Energy Agency. 2022. "*Geopolitics of the Energy Transformation: The Hydrogen Factor"*. IRENA. P. 9
[5] Nagashima, Masaki. 2018. "*Japan's Hydrogen Strategy: Policy Context and International Implications"*. IFRI. P. 4

integrating hydrogen projections into their net-zero scenarios.[6] This global push reflects the shared recognition that hydrogen technologies will play a fundamental role in achieving net-zero emissions targets by mid-century.

Within this worldwide trend, China and Japan have each placed hydrogen at the center of their transportation decarbonization agendas. Japan coined the term "hydrogen society" and commercialised the first FCEV (Toyota Mirai) in 2014. Its 2017 and 2023 strategies aim for an 80% cut in delivered hydrogen cost by 2050, 320 domestic refuelling stations by 2025, and 800 000 FCEVs by 2030. [7] China, the world's largest hydrogen producer and a battery-EV powerhouse, entered the policy arena later but is scaling fast. Its Medium- and Long-Term Plan for the Hydrogen Energy Industry (2021–2035) targets 50 000 FCEVs by 2025 and positions hydrogen as a "strategic emerging industry" for carbon-neutral growth. [8]

1.2 Problem Statement and Research Gap

Despite the proliferation of hydrogen strategies and the growing consensus about hydrogen's critical role in decarbonizing transport, substantial gaps persist between ambition and implementation. The international policy landscape is marked by a proliferation of targets but few cases of sustained, real-world deployment. As of late 2022, over 680 large-scale hydrogen projects had been announced globally, corresponding to USD 240 billion in planned investment, yet only around USD 22 billion—less than 10%—had reached final investment decision.[9] This imbalance reflects a broader uncertainty surrounding commercial viability, infrastructure lock-in, and long-term policy stability. For hydrogen in transport, the uncertainties are especially pronounced, given the capital-intensive nature of refueling networks, high vehicle costs, and relatively limited end-user demand.

[6] International Energy Agency. 2023. "*Global Hydrogen Review 2023"*. IEA. P. 148
[7] Nagashima, M. 2018. P. 22–24
[8] Lou, Y. & A. S. Corbeau. 2023. "*China's Hydrogen Strategy: National vs. Regional Plans"*. Center on Global Energy Policy. P. 26, 50
[9] Hydrogen Council, McKinsey & Company. 2022. "*Hydrogen Insights 2022"*. Hydrogen Council. P. iii

Even in leading countries such as Japan and China, progress remains uneven and segmented. Japan pioneered the commercialization of fuel-cell passenger vehicles with the Toyota Mirai, yet by 2022 cumulative FCEV sales stood at just 7,700 vehicles nationwide—far below its 2020 target of 40,000.[10] China's FCEV fleet surpassed 8,400 units in 2022, which is less then 0,003% of total China's total vehicle fleet and mostly composed of buses and logistics vehicles, reflecting a focus on fleet operations and urban pilots.[11] Hydrogen's share in overall vehicle fuel consumption remains negligible, and in both countries, fueling infrastructure is still nascent. Japan had about 160 operational hydrogen refueling stations by 2023, far below its planned 900 by 2030; China, with over 300 stations, faces uneven geographic distribution and low utilization rates.[12]

Comparable implementation gaps are evident in other advanced jurisdictions: in the United States, the Infrastructure Investment and Jobs Act (2021) and the Inflation Reduction Act (2022) earmark USD 8 billion for regional Clean Hydrogen Hubs and offer a production tax credit of up to USD 3 kg^{-1}, yet the Department of Energy acknowledges that permitting delays, offtake risk and the absence of a coordinated transport-storage network mean only a handful of electrolyser projects have reached ground-breaking stages. [13] In the European Union, the flagship Hydrogen Strategy for a Climate-Neutral Europe (2020) and the subsequent REPowerEU package raised the 2030 renewable-hydrogen target to 10 million tonnes[14], but cumulative installed electrolyser capacity in the EU was still only about 162 MW in 2022, constrained by slow permitting, supply-chain bottlenecks and rising capital costs. [15]

[10] International Council on Clean Transportation (ICCT). 2023. "*Global EV Sales Review 2022"*. Washington, D.C.: ICCT. P. 3.
[11] International Energy Agency (IEA). 2022. "*Global Hydrogen Review 2022"*. Paris: IEA. P. 41
[12] International Energy Agency. 2023. "*Global Hydrogen Review 2023"*. IEA. P. 34
[13] U.S. Department of Energy. 2023. "*National Clean Hydrogen Strategy and Roadmap"*. DOE. P. 9; U.S. Department of Energy. 2024. *Hydrogen Program Plan*. DOE. P. 17
[14] European Commission. 2020. "*A Hydrogen Strategy for a Climate-Neutral Europe"*. COM(2020) 301. P. 6
[15] European Commission Joint Research Centre (JRC). 2023. "*Water Electrolysis and Hydrogen: Growing Deployment Prospects in Europe and Beyond"*. Luxembourg: Publications Office of the European Union. P. 3.

The policy and industrial approaches taken by leaders are shaped by different motives and logics. This divergence in motives, institutional logics, and deployment trajectories raises an important comparative policy question: which models are more effective for catalyzing transport-sector hydrogen uptake, and under what conditions?

1.3 Research Question and Its Relevance

Against this backdrop, this thesis seeks to answer the following research question:

How do China and Japan approach the development of low-carbon hydrogen in their transportation sectors in the context of promoting decarbonized mobility?

Japan and China provide an intriguing comparison – Japan was an early pioneer in hydrogen policy, whereas China's hydrogen efforts have ramped up more recently in tandem with its aggressive climate goals. Comparing these two cases can shed light on the efficacy of different governance and industry models for promoting hydrogen-based transport.

This thesis addresses these gaps by offering a comparative, motive-centered analysis of hydrogen development in China and Japan's transport sectors. It aims to move beyond descriptive policy comparison and tracking current progress toward an explanatory framework that links national motives with sectoral outcomes. In doing so, it not only contributes to academic knowledge but also to practical decision-making in the ongoing global hydrogen transition. Moreover, the thesis will elucidate how both countries are progressing toward decarbonizing their domestic transport sectors and assess which approach has proven more effective to date.

This master's thesis examines low-carbon hydrogen development in the transportation sectors of China and Japan, with a defined temporal scope covering the period from 2015 to the present. Accordingly, the analysis is geographically limited to these two national cases and traces policy, industrial, and market dynamics within this timeframe.

The importance of this question becomes more evident when disaggregated through the perspectives of governments, industries, and international institutions.

Governments of developed countries with established hydrogen industries—such as Germany, France, the United States, and Australia—are closely watching developments in Asia. As global hydrogen markets evolve, these countries must assess whether their own industrial positioning and climate targets remain viable in light of accelerating policy frameworks and cost declines in China and Japan. For example, the European Commission has warned that if Europe does not act swiftly, "its leadership in green hydrogen technology will shrink as China deepens its innovation capacities and strengthens its price competitiveness". [16] Similarly, Australia's national strategy identifies Northeast Asia as its most important hydrogen export market and explicitly positions Australia to serve the import ambitions of Japan and Korea.[17]

Governments of developing countries, including those in Latin America, Africa, and Southeast Asia, are also potential beneficiaries of this research. IRENA argues that many developing countries "may be able to exploit their renewable energy potential to produce green hydrogen locally," contributing to energy access, industrial development, and export diversification.[18] Yet developing countries face significant barriers—technical, institutional, and financial. Understanding the divergent models pursued by China and Japan offers templates.

Chinese and Japanese government and regulatory authorities are themselves important audiences. China's National Development and Reform Commission (NDRC) and National Energy Administration (NEA) are tasked with overseeing implementation of the 2021–2035 hydrogen plan, yet face significant coordination challenges. In Japan, government authorities face a different set of issues: low

[16] Brown, Alexander, Nis Grünberg. 2022. "*China's Nascent Green Hydrogen Sector: How Policy, Research and Business Are Forging a New Industry"*. MERICS. P. 20
[17] Commonwealth of Australia. 2019. "*Australia's National Hydrogen Strategy"*. Department of Industry, Science, Energy and Resources. P. 31
[18] International Renewable Energy Agency. 2022. "*Geopolitics of the Energy Transformation: The Hydrogen Factor"*. IRENA. P. 18

consumer uptake of hydrogen vehicles, high infrastructure costs, and questions around long-term demand certainty. A comparative evaluation of evolving institutional approaches provides Chinese and Japanese regulators with evidence-based feedback on their respective systems, highlighting strengths, blind spots, and opportunities for mutual learning.

Automotive manufacturers and maritime shipping companies are central stakeholders in hydrogen's industrial uptake. Japanese shipbuilders, such as Kawasaki Heavy Industries and IHI, are piloting liquid hydrogen and ammonia carriers, while Chinese ports and SOEs (e.g., COSCO and Sinopec) are building hydrogen refueling docks and hydrogen-based cargo-handling systems. In the automotive sector, Toyota and Honda continue to lead in fuel-cell electric passenger vehicles, but China has taken the global lead in hydrogen-powered buses and logistics trucks.[19] BMW's recent partnership with Toyota to co-develop fuel cell passenger vehicles for European markets further demonstrates the strategic dimension of hydrogen alliances beyond Asia.[20] This thesis provides these companies with macro-level insights into the policy conditions that shape demand and infrastructure development, enabling better alignment between business strategy and public-sector signals.

Finally, international organizations in the fields of transportation, environmental protection, and clean energy, such as the IEA, IRENA, the OECD, and the World Bank, stand to gain from a systematic comparison of China and Japan's national hydrogen systems. These organizations are actively supporting hydrogen roadmaps, funding pilot projects, and facilitating knowledge transfer across regions. These institutions require detailed, empirically grounded studies to inform cross-national benchmarking and to identify best practices. This thesis, by

[19] International Energy Agency. 2022. "*Global Hydrogen Review 2022"*. IEA. P. 44
[20] BMW Group. 2024. "*Hydrogen Pioneers Take Collaboration to the Next Level"*. Munich: BMW Group. Access: https://www.bmwgroup.com/en/news/general/2024/hydrogen-cooperation.html

tracing motives and mechanisms in two leading East Asian hydrogen economies, offers just such a foundation.

1.4 Thesis Structure

The thesis is structured as follows. Chapter 2 reviews the relevant literature on hydrogen in transport and related policies. Chapter 3 describes the methodology of this study, outlining the comparative case analysis framework. Chapter 4 presents a detailed analysis of China's and Japan's low-carbon hydrogen initiatives in the transportation sector, examining policy targets, institutional measures, and industry developments. Building on the preceding country chapters, the remainder of Section 4 expands the cross-case comparison by systematically applying the six analytical lenses introduced in the thesis framework. The next chapter 5 then compares the Chinese and Japanese cases, discussing commonalities and differences in their motives, policy instruments, and outcomes, and deriving lessons for policy and cooperation. Chapter 6 provides an overview on the limitations of the research. Finally, Chapter 7 concludes with a summary of findings, discusses the implications for stakeholders, and suggests areas for further research. Each chapter builds on the preceding analysis to provide a coherent account of how and why China and Japan are advancing low-carbon hydrogen in transportation.

2. LITERATURE REVIEW

2.1 European Union

Academic interest in the European Union's hydrogen policy has evolved from early conceptual explorations of "hydrogen economies" to detailed examinations of the Union's dense legislative and financial architecture. Bleischwitz and Bader were among the first to argue that existing EU climate instruments, while not hostile to hydrogen, lacked the targeted incentives necessary for market formation; they concluded that a multi-level, technologically oriented support scheme would

eventually be indispensable for large-scale deployment.[21] That insight foreshadowed the European Commission's landmark Hydrogen Strategy for a Climate-Neutral Europe, which in 2020 codified phased capacity goals—6 GW of electrolyzers by 2024 and 40 GW by 2030—alongside plans for ten million tonnes of renewable hydrogen and a continent-wide backbone of storage and pipelines.[22]

Subsequent scholarship has treated the 2020 strategy as a "metastrategy" that orchestrates more than thirty legislative and funding instruments. Vivanco-Martín and Iranzo demonstrate that the synergy between supranational targets and national implementation—expressed through Important Projects of Common European Interest, the Clean Hydrogen Partnership and Horizon Europe—creates an iterative policy cycle in which private investment is progressively de-risked.[23] Pinto's comparative analysis of the EU, Germany and Spain shows how such guidance prompts national strategies to converge on common timelines and fiscal measures while still diverging in risk-sharing mechanisms and technology priorities.[24]

Cost and competitiveness issues dominate techno-economic studies. Lagioia and colleagues calculate that the levelised cost of "green" hydrogen in Europe remains two to three times higher than that of hydrogen derived from natural-gas reforming, largely because of electricity prices and electrolyzer capital costs; they conclude that temporary support for low-carbon hydrogen may be necessary during the 2020s transition.[25] Seck and co-authors model demand trajectories consistent with the Union's climate-neutrality goal and project more than 100 Mt of hydrogen consumption by 2050, of which at least ten to fifteen per cent would be economically

[21] Bleischwitz, Raimund, Nikolas Bader. 2010. "*Policies for the Transition towards a Hydrogen Economy: The EU Case*." Energy Policy 38: 5388–5398. P. 5390
[22] European Commission. 2020. "*Hydrogen Strategy for a Climate-Neutral Europe"*. P. 12
[23] Vivanco-Martín, Begoña, Alfredo Iranzo. 2023. "*Analysis of the European Strategy for Hydrogen*: *A Comprehensive Review*". Energies *16:* 3866. Pp. 29-31
[24] Pinto, Jaqueline. 2023. "*The Key Tenets of a Hydrogen Strategy: An Analysis and Comparison of the Hydrogen Strategies of the EU, Germany and Spain*." Global Energy Law & Sustainability 4: 72-95. Pp. 84-87
[25] Lagioia, Giovanni et al. 2023. "*Blue and green hydrogen energy to meet European Union decarbonisation objectives. An overview of perspectives and the current state of affairs*". International Journal of Hydrogen Energy 48: 1304-1322. P. 1318

imported via repurposed pipelines from neighbouring regions.[26] Gantera's optimisation analysis finds that a "least-regret" path requires roughly 9.6 Mt yr^{-1} of low-carbon hydrogen by 2030 and that hybrid investment in electrolysis and SMR-with-CCS reduces supply-chain risk under cost uncertainty.[27]

Regulatory work interrogates the criteria that define "renewable" hydrogen. Brandt and collaborators show that the 2023 Delegated Acts under the Renewable Energy Directive, which cap life-cycle emissions at 3 kg CO_2-eq kg^{-1} and impose hourly matching between electrolyzer load and renewable generation, can lower total system costs if transitional flexibility is retained.[28] Pinto likewise warns that the absence of an EU-wide taxonomy for CCS-based hydrogen risks regulatory fragmentation during the interim decade.[29]

Attention has also turned to the spatial distribution of ambition within the Union. Koneczna and Cader document a ten-fold divergence in national electrolyzer targets—6.5 GW in the Netherlands versus less than 0.5 GW in several Central- and Eastern-European states—and argue that without coordinated infrastructure and certification such disparities could produce a "hydrogen inequality" that undermines the internal market.[30]

Intergovernmental reports contextualise these academic findings. IRENA estimates present European costs of renewable hydrogen at €3–6 kg^{-1} and signals potential convergence towards €2–4 kg^{-1} by 2030 if learning rates and cheap renewables materialise.[31] The IEA's Global Hydrogen Review 2023 records that EU project announcements doubled in the year following adoption of the Alternative

[26] Seck, Georges-S. et al. 2022. "*Hydrogen and the decarbonization of the energy system in europe in 2050: A detailed model-based analysis*." Renewable and Sustainable Energy Reviews 167: 112779. P. 3
[27] Gantera, Abram et al. 2024. "*Minimum-regret hydrogen supply chain strategies to foster the energy transition of European hard-to-abate industries*." arXiv 2407.05988. P. 14
[28] Brandt, Jack et al. 2024. "*Cost and competitiveness of green hydrogen and the effects of the European Union regulatory framework*." Nature Energy 9: 703-713. P. 708
[29] Pinto 2023, P. 87
[30] Koneczna, Renata, Joanna Cader. 2021. " *Hydrogen in the Strategies of the European Union Member States*." Mineral Resources Management 37(3). P. 456
[31] International Renewable Energy Agency. 2022. "*Green hydrogen for industry: a guide to policy making"*. Abu Dhabi. P. 24

Fuels Infrastructure Regulation yet still leave a gap between prospective supply and binding demand quotas in aviation and maritime sectors.[32]

Transport-specific literature refines this broader policy picture. The authors writing for EIT Urban Mobility show that fuel-cell city buses, medium- and heavy-duty trucks and municipal utility vehicles constitute the only segments in which hydrogen can achieve a positive business case before 2030; passenger cars, they argue, face prohibitive costs and infrastructure scarcity.[33] Their investment model values the potential European market for hydrogen trucks at €13 billion by the decade's end, contingent on tripling current RD&D outlays.

Deployment studies corroborate the emerging focus on high-utilisation fleets. Element Energy's final report on the H2ME initiative—after the roll-out of more than 1 400 vehicles and forty-five refuelling stations across ten countries—concludes that "the next phase of European HRS deployment is shifting towards fewer, higher-capacity stations serving buses and trucks", because utilisation levels of passenger-car stations remain too low to support viable business models. [34]

Taken together, the scholarship and institutional reports reviewed here depict the European hydrogen project as a coherent yet dynamically evolving experiment in climate-industrial governance. Researchers converge on the view that the Union's comparative advantage lies in its capacity to align binding supranational objectives with nationally differentiated implementation, thereby transforming an initial strategic vision into a dense lattice of legislation, finance and certification that systematically de-risks private capital. A second common theme is definitional clarity: by embedding strict life-cycle-emissions thresholds and hourly renewable matching in the 2023 Delegated Acts, Brussels has exported a uniform benchmark for what qualifies as "renewable" hydrogen, even as scholars warn that the absence of an EU-wide taxonomy for CCS-based hydrogen could reopen fragmentation risks.

[32] International Energy Agency. 2023. "*Global Hydrogen Review 2023"*. P. 29
[33] EIT Urban Mobility. 2024. "*The Role of Hydrogen in Urban Mobility"*. P. 6
[34] Element Energy. 2020. *H2ME: Emerging Conclusions*. P. 112

Third, virtually every analysis stresses the need for paired supply- and demand-side instruments—carbon contracts-for-difference, the nascent Hydrogen Bank, SAF and maritime quotas—until learning curves and carbon pricing narrow today's cost gap of €1.5–3 kg^{-1} between green and fossil hydrogen. Finally, transport-specific studies now identify high-utilisation heavy-duty fleets as hydrogen's most credible market niche, provided that municipalities aggregate demand and that high-throughput refuelling hubs receive coordinated CAPEX- and OPEX-support.

2.2 United States

Academic and policy analyses trace a distinctive U.S. hydrogen trajectory, shaped not by a single central blueprint but by the confluence of longstanding federal support for R&D, a surge of post-2021 fiscal incentives, and increasingly diverse sub-national experimentation. The U.S. National Clean Hydrogen Strategy and Roadmap identifies clean hydrogen as a "critical decarbonisation lever" and sets volumetric targets of 10 million metric tonnes by 2030, 20 MMT by 2040, and 50 MMT by 2050. The strategy emphasizes deployment in hard-to-electrify segments such as heavy-duty transport, alongside parallel cost-reduction efforts and the development of regional hydrogen hubs.[35] The Hydrogen Program Plan 2024 reinforces this framework, outlining the role of DOE in demonstrating integrated hydrogen systems under the H2@Scale initiative, coordinating R&D, and facilitating infrastructure deployment.[36]

Scholars widely interpret this evolution through the lens of fiscal federalism. The Inflation Reduction Act of 2022, in particular, is described as a "game-changer" that closed the policy gap with other advanced economies. Its ten-year §45V production tax credit—worth up to US $3 per kilogram for hydrogen with life-cycle emissions under 0.45 kg CO_2-eq/kg—is seen as sufficient to drive cost parity with unabated SMR in high-resource regions.[37] However, regulatory ambiguity around

[35] U.S. Department of Energy. 2023. "*National Clean Hydrogen Strategy and Roadmap"*. P. 1
[36] U.S. DOE. 2024. "*Hydrogen Program Plan*". Pp. 8–9
[37] Talus, Kim, Maxwell Martin. 2022. "*A Guide to Hydrogen Legislation in the USA: A Renewed Effort*." Journal of World Energy Law & Business 15(4): 449–472.

temporal matching, emissions accounting, and grid electricity remains a bottleneck for investment, as confirmed by both institutional and academic sources.[38]

Parallel to federal action, a second literature stream examines regional experimentation. California, in particular, has become a focal point for hydrogen mobility. Bade and Tomomewo document that California alone maintains over fifty hydrogen-specific laws and incentives, operates more refuelling stations than all other states combined and deploys policy bundles—low-carbon fuel standards, ZEV mandates, vehicle rebates—that have seeded both light- and heavy-duty fuel-cell markets.[39] Yang and Ogden's long-term modelling shows that this policy mix could deliver 85% well-to-wheel emission reductions compared to gasoline and competitive retail prices around US $4/kg by the mid-2020s, especially when coupled with biomass and CCS pathways.[40] Other states, including Texas and Louisiana, are experimenting with 45Q and fossil-based hydrogen with CCS, creating a diverse national patchwork that encourages innovation but risks fragmentation in the absence of harmonized certification, infrastructure standards, and carbon-intensity thresholds.[41]

The transport sector plays a central role in the federal strategy and academic analyses alike. The National Clean Hydrogen Strategy outlines the potential for hydrogen to decarbonise long-haul trucking, rail, marine, and aviation, highlighting federal support for initiatives such as the Million Mile Fuel Cell Truck Consortium and the 21st Century Truck Partnership.[42] Numerous researchers emphasise the complementary role of hydrogen alongside battery-electric vehicles, particularly for applications requiring long range, high payload, and uptime. Market studies

[38] IEA. 2023. "*Global Hydrogen Review*". Pp. 154–156
[39] Bade, S.O., O.S. Tomomewo. 2024. "*A review of governance strategies, policy measures, and regulatory framework for hydrogen energy in the United States*." International Journal of Hydrogen Energy 78: 1363-1381. P. 1365
[40] Yang, Christopher, Joan Ogden. 2013. "*Renewable and Low-Carbon Hydrogen for California – Modeling the Long-Term Evolution of Fuel Infrastructure Using a Quasi-Spatial TIMES Model*." International Journal of Hydrogen Energy 38(11): 4250–4265. P. 4259.
[41] Dawood, Furat, Martin Anda, G.M. Shafiullah. 2020. "*Hydrogen Production for Energy: An Overview*." International Journal of Hydrogen Energy 45(7): 3847–3869
[42] U.S. Department of Energy. 2023. "*National Clean Hydrogen Strategy and Roadmap*". Washington, DC. Pp. 1, 29

highlight early adoption in logistics and material handling, where over 25,000 hydrogen forklifts are already in use.[43] Madadi Avargani et al. and Tlili et al. confirm hydrogen's advantages in range, payload, and fleet utilisation, but also underscore high vehicle and fuel costs, distribution bottlenecks, and underdeveloped infrastructure as key hurdles.[44] [45]

Techno-economic modelling reinforces the need for hybridised pathways and large-scale investment coordination. Vijayakumar, Jenn, and Ogden use optimisation frameworks to map Western U.S. supply chains under varying policy and demand conditions. Their findings identify California as a key hydrogen hub but also highlight the need to import hydrogen from neighbouring states due to high local electricity prices.[46]

In conclusion, U.S. scholarship depicts a hydrogen economy propelled by three interlocking forces: first, powerful federal incentives—chiefly the IRA's §45V credit—are capable of driving cost convergence, but hinge on regulatory clarity and dependable off-take; second, state-level "experimental federalism" fosters innovation and mobility pilots, yet risks fragmentation without national standards for certification and infrastructure; third, regional hub development is seen as key to clustering production, distribution, and use, but will require hybrid supply chains and inter-agency coordination to overcome CO_2 transport bottlenecks and permitting delays. This multifaceted model offers a crucial comparator for evaluating the structure, ambition, and coherence of hydrogen strategies in China and Japan.

[43] Fuel Cell and Hydrogen Energy Association. 2020. "*Road Map to a U.S. Hydrogen Economy"*. Washington, DC. Pp. 35, 37
[44] Madadi Avargani, Vahid, Sohrab Zendehboudi, Noori M. Cata Saady, Maurice B. Dusseault. 2022. "*A Comprehensive Review on Hydrogen Production and Utilization in North America: Prospects and Challenges*." International Journal of Hydrogen Energy 47(43): 18812–18840.
[45] Tlili, Olfa, Christine Mansilla, David Frimat, Yannick Perez. 2019. "*Hydrogen Market Penetration Feasibility Assessment: Mobility and Natural Gas Markets in the US, Europe, China and Japan*." International Journal of Hydrogen Energy 44(15): 28329–28341.
[46] Vijayakumar, Vishnu, Alan Jenn, Joan Ogden. 2023. "*Modeling Future Hydrogen Supply Chains in the Western United States under Uncertainties: An Optimization-Based Approach Focusing on California as a Hydrogen Hub*." Energy Policy 179: 113858. P. 1224

2.3 Australia

Early commentary on Australia's hydrogen ambitions emphasised the country's exceptional renewable-energy resource endowment and its aspiration to become a "green-hydrogen super-power". The Council of Australian Governments' National Hydrogen Strategy frames hydrogen primarily as an export commodity for North-East Asian markets and sets the political objective of reaching A \$2 kg^{-1} ("H_2 under two") this decade, a target widely used as a benchmark in subsequent techno-economic research. [47] Kar's systematic literature review corroborates that export orientation dominates both public discourse and scholarly output: of the 146 peer-reviewed Australian hydrogen papers published between 2015 and 2021, more than half focus on supply-side cost curves and trade logistics, whereas fewer than 10% examine domestic demand creation.[48] Longden in an ex-post review of the National Hydrogen Strategy argue that the National Hydrogen Strategy underestimates balance-of-plant and water-supply constraints in arid regions, concluding that export volumes above 3 Mt y^{-1} would require large-scale desalination or pipeline imports of water. [49]

Cost-mapping studies locate the economic "fairways" for renewable hydrogen in coastal Western Australia, South Australia and Queensland, where high solar-and-wind capacity factors intersect with port infrastructure. Walsh and Easton model levelised costs of A \$4.1 kg^{-1} today, converging to A \$2.1 kg^{-1} by 2030 under aggressive learning rates; they warn, however, that pipeline transmission to population centres can add up to A \$0.9 kg^{-1}.[50]

While export potential dominates the narrative, recent scholarship tracks a nascent domestic transport focus. The H_2OzBus consortium has demonstrated

[47] Commonwealth of Australia. 2019. "*National Hydrogen Strategy"*. P. 3
[48] Kar, Satyajit. 2022. "*Overview of the Hydrogen Economy in Australia*." WIREs Energy & Environment 11: e457. P. 8
[49] Longden, Thomas. 2021. „*Analysis of the Australian Hydrogen Strategy*." Konrad-Adenauer-Stiftung. P. 16.
[50] Walsh, Stuart D. C., Laura Easton, Zhehan Weng, Changlong Wang, Joseph Moloney, Andrew Feitz. 2021. "*Evaluating the Economic Fairways for Hydrogen Production in Australia*." International Journal of Hydrogen Energy 46(73): 35985–35996.

twelve fuel-cell buses in Victoria and New South Wales, and Queensland's "HyTruck" pilot targets a fleet of thirty heavy-duty trucks by 2026.[51] Sub-national policies reflect distinct strategic orientations: Western Australia's Renewable Hydrogen Strategy concentrates on upstream enablers, offering capital grants, land access and planning support for production facilities, whereas Victoria and Queensland have prioritised downstream deployment, including public procurement of hydrogen vehicles and co-investment in refuelling infrastructure.

A further body of work interrogates Australia's positioning in emerging certification regimes. Adelphi's comparative study notes that Canberra's proposed Guarantee-of-Origin scheme mirrors the EU threshold of 3 kg CO_2-eq kg^{-1} but allows temporal averaging of renewable input over a month, an approach favoured by exporters yet questioned by environmental NGOs.[52]

To sum up, Australian scholarship portrays a hydrogen landscape shaped by three interlocking dynamics: first, an export-first narrative—anchored in the "H_2 under two" target and Western Australia's and Queensland's solar-wind "fairways"—frames hydrogen chiefly as a commodity for Asian markets and drives most techno-economic modelling; second, cost studies agree that achieving sub-A $2 kg^{-1} prices is plausible only in optimal coastal zones and is highly contingent on rapid electrolyser learning, abundant low-cost capital and parallel investments in desalination, storage and port logistics; third, the incipient domestic market remains fragmented across states, with pockets of momentum in bus and heavy-truck pilots but no unified certification, pipeline or offtake framework—leaving Australia's internal hydrogen demand modest and its infrastructure build-out vulnerable to coordination gaps even as it races to secure a foothold in global green-hydrogen trade.

[51] Department of Climate Change, Energy, the Environment and Water. 2024. Disclosure Log 22-022-70711. P. 11
[52] Sieler, Roman Eric; Henri Dörr. 2023. "*Certification of green and low-carbon hydrogen"*. Adelphi. P. 30

2.4 China

Early scholarship reconstructs the long gestation of a national hydrogen agenda in China. Yuan and Tan-Mullins trace three policy phases—"infancy" (2001-12), "gradual development" (2012-19) and "acceleration" (2019-20)—and show that only in the third phase did instruments move beyond generic technology rhetoric to concrete targets for fuel-cell vehicles and refuelling infrastructure.[53] Lou and Corbeau argue that this incrementalism reflects Beijing's wider approach to nascent clean-energy technologies: pilot, monitor cost curves and scale only once local state-owned enterprises can dominate value chains.[54]

The subsequent release of the Medium- and Long-Term Hydrogen Industry Development Plan (2022-35) confirmed the pattern. MERICS analysts note that, while the plan elevates hydrogen to "strategic emerging industry" status, its production goal—100,000-200,000 t yr^{-1} of renewable H_2 by 2025—lags far behind the European Union's 1 Mt benchmark and omits a life-cycle carbon-intensity threshold, leaving definitional clarity to future standards.[55] WEF's Green Hydrogen in China likewise judges the plan an "orientation document" whose specificity is deliberately deferred to provincial implementation.[56]

Most empirical work converges on clustered provincial experimentation as the engine of deployment. Using input–output metrics, Li et al. reveal that Guangdong, Shanghai and Beijing-Tianjin-Hebei possess the highest coordinated-development capacity across the hydrogen value chain—production equipment, storage, logistics and end-use—largely because provincial targets and subsidies

[53] Yuan, Xinxin, May Tan-Mullins. 2023. "*An Innovative Approach for Energy Transition in China: Chinese National Hydrogen Policies from 2001 to 2020"*. Sustainability 15(2):1265. P. 7.
[54] Lou, Yushan, Anne-Sophie Corbeau. 2023. "*China's Hydrogen Strategy: National vs. Regional Plans"*. Center on Global Energy Policy. P. 14.
[55] Brown, Alexander, and Nis Grünberg. 2022. "*china's nascent green hydrogen sector: How policy, research and business are forging a new industry"*. MERICS China Monitor No. 77. Mercator Institute for China Studies. P. 7.
[56] World Economic Forum. 2023. "*Green Hydrogen in China: A Roadmap for Progress"*. Geneva: World Economic Forum. P. 11.

preceded national benchmarks.[57] Case studies of Zhangjiakou, Shanghai and Foshan show that local governments bundle land-use concessions, tax rebates and SOE joint-ventures to crowd-in private capital, creating what Corbeau terms "municipal industrial policy laboratories".[58]

The literature also dissects evolving subsidy mechanisms. National purchase premiums for H-FCVs—still CNY 200,000 for a 100 kW bus—remain generous, yet several studies show that local incentives increasingly target infrastructure and operating costs. Li et al. model hydrogen-refuelling-station subsidies in Zhejiang: a dynamic scheme that front-loads capital support and introduces declining per-kilogram OPEX grants yields 27 % higher H-FCV uptake than a flat-rate design.[59] Xiong et al. confirm the importance of OPEX relief: provinces offering usage-based grants (e.g., CNY 20 kg^{-1} in Jiangsu) achieve station utilisation factors above 30 %, twice the national mean.[60]

Transport remains hydrogen's primary market pull. He et al. document that by end-2023 China had 17,000 registered H-FCVs, over 80 % of them buses, logistics vans and heavy-duty trucks clustered in six provinces; they attribute success to "city-cluster" reward programmes that allocate central funds only after provincial fleets meet cumulative-range milestones.[61] Wang et al. project that heavy-duty trucks could create annual demand of 3 Mt H_2 by 2030 under current policy intensity, but only if low-carbon hydrogen costs fall below CNY 18 kg^{-1}.[62] The RMI roadmap adds that coastal synthetic-ammonia bunkering and Yangtze River fuel-cell tugboats

[57] Gao, Xinwei, and Ruichao An. 2022. "*Research on the coordinated development capacity of China's hydrogen energy industry chain"*. Journal of Cleaner Production 384: 134177. P. 10.
[58] Lou & Corbeau 2023, p. 19
[59] Li, Zhi, Wenju Wang, Meng Ye, and Xuedong Liang. 2021. "*The Impact of Hydrogen Refueling Station Subsidy Strategy on China's Hydrogen Fuel Cell Vehicle Market Diffusion"*. International Journal of Hydrogen Energy 46(35): 18461–18475. P.3
[60] Li, Chengzhe, Libo Zhang, Zihan Ou, and Jiayu Ma. 2022. "*Using System Dynamics to Evaluate the Impact of Subsidy Policies on Green Hydrogen Industry in China"*. Energy Policy 165: 112981. P. 11
[61] Yeung, Godfrey, and Yi Liu. 2023. "*Local Government Policies and Public Transport Decarbonization through the Production and Adoption of Fuel Cell Electric Vehicles (FCEVs) in China"*. Journal of Cleaner Production 422: 138552. P. 12
[62] Yang, Lei, Shuning Wang, Zhihu Zhang, Kai Lin, and Minggang Zheng. 2023. "*Current Development Status, Policy Support and Promotion Path of China's Green Hydrogen Industries under the Target of Carbon Emission Peaking and Carbon Neutrality"*. Sustainability 15(13): 10118. P. 3.

are likely next-wave niches because they allow high-utilisation of refuelling assets and leverage China's port authority financing structures. [63]

Techno-economic papers reach a consistent verdict on costs. Prospects-of-Renewable-Hydrogen scenarios show levelised green-hydrogen prices at solar–wind "sweet spots" in Inner Mongolia and Qinghai falling from CNY 26 kg^{-1} in 2023 to CNY 14 kg^{-1} by 2030, contingent on electrolyser capital falling below US$ 300 kW^{-1}. [64] Yet Renewable-Hydrogen-100 Roadmap authors warn that, without a national standard defining "renewable hydrogen" and mandating temporal matching, provincial grid electricity could undercut climate integrity and distort costs.[65]

Taken together, the scholarship and institutional reports reviewed here depict China's hydrogen strategy as a state-led but locally executed experiment in industrial policy. National plans provide broad direction, while provinces drive implementation through varied subsidy schemes, infrastructure pilots and transport-focused deployment. Researchers agree that this decentralised dynamism—anchored in provincial experimentation and SOE coordination—is China's key advantage in scaling hydrogen. Yet the absence of binding definitions for "green" hydrogen, including life-cycle emissions thresholds and temporal matching, remains a critical gap. Most analyses highlight the need for sustained, targeted support—especially capital and OPEX subsidies—to close the cost gap with fossil hydrogen.

2.5 Japan

The scholarly examination of Japan's hydrogen strategy represents a rich body of research spanning technology assessment, policy analysis, and economic evaluation. As the first country to formulate a national hydrogen strategy in 2017,

[63] Li, Ting, Wei Liu, Yanming Wan, Zhe Wang, Monroe Zhang, and Yan Zhang. 2022. "*China's Green Hydrogen New Era: A 2030 Renewable Hydrogen 100 GW Roadmap"*. RMI and China Hydrogen Alliance Research Institute. P. 11

[64] RIFS. 2023. "*China's Emerging Hydrogen Economy: Policies, Institutions, Actors"*. RIFS Study. Potsdam: Research Institute for Sustainability (RIFS). P. 88.

[65] Li et al. 2022. "*China's Green Hydrogen New Era*". P. 6.

Japan's approach has attracted significant academic attention, with researchers analyzing its evolution from multiple perspectives.[66]

Academic analysis of Japan's hydrogen strategy typically identifies three distinct phases of development. The initial phase began with the 2014 Strategic Roadmap for Hydrogen and Fuel Cells, which Behling, Williams, and Managi characterize as primarily technology-oriented.[67] The second phase emerged with the 2017 Basic Hydrogen Strategy, which Ozawa et al. identify as marking Japan's transition toward a more comprehensive approach.[68] The current phase, initiated by the 2023 strategy revision, reflects what Osaki describes as a more nuanced approach balancing domestic capabilities with international partnerships.[69]

Nagashima identifies three primary policy objectives driving Japan's hydrogen strategy: energy security enhancement, industrial competitiveness, and environmental sustainability.[70] This tripartite focus is echoed in subsequent analyses by Chaube et al. who emphasize how these objectives became more explicitly linked to climate commitments following Japan's 2020 carbon neutrality pledge.[71]

Researchers have extensively analyzed Japan's institutional approach to hydrogen development. Behling et al. detail how the Ministry of Economy, Trade and Industry (METI) coordinates policy implementation through multiple agencies, with the New Energy and Industrial Technology Development Organization (NEDO) playing a central role in technology development.[72] The literature particularly

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[66] Nagashima, Monica. 2018. "*Japan's Hydrogen Strategy and its Economic and Geopolitical Implications*." Études de l'Ifri. P. 12
[67] Behling, Noriko, Mark C. Williams, and Shunsuke Managi. 2015. "*Fuel cells and the hydrogen revolution: Analysis of a strategic plan in Japan*." Economic Analysis and Policy 48: 70-81. P. 72
[68] Ozawa, Akito, Yuki Kudoh, Akinobu Murata, Tomonori Honda, Itoko Saita, and Hideyuki Takagi. 2018. "*Hydrogen in low-carbon energy systems in Japan by 2050: The uncertainties of technology development and implementation*." International Journal of Hydrogen Energy 43(43): 18083-18094. P. 18085
[69] Osaki, Yuki, and Laura Hughes. 2024. "*Japan: Putting Hydrogen at the Core of its Decarbonization Strategy*." RIFS Discussion Paper (June). P. 7
[70] Nagashima, Monica. 2020. "*Japan's Hydrogen Society Ambition: 2020 Status and Perspectives*." Notes de l'Ifri. Ifri. P. 13
[71] Chaube, Anshuman, Andrew Chapman, Yosuke Shigetomi, Kathryn Huff, and James Stubbins. 2020. "*The Role of Hydrogen in Achieving Long Term Japanese Energy System Goals."* Energies 13(17): 4539. P. 2
[72] Behling, Noriko, Mark C. Williams, and Shunsuke Managi. 2015. "*Fuel cells and the hydrogen revolution: Analysis of a strategic plan in Japan.*" Economic Analysis and Policy 48: 70-81. P. 73

emphasizes Japan's distinctive public-private partnership model. As documented by Harada et al., this approach has facilitated rapid infrastructure deployment, especially in the transportation sector.[73]

Researchers have extensively examined the economic viability of Japan's hydrogen ambitions. Ozawa et al. develop sophisticated models incorporating various technology pathways and cost trajectories.[74] Their findings suggest that achieving cost competitiveness requires significant technological advancement and scale economies.

The transportation sector has received particular scholarly attention, with researchers examining Japan's ambitious targets for fuel cell vehicle deployment. Yoshida analyzes Japan's early leadership in fuel cell vehicle commercialization, noting Toyota's pioneering role with the Mirai.[75] However, several scholars identify challenges in market development. Khan et al. conduct detailed consumer surveys, finding that despite government support, public acceptance remains a significant barrier.[76]

Khan, Yamamoto, and Sato also provide detailed analysis of Japan's policy support mechanisms, particularly noting the evolution of subsidy schemes for fuel cell vehicles and hydrogen refueling stations. Their research emphasizes how policy support has shifted from broad technology promotion toward more targeted market creation efforts.

Ogimoto and Williams offer comparative analysis of hydrogen mobility strategies across different markets, positioning Japan's approach as particularly

[73] Harada, M., T. Ichikawa, H. Takagi, and H. Uchida. 2016. "*Building a hydrogen infrastructure in Japan.*" In Compendium of Hydrogen Energy Volume 4: Hydrogen Use, Safety and the Hydrogen Economy, edited by R.B. Gupta, A. Basile, and T.N. Veziroglu, 333-354. Woodhead Publishing. P. 335
[74] Ozawa, Akito, Yuki Kudoh, Akinobu Murata, Tomonori Honda, Itoko Saita, and Hideyuki Takagi. 2018. "*Hydrogen in low-carbon energy systems in Japan by 2050: The uncertainties of technology development and implementation.*" International Journal of Hydrogen Energy 43(43): 18083-18094. P. 18087
[75] Yoshida, Toshihiko, and Koichi Kojima. 2015. "*Toyota MIRAI Fuel Cell Vehicle and Progress Toward a Future Hydrogen Society*." Electrochemical Society Interface 24: 45–49. P. 45
[76] Khan, Urwah, Toshiyuki Yamamoto, and Hitomi Sato. 2021. "*An insight into potential early adopters of hydrogen fuel-cell vehicles in Japan."* International Journal of Hydrogen Energy 46(19): 10863-10874. P. 10865

comprehensive but noting implementation challenges.[77] Their research highlights how Japan's early focus on passenger vehicles has gradually shifted toward heavy-duty applications, where hydrogen's advantages may be more compelling.

A distinctive feature of Japan's strategy that has attracted significant scholarly attention is its emphasis on developing international hydrogen supply chains. Ishimoto et al. provide detailed technical and economic analysis of various transport options, including liquid hydrogen and organic carriers.[78] Their work emphasizes the critical role of cost reduction in making international hydrogen trade viable.

Several scholars offer critical perspectives on Japan's hydrogen strategy. The Renewable Energy Institute argues that the strategy's initial focus on fossil-based hydrogen with carbon capture and storage may have delayed development of renewable hydrogen capacity.[79]

The academic literature reveals several key themes in Japan's hydrogen strategy development. First, scholars generally agree that Japan's early movement on hydrogen has provided valuable policy and technical lessons, though views differ on the effectiveness of specific approaches. Second, researchers identify a consistent tension between ambitious goals and practical implementation challenges, particularly in the transportation sector. Third, analysis of international supply chain development suggests both opportunities and risks in Japan's import-dependent approach.

[77] Ogimoto, Kazuhiko, and Eric Williams. 2021. "*Projecting the Future Cost and Performance of Hydrogen Technologies for Transport in Japan: An Expert Elicitation*." International Journal of Hydrogen Energy 46(1): 123–135.
[78] Ishimoto, Yuki, Miyuki Kurosawa, and Masaharu Sasakura. 2020. "*Large-scale production and transport of hydrogen from Norway to Europe and Japan: Value chain analysis and comparison of liquid hydrogen and ammonia as energy carriers*." International Journal of Hydrogen Energy 45(58): 32865-32883. P. 32867
[79] Renewable Energy Institute. 2022. "*Re-examining Japan's Hydrogen Strategy: Moving Beyond the "Hydrogen Society" Fantasy*." P. 5

3. ANALYTICAL FRAMEWORK AND METHODOLOGY

3.1 "Motives-in-Motion" Conceptual Model

The preceding literature review mapped the global and regional scholarship on hydrogen development in the main markets—from the European Union's regulation-dense "metastrategy," through the United States' fiscal-federal experimentation, to Australia's export-centric cost curves and East Asia's contrasting governance models — with an eye to what these insights mean for transport decarbonisation. Across these studies, hydrogen's viability in mobility hinges on a recurring analytical toolkit. (1) the governance architecture that aligns national and sub-national hydrogen-mobility objectives; (2) the robustness of sustainability certification that authenticates "low-carbon" claims; (3) the domestic-versus-import sourcing balance that underpins transport supply security; (4) the cost trajectory and fiscal incentives that close the competitiveness gap with fossil fuels; (5) the spatial integration of refuelling and storage infrastructure with high-throughput corridors; and (6) the observable market uptake reflected in fleet deployments and hydrogen projects reaching final investment decision. Each criterion focuses on the research question that can be answered with publicly available statistics, official documents, and peer-reviewed studies, i.e. within the empirical window of this thesis. Together they form a coherent line of inquiry that links government intent, market signals, and observable deployment outcomes and provide a theory-derived yardstick against which the empirical chapters will later assess China and Japan's low-carbon-hydrogen strategies for mobility.

1. Regulatory and Institutional Framework

This criterion evaluates the breadth and legal force of the policy corpus that shapes hydrogen use in transport. Particular attention is paid to (i) whether transport-related targets are anchored in binding statutes or remain consultative, (ii) how clearly mandates, budgets, and oversight responsibilities are distributed across ministries and sub-national agencies, and (iii) the extent to which regional initiatives complement, adapt, or fill gaps in the national blueprint. A well-structured,

obligation-creating network of strategies and regulations can deliver the policy certainty required for large-scale low carbon hydrogen industry development.

2. Sustainability Assurance and Certification

Because “low-carbon” remains a contested label, the second lens evaluates the strictness and transparency of life-cycle carbon-intensity thresholds, the auditing regime behind them, and any mutual-recognition agreements that facilitate cross-border fuel trade. Certification quality determines whether hydrogen genuinely advances climate goals and whether domestic producers can access export markets.

3. Supply Structure and Sourcing Pathways

Here the focus shifts to the volume and composition of hydrogen available for mobility. The analysis distinguishes between domestic production routes (grey, blue, green) and imports secured through offtake agreements. Comparing supply with projected transport demand and renewable-resource potential reveals each country’s exposure to resource or trade risks.

4. Economic Viability and Incentive Alignment

Criterion 4 reconstructs the delivered cost of hydrogen to end-users today and in 2030, then maps the fiscal instruments—CAPEX grants, OPEX subsidies, tax credits, contracts-for-difference—that narrow the gap with incumbent fuels. Only by linking cost curves with incentive design can one judge whether fleets have a rational business case to switch.

5. Infrastructure Readiness and Spatial Integration

A credible hydrogen strategy requires a backbone of refuelling stations, pipelines, storage and port facilities. The fifth criterion therefore inventories operational assets, utilisation rates, and the spatial match between production hubs and high-throughput transport corridors. Misalignments often explain slow uptake even when supply and policy are favourable.

6. Market Uptake and Industrial Implementation

Finally, the framework measures what ultimately matters: real vehicles on the road, trains on the track, ships in port, and corporate projects that have reached final investment decision. Disaggregating uptake by transport segment (city buses, heavy-duty trucks, rail, maritime) and by corporate consortium shows whether policy signals are translating into decarbonised mobility.

Table 1. Criterion for the Analytical Framework

Criterion	Achievable Indicators	Illustrative Primary Sources
Regulatory and Institutional Framework	(i) Total number of hydrogen-related policy instruments and strategis. (ii) Share of transport-specific targets codified in binding laws or ordinances (%). (iii) Explicit assignment of lead agency, budget line and oversight mechanism in each instrument. (iv) Proportion of provinces/prefectures that have issued hydrogen-transport plans aligned with national targets (%). (v) Average revision cycle of national hydrogen strategy (years).	e-Gov Law & Regulation Database; NDRC–NEA; METI; provincial/prefectural gazettes and budget bills
Sustainability Assurance and Certification	(i) Carbon-intensity threshold (kg CO_2-eq kg^{-1} H_2, LHV). (ii) Frequency of third-party audits (yrs). (iii) System-boundary definition. (iv) Responsible certification authority.	Standards bodies; Ministry circulars (NDRC & NEA, METI); Hydrogen associations; IEA
Supply Structure and Sourcing Pathways	(i) Domestic output by route: grey / blue / green, kt y^{-1}	China Hydrogen Alliance; METI; Customs data;

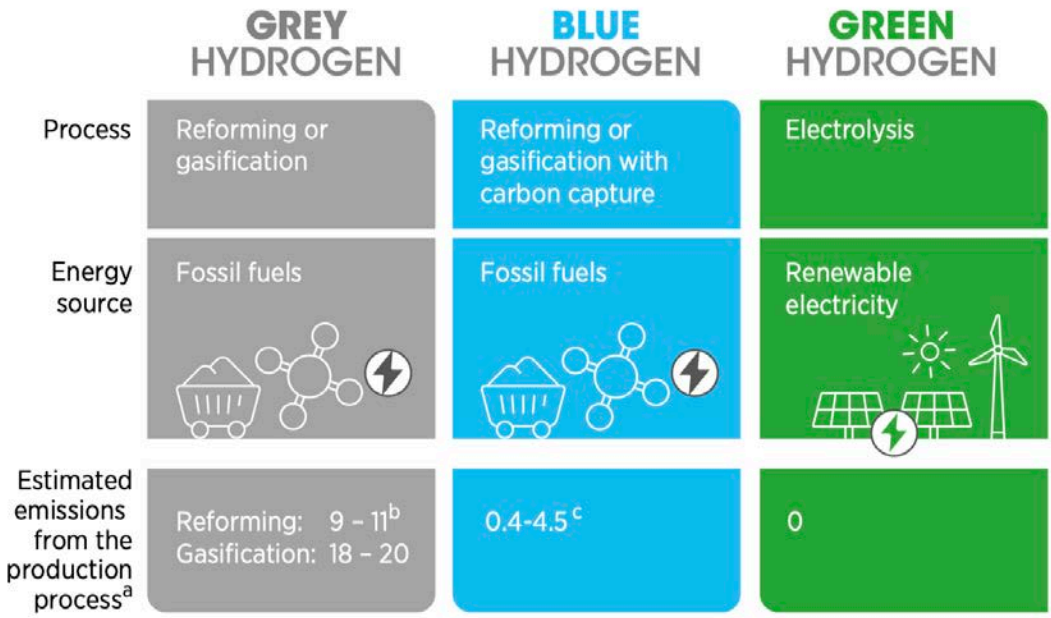
	(ii) Imported H_2 or NH_3 under binding contracts (kt yr^{-1}). (iii) Regional hub map & lead projects: name and capacity	IEA/IRENA databases; Consulting reports
Economic Viability and Incentive Alignment	(i) Delivered H_2 cost and cost projection by 2030. (ii) Aggregate CAPEX + OPEX support. (iii) Support duration & phase-out schedule. (iv) Retail price of conventional fuels.	BloombergNEF; IEA-IRENA Hydrogen Cost Tracker; national subsidy catalogues; National statistics bureau
Infrastructure Readiness and Spatial Integration	(i) Operational refuelling stations (number) and average utilisation (%). (ii) Pipeline or trucking capacity dedicated to H_2 (km). (iii) Storage capacity co-located with ports or logistics hubs (GWh). (iv) Electrolysers capacity (GW)	China Hydrogen Alliance statistics; Transport-ministry registries – industry white papers; corporate press releases
Market Uptake and Transport Implementation	(i) Registered FCEVs (units, %). (ii) Fuel-cell rail or maritime pilots in operation (number). (iii) Transport-related H_2 projects reaching FID. (iv) Private-sector leaders in hydrogen transportation: automotive OEMs, maritime carriers / shipbuilders, airlines / aerospace OEMs	NEDO; China MIIT vehicle registry; BloombergNEF; Company annual reports; Market reviews

3.2 Main Definitions

Low-carbon hydrogen: in the context of energy transitions, "low-carbon hydrogen" refers to hydrogen produced with significantly reduced greenhouse gas emissions compared to conventional "grey" hydrogen (which is typically made from unabated fossil fuels). Low-carbon hydrogen can be generated via green pathways –

such as water electrolysis using renewable (or nuclear) electricity – or via blue pathways, where hydrogen is produced from fossil fuels but with carbon capture, utilization, and storage (CCUS) to curb emissions. For example, the International Energy Agency defines low-emissions hydrogen as hydrogen made from renewables, nuclear, or fossil fuels with CCUS.[80] This distinguishes it from traditional hydrogen production methods (like steam methane reforming of natural gas without CCUS) that emit substantial CO_2. Some jurisdictions are now quantifying what "low-carbon" means. Such definitions are crucial for certification, as they link incentives and policies to hydrogen that genuinely contributes to climate goals.

Figure 1. Colour-Code Typology of Hydrogen Production



Source: IRENA. 2022. *Geopolitics of the Energy Transformation.* P. 26

Decarbonized mobility: this term denotes transportation systems that emit little to no net carbon dioxide, achieved by shifting away from fossil fuels to cleaner energy sources. Decarbonizing mobility encompasses battery-electric vehicles, hydrogen fuel cell electric vehicles, sustainable biofuels, and other alternative fuels,

[80] International Energy Agency. 2022. "*Global Hydrogen Review 2022*". IEA.

as well as modal shifts and efficiency improvements. The concept is grounded in the need to reduce the transport sector's hefty carbon footprint. Globally, transport CO_2 emissions have been hard to abate, requiring a move from petroleum fuels to electrification and renewable-based fuels.

National hydrogen strategies and approaches: over the past few years, a wave of countries have published national hydrogen strategies, outlining how hydrogen fits into their decarbonization and industrial plans. Generally, a national approach to hydrogen involves government coordination on R&D, infrastructure investment, regulations (e.g. standards for hydrogen fuel quality or safety), and often subsidies or mandates to stimulate both supply and demand of low-carbon hydrogen. Each country's approach is shaped by its context: resource endowment (renewables vs fossil), industrial structure, and strategic goals (e.g. energy security, technology leadership).

In summary, low-carbon hydrogen and decarbonized mobility are intertwined concepts – hydrogen is one energy carrier that can enable cleaner transport, but realizing its potential requires clear definitions (to ensure the hydrogen is truly low-carbon) and strategic national planning to overcome the current fossil-fuel-dominated status quo.

4. EMPIRICAL ANALYSIS

4.1 China

4.1.1 Regulatory and Institutional Framework

China's policy regime for low-carbon hydrogen in transport has evolved over roughly two decades from a loose collection of technology-oriented measures into a multi-level architecture anchored in the "dual-carbon" goals and medium- to long-term hydrogen planning. Early national documents between 2001 and 2020 treated hydrogen mainly as a supportive technology within broader innovation, energy and environmental strategies; a coding of 49 national-level policies shows that most instruments took the form of non-binding plans, programmes and industrial guidelines, with only gradual differentiation of hydrogen from fuel-cell and electric-vehicle policy and limited attention to life-cycle emissions or sectoral integration. [81] Within this framework, fuel-cell vehicles were identified as a core application area but remained embedded in a wider "new energy vehicle" agenda and in demonstration programmes rather than in a dedicated statutory regime.

The policy pathway began on the transport side with the New Energy Vehicle Industry Development Plan (2021–2035), which placed fuel-cell vehicles inside the national NEV strategy and called for integrated "oil–gas–hydrogen–electric" service networks and hydrogen fuel supply chains—an early signal that refuelling would be co-planned with charging. [82] Compared with the earlier strategies wave, this second generation of NEV policy is more explicit about corridor planning, urban demonstration clusters and performance-based fiscal support, which lays the institutional groundwork for hydrogen use in freight and public transport.

Comprehensiveness arrived with the Hydrogen Energy Industry Medium- and Long-Term Development Plan (2021–2035), issued by the National Development

[81] Yuan, Yiqi, and May Tan-Mullins. 2023. "Chinese National Hydrogen Policies from 2001 to 2020: A Textual Analysis." Sustainability 15: 1265. P. 1

[82] 中华人民共和国全国人民代表大会常务委员会.《中华人民共和国能源法》（2024 年通过，2025 年施行）[Energy Law of the People's Republic of China (adopted 2024, effective 2025).]

and Reform Commission and the National Energy Administration. The plan framed hydrogen as a strategic component of the future energy system, identified transport as an anchor early market, warned against "low-level, duplicate construction," and — critically — embedded supervisory and evaluation provisions mandating periodic monitoring and mid-course optimization. Notably, the plan sets a quantitative target for fuel-cell vehicles: by 2025, the stock of fuel-cell vehicles is to reach approximately 50 000 units. Moreover, it specifies that—while a precise national target for hydrogen refuelling stations is not explicitly given in the public summary—the plan mandates "deployment of a batch of hydrogen refuelling stations" during the 14th Five-Year Plan period. [83]

From 2022 onward, hydrogen was embedded into adjacent industrial strategies that stabilise upstream supply while generating learning effects relevant to mobility. Guidance for the steel industry (2022) set a pathway toward hydrogen metallurgy and deepened low-carbon transformation[84], while the joint NDRC–NEA guidance for the refining industry (2023) encouraged green-hydrogen substitution and CCUS pilots and called for optimisation of intra-refinery hydrogen networks.[85] In 2024, MIIT together with NDRC and NEA issued an implementation plan to accelerate clean, low-carbon hydrogen use across metallurgy, ammonia, methanol and refining—explicitly bridging industrial feedstock and transport applications by improving market interfaces and siting for "produce-and-refuel" projects. [86]

A dense layer of "soft law" then reduced equipment and investment risk. The Guidance Catalogue for Green and Low-Carbon Transformation Industries (2024) and its official interpretation classify hydrogen production, storage, transport and

[83] 国家能源局节能和科技装备司、国能氢能创新科技有限公司（编）.《中国氢能发展报告（2025）》[China Hydrogen Development Report (2025).]
[84] 工业和信息化部、国家发展改革委、生态环境部.《关于促进钢铁工业高质量发展的指导意见》（工信部联原〔2022〕6号）[Guiding Opinions on Promoting High-Quality Development of the Steel Industry.]
[85] 国家发展改革委、国家能源局、工业和信息化部、生态环境部.《关于促进炼油行业绿色创新高质量发展的指导意见》（发改能源〔2023〕1364号）[Guiding Opinions on Promoting Green Innovation and High-Quality Development in the Refining Industry.]
[86] 工业和信息化部、国家发展改革委、国家能源局等.《加快工业领域清洁低碳氢应用实施方案》[Implementation Plan for Accelerating Clean, Low-Carbon Hydrogen Applications in the Industrial Sector]

refuelling as eligible tracks and link them to permitting and safety codes[87]; the First-(Set) Major Technical Equipment Catalogue (2024 ed.) sets performance thresholds for high-pressure components and other hydrogen-relevant kit that unlock demonstration insurance and procurement preferences[88]; and MIIT's Standards-Upgrading Action Plan for the Raw-Materials Industry (2025–2027) prioritises standardisation and accelerated uptake, alongside a guide for developing carbon-footprint rules for key products.[89] Together these measures connect R&D to bankable transport projects by clarifying market access and shortening the path from prototype to qualified equipment.

Transport integration tightened in 2024–2025. The Ten-Ministry Guiding Opinions on Promoting the Integrated Development of Transport and Energy (March 2025) instruct provinces and operators to co-plan charging, battery-swapping and hydrogen refuelling at hubs, corridors and service areas, and to deploy unified digital platforms for dispatch, billing and safety monitoring—administrative infrastructure that heavy-duty corridors require.[90] In parallel, the Action Plan for Large-Scale Equipment Renewal in the Transport Sector (2024) creates upgrade channels under which hydrogen vehicles and stations can qualify[91], while the Outline for the Development of Green Aviation Manufacturing (2023–2035) sets a long-run R&D trajectory for new-energy aircraft.[92]

The Energy Law consolidated this framework by bringing hydrogen under statutory energy governance and providing legal hooks for market entry, grid

[87] 国家发展改革委.《绿色低碳转型产业指导目录（2024 年版）》[Guidance Catalogue for Green and Low-Carbon Transformation Industries (2024 Edition).]
[88] 工业和信息化部等.《首台（套）重大技术装备推广应用指导目录（2024 年版）》[Guidance Catalogue for the Promotion and Application of First-(Set) Major Technical Equipment (2024 Edition)]
[89] 工业和信息化部等.《标准提升引领原材料工业优化升级行动方案（2025—2027 年）》[Action Plan (2025–2027) for Standards Upgrading to Guide Optimization and Upgrading of the Raw-Materials Industry].
[90] 交通运输部等十部门.《关于推动交通运输与能源融合发展的指导意见》（交规划发〔2025〕42 号）[Guiding Opinions on Promoting the Integrated Development of Transport and Energy].
[91] 交通运输部等十三部门.《交通运输大规模设备更新行动方案》（交规划发〔2024〕62 号）[Action Plan for Large-Scale Equipment Renewal in the Transport Sector].
[92] 《绿色航空制造业发展纲要（2023—2035 年）》[Outline for the Development of Green Aviation Manufacturing (2023–2035)].

interaction and safety.[93] Central "Opinions" on accelerating the comprehensive green transformation (2024) further mandate whole-chain development—production, storage, transport, use—and call for a coherent standards system, including for green transport infrastructure.[94] National reporting for 2024–2025 notes that an inter-ministerial hydrogen coordination mechanism now links law implementation with plan execution and power-market reforms. [95]

Administrative "teeth" arrived with the NEA's national pilot programme in June 2025. The Notice on Organizing Hydrogen-Energy Pilots launches both project pilots (e.g., RES-to-hydrogen electrolysis, by-product hydrogen purification, long-distance transport, salt-cavern storage, liquid-hydrogen logistics) and regional pilots, and appends standardised forms and evidentiary requirements, including approvals from planning, land and environmental authorities and defined safety supervision arrangements—portable templates that raise consistency across provinces and project types. [96]

Subnational Level of Hydrogen Policy

As of September 2025, the Hydrogen Industry Observation had catalogued 634 subnational hydrogen-policy instruments in China, including 233 development plans, 166 fiscal-support measures, 140 project-support policies, 79 management measures, 11 hydrogen-safety regulations and 5 standard-system documents; 187 policies were at the provincial level and 447 at the municipal or county level, with 443 currently in force and 56 under public consultation. [97]

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[93] 中华人民共和国全国人民代表大会常务委员会. 《中华人民共和国能源法》（2024 年通过，2025 年施行）[Energy Law of the People's Republic of China (adopted 2024, effective 2025)].
[94] 中共中央、国务院. 《关于加快经济社会发展全面绿色转型的意见》[Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development]. 2024.
[95] 国家能源局节能和科技装备司、国能氢能创新科技有限公司（编）. 《中国氢能发展报告（2025）》[China Hydrogen Development Report (2025)].
[96] 国家能源局综合司. 《关于组织开展能源领域氢能试点工作的通知》（国能综通科技〔2025〕91 号）[Notice on Organizing Hydrogen-Energy Pilots in the Energy Sector (NEA Comprehensive Department Notice No. 91 [2025])].
[97] Hydrogen Industry Observation (氢能产业观察). 2025. "*氢能数据速递 [Hydrogen Data Express].*" 氢能产业观察：2025 年 9 月刊 [Hydrogen Industry Observation: September 2025 Issue], p. 3.

Beneath this national scaffolding, subnational governments translate objectives into enforceable, budgeted programmes and coordinate horizontally where corridors or ports matter. Shanghai exemplifies how local finance, industrial policy and operating support are braided to move supply and demand in step with national evaluation metrics. The city's 2021 measures for FCV demonstration and industrial development created a pooled municipal fund that matches central city-cluster awards 1:1 and requires districts to co-finance, thereby reducing intra-metropolitan free-riding. [98] Capital grants cover up to 30% of eligible station capex, with per-station caps stepping down from RMB 5 million (permits obtained by end-2022) to RMB 3 million (2024–2025), and an output-linked operating grant supports retail prices at ≤RMB 35/kg, stepping down from RMB 20/kg (2021) to RMB 10/kg (2024–2025). [99] The policy suite also keys industrial-upgrading awards to localisation of stacks, MEAs, bipolar plates, PEMs, catalysts, carbon paper, compressors and valves.

Beijing's approach highlights cross-jurisdictional coordination at the city-region scale. The capital's "14th Five-Year" energy plan and the city's hydrogen implementation plan explicitly mobilise central SOEs and mixed-ownership vehicles to co-develop pipelines, large-scale RES-to-hydrogen and cross-regional logistics; they also call for shared operating rules on subsidies, insurance, certification and trading and for a unified data platform covering safety, supply and performance—elements designed to internalise corridor externalities across Beijing–Tianjin–Hebei. [100] [101]

[98] 上海市发展和改革委员会等.《关于支持上海市燃料电池汽车产业发展若干政策》（沪发改规范〔2021〕10号）[Policies to Support the Development of the Fuel-Cell Vehicle Industry in Shanghai (Hu Fa Gai Gui Fan [2021] No. 10)].
[99] 上海市人民政府.《上海市氢能产业发展中长期规划（2022—2035年）》[Shanghai Hydrogen Industry Medium- and Long-Term Development Plan (2022–2035)]
[100] 北京市发展和改革委员会.《北京市"十四五"时期能源发展规划》[Beijing "14th Five-Year" Energy Development Plan]. 2022.
[101] 北京市发展和改革委员会等.《北京市氢能产业发展实施方案（2021—2025年）》[Beijing Hydrogen Industry Development Implementation Plan (2021–2025)].

Other provinces tailor instruments to local comparative advantage while remaining tethered to central supervision. Shandong piloted two-year highway toll exemptions for hydrogen vehicles to lower OPEX along trunk routes [102]; Guangdong's "Guang-Zhan Hydrogen Highway" integrates station build-out—including produce-and-refuel sites—with cold-chain FC logistics across coastal cities[103]; Sichuan advances a standards-led model that expands the supply and uptake of technical standards through tight "industry–academia–research" collaboration[104]; and Liaoning emphasises safety governance and public acceptance, assigning firm-level responsibilities across production, logistics, refuelling and use and strengthening monitoring and emergency preparedness. [105]

National pilots knit these local efforts together. The NEA's 2025 hydrogen pilot programme combines project pilots (from large-scale wind-/solar-to-hydrogen to liquid-hydrogen logistics) with regional pilots that group cities into cooperative zones and explicitly task provincial development and energy agencies with siting, safety, land and power interfaces, and schedule control—under central evaluation and potential claw-backs. This vertical discipline conditions local experimentation while closing gaps in interoperability and safety—preconditions for high-throughput, heavy-duty transport. [106]

A maritime/port interface has also emerged from the local level. Shanghai's work plan for the green transition of international shipping fuels (2024–2025) aims to build a world-class green-fuel bunkering hub by 2030, accelerating standards, certification and international cooperation for hydrogen-based carriers such as green

[102] 山东省交通运输厅等.《关于对氢能车辆暂免收取高速公路通行费的通知》[Notice on Temporarily Exempting Hydrogen Vehicles from Expressway Tolls]. 2024.
[103] 广东省发展和改革委员会.《广东省广湛氢能高速示范项目实施方案》[Implementation Plan for the Guangdong Guang-Zhan Hydrogen Highway Demonstration Project]. 2024.
[104] 四川省市场监督管理局.《四川省以标准提升推动氢能全产业链发展及推广应用工作方案》[Work Plan for Promoting the Hydrogen Full-Chain via Standards in Sichuan]. 2024.
[105] 辽宁省工业和信息化厅等.《辽宁省氢能产业发展规划（2021—2025 年）》[Liaoning Hydrogen Industry Development Plan (2021–2025)]. 2021.
[106] 国家能源局综合司.《关于组织开展能源领域氢能试点工作的通知》（国能综通科技〔2025〕91 号）[Notice on Organizing Hydrogen-Energy Pilots in the Energy Sector (NEA Comprehensive Department Notice No. 91 [2025])].

methanol and ammonia—an increasingly important complement to land transport decarbonisation. [107]

Taken together, the emerging hydrogen regime is therefore best understood as a hierarchical yet multi-centre system. At the apex, the Energy Law – even in draft form – symbolically elevates hydrogen to an energy source alongside fossil fuels and renewables, providing the statutory hook for subsequent regulations on market entry, grid interaction and safety management. Below this level sit the hydrogen industry plan, NEV strategy and "dual-carbon" guidance, which jointly set the strategic direction for hydrogen production, storage, transport and use in industry and mobility. Further down, sectoral policies – for steel, refining, coal-chemicals and renewable power integration – define specific use cases and demonstration priorities, while a growing body of technical standards, catalogues and evaluation rules translate these priorities into equipment specifications, project-screening criteria and eligibility rules for fiscal support.

In terms of legal force, the regime has clearly shifted from non-binding guidance toward binding obligations. The Energy Law now provides statutory backing for market access, infrastructure protection and safety, and it expressly defines hydrogen as energy; ministerial plans and opinions retain programmatic character but are increasingly tied to supervision clauses, evaluation cycles and fiscal performance conditions.

Institutional responsibility is shared but differentiated. NDRC and NEA provide overall energy governance and pilot administration; MIIT leads on equipment, standardisation and industrial deployment; and the Ministry of Transport steers corridor and hub integration alongside state grid companies. Subnationally, development and energy bureaus, transport commissions and market-supervision agencies co-implement, often with central SOEs as development partners. This

[107] 上海市人民政府办公厅. 《上海市绿色航运燃料转型工作方案（2024—2025 年）》[Shanghai Work Plan for the Green Transition of International Shipping Fuels (2024–2025)].

division of labour is visible in the integrated transport–energy guidance's signatories and in the subnational plans' assignments of fiscal and safety responsibilities.

4.1.2 Sustainability Assurance and Certification

China's approach to "low-carbon hydrogen" in transport rests on a much broader project: standardising greenhouse-gas (GHG) accounting across sectors and then layering a hydrogen-specific carbon-intensity label on top. The set of identified official documents sit at different levels of this architecture: (i) hydrogen product and purity standards, (ii) economy-wide GHG accounting guidelines for enterprises and provinces, (iii) sectoral GHG standards including land transport, and (iv) a dedicated group standard that defines and certifies low-carbon, clean and renewable hydrogen. Together they shape how far hydrogen used in mobility can actually be claimed as "green".

Multi-layer GHG accounting architecture

At the top level, China requires provinces to compile comprehensive GHG inventories using a unified methodology. The Provincial Greenhouse Gas Inventory Compilation Guidelines (2025 Revision) specify sectoral coverage, data requirements and links to Intergovernmental Panel on Climate Change (IPCC) methods, ensuring that energy, industry, and transport emissions are consistently reported across the country.[108] This provincial inventory frame is what ultimately aggregates any emission reductions from hydrogen use in transport into China's official climate statistics.

Below this, several enterprise-level guidelines operationalise emissions accounting at plant and company level. Most relevant for transport is Onshore Transport Enterprises.[109] This standard defines the accounting boundary and reporting requirements for road, rail and other land-based transport companies,

[108] 《省级温室气体清单编制指南（2025 修订版）》 [Provincial Greenhouse Gas Inventory Compilation Guidelines (2025 Revision)]
[109] 《温室气体排放核算与报告要求》 [Requirements for Greenhouse Gas Emissions Accounting and Reporting]

specifying how fuel consumption and electricity use are converted into CO_2-equivalent emissions and integrated into the national GHG reporting system. While the text primarily focuses on conventional fuels and grid electricity, the generic structure—activity data multiplied by standardised emission factors—can be applied to hydrogen fuel.

Hydrogen as a standardised industrial product

Before hydrogen can be certified as "low-carbon", it must be defined as a physical commodity with agreed purity, impurity limits and test methods. This role is played by several long-standing product standards.

The standard Hydrogen — Part 1: Industrial Hydrogen classifies hydrogen by purity grades and specifies permissible levels of key impurities such as oxygen, nitrogen and moisture, together with sampling and analysis methods.[110] The companion Hydrogen — Part 2: Pure Hydrogen, High-Purity Hydrogen and Ultra-High-Purity Hydrogen extends this classification to very high purity levels, tightening impurity thresholds and referencing appropriate analytical techniques.[111]

These product standards are not transport-specific, but they provide the measurement infrastructure for hydrogen-as-a-commodity: purity is clearly defined, and producers must maintain metering and analytical systems that can generate reliable data on hydrogen quality. That infrastructure is later reused in the low-carbon hydrogen standard, which sets its life-cycle assessment (LCA) functional unit at 1 kg of hydrogen with a purity of at least 99% and a pressure of 3 MPa. This alignment means that the carbon-intensity label attaches to a well-defined physical product, which is crucial for tracing emissions along supply chains, including to hydrogen refuelling stations and vehicle fleets.

[110] 《氢气 第 1 部分：工业氢》 [Hydrogen – Part 1: Industrial Hydrogen]
[111] 氢气 第 2 部分：纯氢、高纯氢和超纯氢》 [Hydrogen – Part 2: Pure Hydrogen, High-Purity Hydrogen and Ultra-High-Purity Hydrogen]

Defining "low-carbon", "clean" and "renewable" hydrogen

The group standard T/CAB 0078-2020 Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen is the core instrument that translates generic MRV practice into hydrogen-specific carbon-intensity thresholds.[112] Developed under the China Hydrogen Alliance (中国氢能联盟) and issued by the China Association for the Promotion of Industry-Academia-Research Cooperation (中国产学研合作促进会), the standard explicitly frames hydrogen as "a key lever for energy system transformation and carbon neutrality" and aims to drive high-emission production routes towards cleaner options.

Substantively, T/CAB 0078-2020 defines three labels: "low-carbon hydrogen", "clean hydrogen" and "renewable hydrogen". All three are differentiated by the life-cycle GHG emissions per unit of hydrogen and, in the renewable case, by the energy source for production. Low-carbon hydrogen must have a carbon intensity of no more than 14.51 kgCO_2-equivalent per kg H_2, while both clean hydrogen and renewable hydrogen must not exceed 4.9 kgCO_2e/kgH_2. For renewable hydrogen, the electricity or other energy used in production must come from renewable sources such as wind, solar, hydro, biomass, geothermal or ocean energy.

The system boundary for hydrogen includes raw material extraction, raw material transport, hydrogen production and on-site storage and transport, but explicitly excludes the design and construction of fixed assets and ancillary services such as canteens or dormitories. The functional unit is set at 1 kg of hydrogen at 99% purity and 3 MPa. The evaluation period must cover at least the most recent year of mass hydrogen production, and never less than six months, including any periodic or intermittent production cycles, to ensure representativeness of the calculated carbon intensity.

[112] 《低碳氢、清洁氢与可再生氢的标准与评价》 [Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen]

Certification governance, audits and data integrity

T/CAB 0078-2020 also defines a full certification and audit process. First, it introduces "verification bodies" as qualified third-party organisations that conduct the assessment according to the standard. Hydrogen producers seeking certification must apply to a "public service platform recognised by the national energy authority". The platform commissions a verification body to conduct a two-step process: (i) a documentary review of life-cycle data, process descriptions, energy metering systems and other supporting evidence, and (ii) an on-site inspection to verify boundaries, data collection procedures, and the accuracy of primary and secondary data.

Only if both document review and site audit confirm compliance with the carbon-intensity thresholds and methodological requirements may a certificate be issued for low-carbon, clean or renewable hydrogen. Certificates apply to specific hydrogen production projects rather than companies in general, and the holder must not claim a production volume beyond the amount covered by the certificate when marketing or trading hydrogen.

Certificates are subject to annual surveillance audits, during which the verification body checks ongoing compliance, including production volumes, process changes and consistency with the standard. This creates a relatively stringent governance regime compared with purely self-declaratory schemes.

Implications for transport

For transport specifically, the current arrangement can be summarised as follows. Upstream, hydrogen producers can obtain low-carbon, clean or renewable hydrogen certificates based on T/CAB 0078-2020, with carbon-intensity values calculated under strict LCA rules and audited by third-party verification bodies. Mid-stream, hydrogen product purity and measurement standards ensure that what is traded and dispensed at stations is a well-defined physical product. Downstream,

onshore transport enterprises must report their overall GHG emissions according to the sectoral GB/T standard and the generic enterprise accounting guidelines, which already accommodate fuel and electricity consumption as activity data.

What the documents do not yet make explicit is the operational linkage between batch-level hydrogen certificates and fleet-level emissions reporting. There is no clear prescription in these texts for how a bus operator using certified renewable hydrogen should incorporate the producer's LCA carbon-intensity value into its own GHG report, versus using generic emission factors; nor do the standards specify how provincial inventories should distinguish between hydrogen of different carbon-intensity classes. This can be framed as a key implementation gap: the technical and institutional pieces for robust hydrogen sustainability assurance exist upstream, but their integration into transport-sector MRV and policy instruments (subsidies, mandates) is still evolving and not fully observable in the current standards corpus.

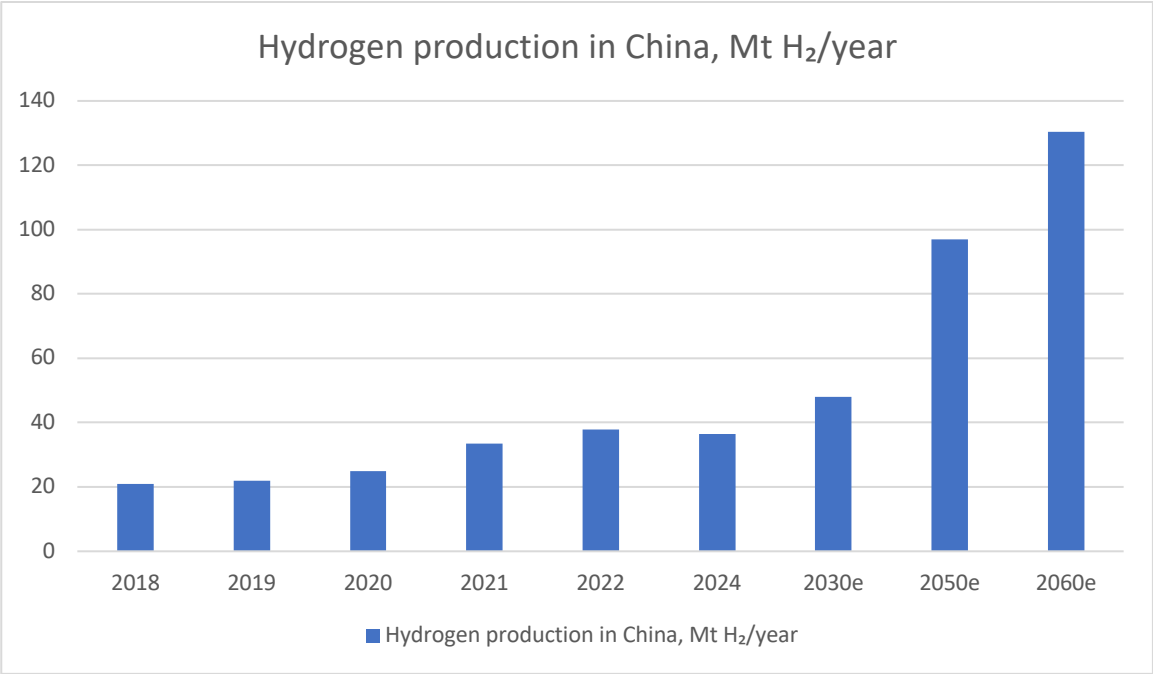
4.1.3 Supply Structure and Sourcing Pathways

China's hydrogen economy is already the largest in the world and is undergoing a profound structural transition. Roughly one third of global hydrogen production is located in China, reflecting the scale of its refining, ammonia, methanol and steel industries and the corresponding internal demand for hydrogen as an industrial feedstock. In physical terms, total output has grown steadily from around 21 Mt in 2018 to 36.5 Mt in 2024 (Figure 2.).[113] Projections used in this thesis anticipate further expansion to approximately 48 Mt by 2030, 96.9 Mt by 2050 and about 130.3 Mt by 2060, implying a three-and-a-half-fold increase over four decades. Within this aggregate trajectory, Chinese planners expect "green" or renewable hydrogen to reach on the order of 100 Mt by 2060, so that most incremental growth in supply would be delivered through low-carbon pathways.[114]

[113] TrendBank. 2023. "2023 势银绿氢产业大会会后报告 [2023 TrendBank Green Hydrogen Industry Conference Post-Event Report]." P. 6. Access at: https://zhuanlan.zhihu.com/p/635457241

[114] Rocky Mountain Institute (RMI) & China Hydrogen Alliance Research Institute. 2022. "*Renewable Hydrogen 100 Roadmap of China 2030"*. Beijing. P.9. Access at: https://rmi.org/wp-content/uploads/dlm_uploads/2022/09/china_green_hydrogen_new_era_renewable_hydrogen_roadmap.pdf

Figure 2. Actual and Projected Hydrogen Production in China



Source: TrendBank. 2023. *"Green Hydrogen Industry Conference Post-Event Report". P. 6;* RMI & China Hydrogen Alliance Research Institute. 2022. *"Renewable Hydrogen 100 Roadmap of China 2030". P.9*

The current production mix, however, remains overwhelmingly fossil based and therefore "grey" in lifecycle-emissions terms. In 2020, when total output was about 25 Mt, coal gasification accounted for roughly 62 per cent of hydrogen production, natural gas reforming for about 18 per cent and hydrogen recovered as an industrial by-product (for example in coking, chlor-alkali and other chemical processes) for around 19 per cent. Only in the order of 1 per cent of Chinese hydrogen was produced via water electrolysis powered by electricity, the only route that can yield genuinely green hydrogen when supplied with low-carbon power.[115] This structure means that more than 99 per cent of hydrogen output in the early 2020s is "grey" in the international colour taxonomy.

[115] Zhongshang Qianzhan Consulting Co., Ltd. 2023. "2023 年中国制氢市场前景及投资研究报告 [2023 China Hydrogen Production Market Prospects and Investment Research Report]." Access at: https://baijiahao.baidu.com/s?id=1774163845301843510

China's hydrogen supply landscape is shaped by a large number of producers, but a small group of state-owned and private enterprises dominate national output. The single largest player is China Energy Investment Corporation (CHN Energy), whose coal-gasification complexes together produce more than 4 million tonnes of hydrogen per year, primarily as an intermediate for coal-to-chemicals value chains. Sinopec and PetroChina occupy the next two positions, with annual hydrogen production of about 3.5 million tonnes and 2.6 million tonnes respectively, generated mainly as a by-product of petroleum refining. Alongside these giants, specialised chemical companies make a visible but much smaller contribution: Jiangsu Huachang Chemical, for example, produces roughly 200 thousand tonnes of hydrogen annually from sodium borohydride processes, while Shanxi Meijin Energy recovers around 59 thousand tonnes from coke-oven gas. Taken together, CHN Energy, Sinopec and PetroChina account for roughly 30 per cent of China's hydrogen output, underscoring the extent to which current production is embedded in coal and oil value chains controlled by large state-owned enterprises, even though numerous small and medium-sized firms also operate in the market. [116]

The dominance of coal-based hydrogen is not accidental but reflects China's resource endowment and the historical evolution of its energy system. Coal is abundant, domestically controlled and deeply embedded in industrial infrastructure, making coal gasification a technically mature and economically convenient route for bulk hydrogen production. Industrial by-product hydrogen, meanwhile, is generated unavoidably in refineries, coke ovens and selected chemical processes; recovering this hydrogen as a feedstock has long been rational on purely economic grounds, even in the absence of climate incentives. By contrast, green hydrogen from electrolysis requires substantial capital investment in electrolysers and access to low-cost renewable electricity. Both of these enabling conditions have only begun to scale over the last decade, so that electrolysis still contributes marginal volumes

[116] Cyzone Research Institute. 2023. "2023 年中国氢能产业研究报告 [2023 China Hydrogen Industry Research Report]." Access at: https://max.book118.com/html/2023/0912/6152052203005225.shtm

to total output even though it occupies a central place in official decarbonisation narratives.

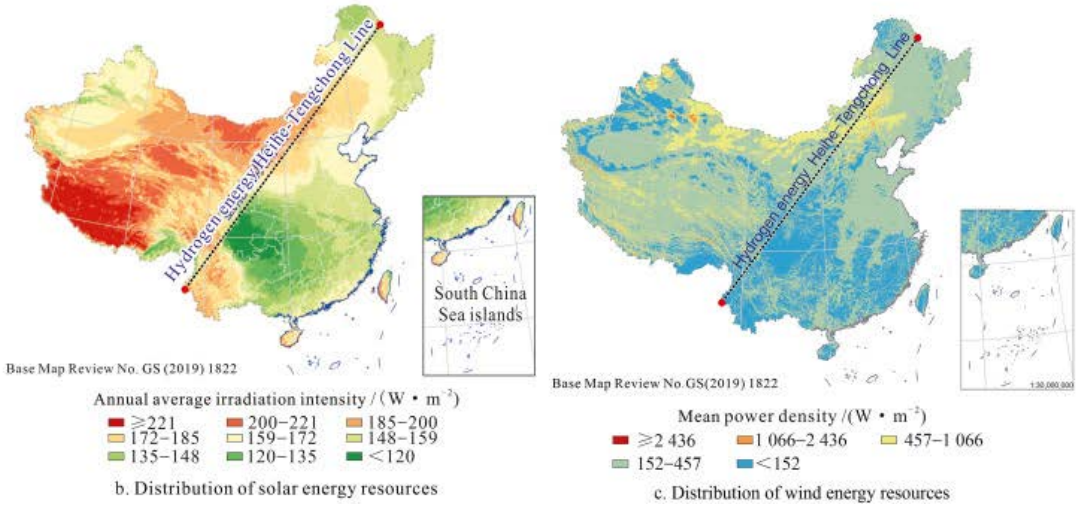
Geographical Characteristics of Hydrogen Production

Geography further shapes the evolution of China's production mix. Mapping exercises of solar irradiance and wind power density show that high-quality renewable resources are concentrated to the west of the classic Heihe–Tengchong (Hu) line, in sparsely populated provinces such as Inner Mongolia, Xinjiang, Gansu and Qinghai, home to sandy deserts covering more than 260×10^4 km², offering substantial potential for the development of renewable energy sources (Figure 3). These regions contain vast desert and steppe areas suitable for utility-scale wind and solar complexes; the north-west alone is estimated to host more than 60 per cent of national photovoltaic potential, while Inner Mongolia and Xinjiang together account for roughly half and one quarter, respectively, of the technically suitable onshore wind resources for centralised development.[117] When these resource layers are translated into prospective green hydrogen output, the resulting spatial distribution for 2060 shows a dense cluster of high-potential production bases in the inland north-west and relatively modest volumes in the coastal provinces. In an extreme scenario in which all technically available wind and solar resources were dedicated to electrolysis, China could theoretically produce several billion tonnes of renewable hydrogen per year; almost all of this volume, however, would be generated far from existing coastal demand centres.[118]

[117] Meng, Xiang, Ming Chen, Ang Gu, Xinyu Wu, Bo Liu, Jian Zhou, and Bo Sun. 2022. *"China's Hydrogen Development Strategy in the Context of Double Carbon Targets."* Natural Gas Industry B 9(6): 521–547. P. 526. https://doi.org/10.1016/j.ngib.2022.11.004

[118] Wu, Jiawei, Jinyu Xiao, Jinming Hou, Jinxuan Zhang, Chen Jin, and Ruoyu Han. 2022. "*Generation Potential and Economy Analysis of Green Hydrogen in China."* In Proceedings of the 2022 IEEE 5th International Electrical and Energy Conference (CIEEC), 4477–4482. https://doi.org/10.1109/CIEEC54735.2022.9846489

Figure 3. Spatial Distribution of Solar Irradiation and Wind Power Density Across China

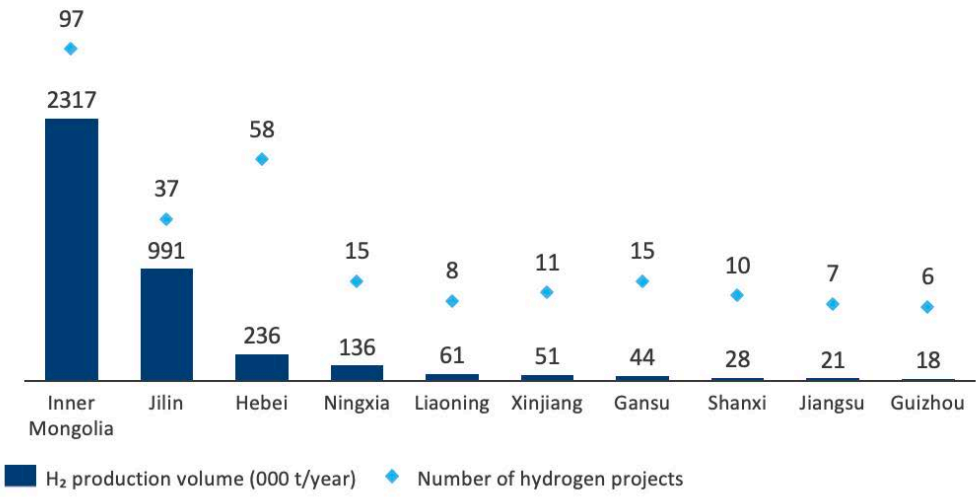


Source: Meng, Xiang. 2022. *"China's Hydrogen Development Strategy in the Context of Double Carbon Targets."*. Natural Gas Industry B 9(6). P. 526

Empirical deployment patterns up to 2023 confirm that early green hydrogen investment has gravitated towards these renewable-rich regions. By mid-2023, the combined volume of operational, under-construction and planned green/renewable hydrogen projects in China amounted to roughly 3.794 Mt per year, but about 93 per cent of this capacity remained at the planning or final-investment-decision stage, 4.9 per cent was under construction and only 1.9 per cent was already commissioned. [119] The spatial distribution of this pipeline is highly skewed. Inner Mongolia alone hosts ninety-seven hydrogen projects with a combined capacity of approximately 2.317 Mt per year—by far the largest provincial portfolio. Jilin in the north-east follows with thirty-seven projects totaling about 991 kt per year, while Hebei (fifty-eight projects; 236 kt), Ningxia (fifteen projects; 136 kt) and Liaoning (eight projects; 61 kt) form a second tier of emerging production hubs. Xinjiang's eleven projects amount to a more modest 50–60 kt per year, but several of them are already operating, reflecting an earlier wave of demonstration projects (Figure 4).

[119] International Energy Agency (IEA). 2023. "Hydrogen Production and Infrastructure Projects Database." Access at: https://www.iea.org/data-and-statistics/data-product/hydrogen-production-and-infrastructure-projects-database

Figure 4. Top 10 Provinces by Green H2 Production Volume as of 2023 (Operational, Under Construction and Planned Projects)



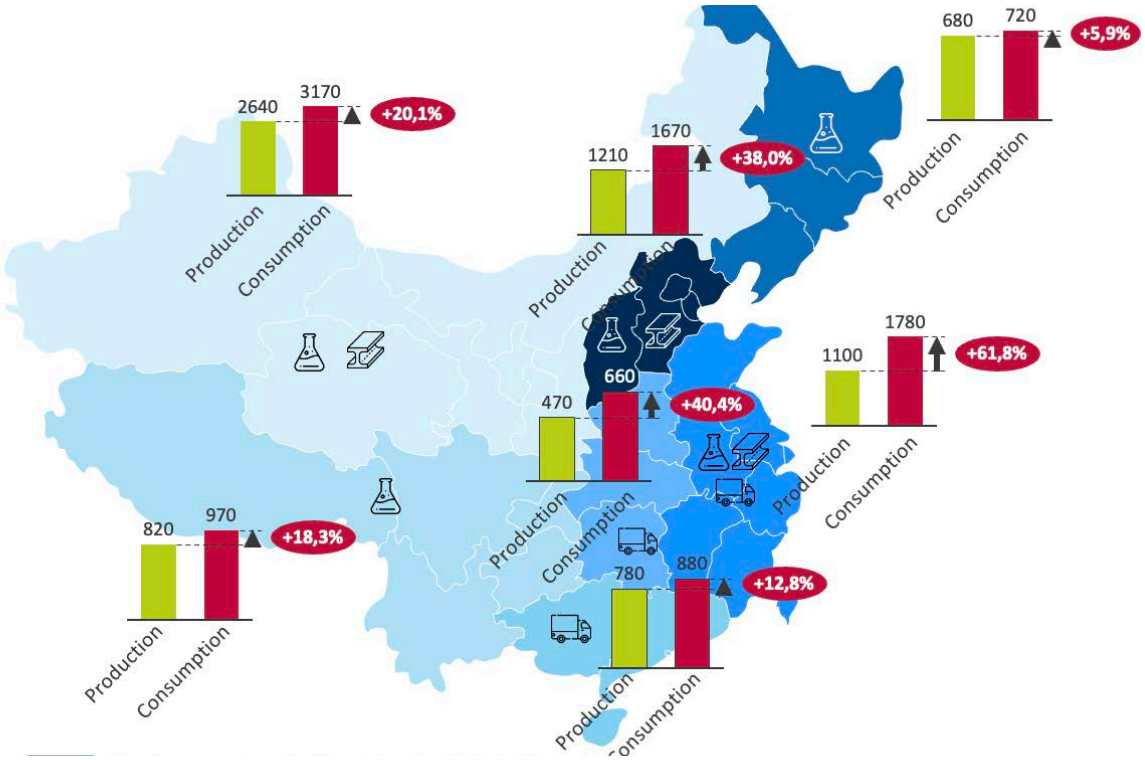
Source: Author based on IEA Hydrogen Production and Infrastructure Projects Database

Forward-looking modelling to 2030 suggests that these geographical concentrations will persist, but they will not make any region self-sufficient in green hydrogen. In the scenario used in this thesis, total green hydrogen production rises to around 7.7 Mt per year by 2030, while aggregate demand across industry and transport reaches approximately 9.85 Mt. The implied national deficit of about 2.15 Mt masks pronounced regional imbalances. At the macro-regional level, the north-western region is projected to supply 34 per cent of total green hydrogen output, owing to large wind–solar–electrolyser bases in Inner Mongolia, Gansu, Ningxia, Qinghai and Xinjiang, yet even these renewable-rich areas are expected to experience deficits once energy-intensive chemical and steel plants relocate inland in pursuit of lower electricity prices and corporate decarbonisation targets. [120] Eastern coastal provinces, by contrast, face the highest relative shortfall, with their combined consumption exceeding local green hydrogen production by roughly 61.8 per cent in 2030 despite some offshore wind and coastal electrolysis coming online.

[120] Rocky Mountain Institute (RMI) & China Hydrogen Alliance Research Institute. 2022. "*Renewable Hydrogen 100 Roadmap of China 2030"*. Beijing. P.21-45. Access at: https://rmi.org/wp-content/uploads/dlm_uploads/2022/09/china_green_hydrogen_new_era_renewable_hydrogen_roadmap.pdf

Other macro-regions—including the north, north-east, centre, south and south-west—also remain in deficit, although the magnitude of their gaps is smaller (Figure 5).

Figure 5. Map of Green H2 Production and Consumption in 2030
(by regions of China and main H2 application sectors, 000 tonnes per year)



Source: Author based on RMI. 2022. “Renewable Hydrogen 100 Roadmap of China 2030”

These findings have two implications for the structure of China’s hydrogen sector. First, because no macro-region is projected to become self-sufficient in green hydrogen by 2030, the country cannot rely on a simple division between a “producing hinterland” and a “consuming coast”. Instead, the emerging geography is likely to take the form of a mosaic of regional clusters in which local production facilities are tightly coupled to nearby anchor consumers—such as steel complexes, chemical hubs, or fuel-cell vehicle corridors—often within a single province or group of neighbouring provinces. Second, since overall hydrogen demand is much larger than the green hydrogen volumes foreseen for 2030, grey and, increasingly,

blue hydrogen will remain integral to the system. The International Energy Agency stresses that in the medium term coal-based hydrogen, equipped with high-performance carbon capture, utilisation and storage, will remain "vital for China to meet its climate change mitigation goals", and that China is "unlikely to become a major exporter of low-emission hydrogen," not least because national policy "prioritises self-sufficiency by building out a domestic supply chain" rather than targeting export markets. [121]

The international trade dimension is therefore best understood as complementary to, rather than constitutive of, China's hydrogen strategy. Policy documents such as the "Hydrogen Industry Development Plan (2021–2035)" and provincial hydrogen roadmaps focus overwhelmingly on domestic production, infrastructure and end-use pilots; unlike the strategies of the European Union, Japan or Korea, they do not articulate quantitative import targets or design specific mechanisms to facilitate hydrogen imports. Expert assessments echo this domestic orientation. A 2024 Columbia University study on China's renewable ammonia/hydrogen market notes that "many experts are convinced that China will primarily focus on being self-sufficient," arguing that large domestic renewable resources and industrial capabilities make heavy reliance on imported hydrogen unlikely, even though trade in low-carbon ammonia may expand at the margin.[122]

At the same time, several concrete and prospective projects illustrate how imports of blue and green hydrogen carriers could play a targeted role. In May 2023, the Saudi Arabian Mining Company Ma'aden exported its first shipment of certified low-carbon blue ammonia to China under an agreement to supply 25,000 tonnes to Shenghong Petrochemicals; the first cargo departed Ras Al Khair port on 18 May

[121] International Energy Agency (IEA). 2022. "*Opportunities for Hydrogen Production with CCUS in China*". Paris: International Energy Agency. Available at: https://www.iea.org/reports/opportunities-for-hydrogen-production-with-ccus-in-china.
[122] Lou, Yushan, Ray Hongliang Cai, Anne-Sophie Corbeau, and Zhiyuan Fan. 2024. "*Why China's Renewable Ammonia Market Is Poised for Significant Growth*." New York: Center on Global Energy Policy, Columbia University. Available at: https://www.energypolicy.columbia.edu/why-chinas-renewable-ammonia-market-is-poised-for-significant-growth/.

2023.[123] Subsequent reporting indicates that Ma'aden sees this contract as part of a broader plan to export more than 138,000 tonnes of blue ammonia to East Asian markets, including China. These flows are still minuscule compared with China's total hydrogen consumption, and they currently serve primarily as low-carbon feedstock for petrochemicals rather than transport fuels. Nonetheless, they demonstrate that full value chains—from certification and production in the Middle East to utilisation in Chinese industrial facilities—can be put in place at commercial scale.

Russia's Far East constitutes a second potential source of imported low-carbon hydrogen. Rosatom and Chinese partners such as China Energy Engineering Group and LS Group have signed memoranda of understanding for a hydrogen plant on Sakhalin Island, explicitly marketing liquefied hydrogen exports to China as a core objective.[124] While the commercial model and final investment decisions remain uncertain, the Sakhalin project illustrates how China may use cross-border hydrogen cooperation under broader energy and industrial agreements to diversify supply options without assuming the role of a structurally import-dependent buyer.

Australian projects add a further layer of optionality. Analyses by the International Renewable Energy Agency and other think tanks identify Australia as a likely exporter of green ammonia to North-East Asia, including China, in scenarios where its exceptionally low-cost solar and wind resources allow it to produce hydrogen more cheaply than coastal Chinese provinces even after accounting for shipping costs.[125] Large export-oriented projects in Western Australia, backed by multi-gigawatt wind and solar complexes and supported by the Australian government's Hydrogen Headstart scheme, are being designed with East Asian offtakers in mind; even where Chinese firms have not yet signed binding purchase

[123] Offshore Energy. 2023. "*Ma'aden Exports Its First Shipments of Blue Ammonia to China*." 19 May 2023. Available at: https://www.offshore-energy.biz/maaden-exports-its-first-shipments-of-blue-ammonia-to-china/.
[124] Interfax. 2022. "*Rosatom Structure and China's CEEC Plan to Start Exporting Low-Carbon Hydrogen from Sakhalin to China in 2025*." 6 September 2022. Available at: https://interfax.com/newsroom/top-stories/82867/.
[125] International Renewable Energy Agency (IRENA). 2022. "*Global Hydrogen Trade to Meet the 1.5°C Climate Goal: Part II – Technology Review of Hydrogen Carriers*". Abu Dhabi: IRENA.

agreements, associated investments in port and bunkering infrastructure along established iron-ore shipping routes effectively create the physical preconditions for future ammonia trade.

Taken together, these developments point towards a long-term equilibrium in which China remains predominantly reliant on domestic resources for hydrogen production but engages in selective international trade in low-carbon hydrogen and its derivatives. On the supply side, the country will continue to operate a very large grey hydrogen base, gradually retrofitting portions of coal- and gas-based capacity with CCUS to create blue hydrogen, while at the same time scaling green hydrogen production in inland renewable-rich provinces and, increasingly, in coastal and offshore wind regions. On the demand side, decarbonisation of ammonia, methanol, steel and, crucially, transport will drive up the need for low-emission hydrogen more rapidly than green supply can expand, at least during the 2020s and early 2030s. The resulting structural deficit will be managed primarily through domestic measures (continued use of grey and blue hydrogen, improved energy efficiency, and the construction of west–east hydrogen pipelines and carrier-based logistics), with international imports of blue or green ammonia and, potentially, liquefied hydrogen operating at the margin as cost-effective supplements in specific locations and sectors.

4.1.4 Economic Viability and Incentive Alignment

Hydrogen price formation in China reflects the interaction of very low-cost fossil routes, rapidly improving but still more expensive renewable pathways, non-trivial transport and distribution costs between inland production bases and coastal demand centers, and an increasingly complex layer of public support.

On the production side, the cheapest large-scale option remains coal-based hydrogen without carbon capture and storage (CCS). Bottom-up plant simulations

for 30 Chinese provinces estimate levelized costs of around 1.26 USD/kg[126] on average, with a provincial range of 0.90–1.46 USD/kg depending on coal prices and plant scale.[127] When post-combustion CCS is added, costs rise to roughly 1.88 USD/kg and up to 2.11 USD/kg in high-cost provinces, but the cost penalty is partly offset when carbon prices above 40 USD/tCO_2 are applied.[128] Independent engineering-economic work confirms that coal gasification yields the lowest levelized cost of hydrogen (LCOH) among major routes, at about 8.68 CNY/kg (≈1.24 USD/kg), compared with 22.27 CNY/kg (≈3.18 USD/kg) for natural-gas reforming and 17.97 CNY/kg (≈2.57 USD/kg) for hydrogen recovered as a by-product from coke-oven gas.[129] Sector-wide reviews report by-product hydrogen selling for as little as 5–8 CNY/kg (≈0.71–1.14 USD/kg), positioning it as a transitional low-carbon supply option so long as upstream emissions are regulated.

Renewable hydrogen produced by water electrolysis is substantially more expensive but displays wide variation depending on electrolyser technology and power source. A detailed comparison of electrolysis routes finds LCOH values of roughly 26.20 CNY/kg (≈3.74 USD/kg) for alkaline electrolysers (ALK) and 38.04 CNY/kg (≈5.43 USD/kg) for proton-exchange-membrane (PEM) systems under current Chinese conditions.[130] Cost-structure analysis shows that electricity accounts for around 60–65% of ALK LCOH and 58% for PEM, underscoring the centrality of power prices in Chinese green-hydrogen economics.[131] As illustrated in Figure 6, China's Renewable Hydrogen Competitiveness Index shows a fluctuating improvement of the renewable hydrogen price competitiveness in comparison to the

[126] To make values comparable, all yuan figures from the cited studies are converted here at an indicative rate of roughly 7 CNY per USD.
[127] Li, Jiaquan, Yi-Ming Wei, Lancui Liu, Xiaoyu Li, and Rui Yan. 2022. "*The Carbon Footprint and Cost of Coal-Based Hydrogen Production with and without Carbon Capture and Storage Technology in China*."Journal of Cleaner Production 362: 132514. P.2. https://doi.org/10.1016/j.jclepro.2022.132514.
[128] Ibid. P.3
[129] Guo, Kewen, Xu Yongjie, and Shi Ruijing. 2024."*3 种制氢技术路线的经济性分析 [Economic Analysis of Three Hydrogen Production Technology Routes]*." Electrical Engineering Technology 45(7): 4–14. https://doi.org/10.19768/j.cnki.dgjs.2024.07.009.
[130] Liang, Xiaojing, Hong Zufang, Xue Xingyu, Xie Xiaomin, and Huang Zhen. 2024. "*不同制氢路线的经济性分析及比较 [Economic Analysis and Comparison of Different Hydrogen Production Routes]*." Energy Chemical Industry 45(1). P. 32. https://doi.org/10.19768/j.cnki.dgj s.2024.01.0030-08.
[131] Ibid. P. 36

grey hydrogen price from late 2021 to 2024, reflecting declining renewable-power costs and increasing electrolyser efficiency — both key drivers behind the gradual reduction of green hydrogen production costs.

Figure 6. China's Renewable Hydrogen Competitiveness Index

Source: China Hydrogen Alliance (中国氢能联盟). 2025.《中国氢价指数年度报告（2025 年版）》 [China Hydrogen Price Index Annual Report (2025 Edition)].

Scenario studies specifically targeting renewable hydrogen confirm these levels while highlighting substantial regional and temporal spread. Using province-level power-system data and considering both grid mixes and dedicated renewables, Zhang et al. estimate that grid-connected electrolysis, including the cost of carbon emissions, produces hydrogen at 24.8–48.0 CNY/kg (≈3.54–6.86 USD/kg). [132] Another focused trend analysis of green hydrogen based on current project data finds that, even under today's technology parameters, renewable-based routes yield costs between 16.42 and 33.47 CNY/kg (≈2.35–4.78 USD/kg) across combinations of ALK, PEM, grid power and wind/solar farms, and that Northwest and North China

[132] Zhang, Wenzuo, Xinying Li, Jiezhi Yang, Jianguo Liu, and Chuanbo Xu. 2023. "*Economic Analysis of Hydrogen Production from China's Province-Level Power Grid Considering Carbon Emissions*." Clean Energy 7(1): 30–40. P. 38. https://doi.org/10.1093/ce/zkac091.

can already reach the lower end of this range thanks to low renewable-electricity prices and high full-load hours.[133] Brokerage modelling arrives at similar break-even conditions: when renewable-power prices fall to 0.2 CNY/kWh or below, green hydrogen becomes cost-competitive with coal-based hydrogen, especially in regions granted preferential tariffs or exempted from transmission fees.[134]

While techno-economic studies focus on production, actual market prices are captured by the China Hydrogen Price Index maintained by the China Hydrogen Alliance and operationalised through a formal index design in Liu et al. (2023). [135] The 2025 annual report indicates that the national weighted average ex-factory production price in 2024 was 27.99 CNY/kg (≈4.00 USD/kg), while the average terminal consumption price reached 48.57 CNY/kg (≈6.94 USD/kg).[136] Provincial cluster prices vary markedly: Guangdong's production price stands around 44.12 CNY/kg (≈6.30 USD/kg), Shanghai's at 26.38 CNY/kg (≈3.77 USD/kg), whereas Beijing–Tianjin–Hebei and inland hubs such as Hebei and Zhengzhou are closer to 23–26 CNY/kg (≈3.3–3.8 USD/kg). The spread between production and consumption prices, commonly exceeding 2–3 USD/kg, reflects the combined effect of storage, transport, retail margins and taxes.

Transport and storage costs are a key component of this wedge. A detailed techno-economic assessment of hydrogen logistics in China shows that for compressed gaseous hydrogen moved by 20 MPa tube trailers, the levelized cost of transport increases by about 3.44 CNY/kg for every additional 100 km (≈0.49 USD/kg/100 km).[137] For a 30 t/d liquid-hydrogen tanker, the corresponding increase

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[133] Luo, Yujie, and Li Nan. 2025. "*绿氢制备成本趋势分析 [Trend Analysis of Green Hydrogen Production Costs]*."Sino-Global Energy 30(2): 30–37. https://doi.org/10.19944/j.eptep.1674-8069.2024.05.001.

[134] Sinolink Securities (国金证券). 2024. "*氢能&燃料电池行业研究——绿氢经济性可期，高碳场景替代加速 [Hydrogen & Fuel Cell Industry Research — Green Hydrogen Economics Improving, High-Carbon Scenario Substitution Accelerates]."* Industry Research Report, February 2024.

[135] Liu, Wei, Yanming Wan, Yan Zhang, and Qi Liu. 2023. "*Design and Implementation of China Hydrogen Price Index System."* Clean Energy 7(1): 148–156. https://doi.org/10.1093/ce/zkad008.

[136] China Hydrogen Alliance (中国氢能联盟). 2025. *《中国氢价指数年度报告（2025 年版）》[China Hydrogen Price Index Annual Report (2025 Edition)]*.Beijing: China Hydrogen Alliance.

[137] 氢能源与燃料电池. 2023. "氢气的输运情况与经济性分析 [Analysis of Hydrogen Transport Conditions and Economics]." Published September 10, 2023. Access at: http://www.360doc.com/content/12/0121/07/39942325_1095879204.shtml.

is only 0.27 CNY/kg per 100 km (≈0.04 USD/kg), while dedicated hydrogen pipelines add roughly 0.41 CNY/kg per 100 km (≈0.06 USD/kg). At a delivery distance of 600 km, the levelized cost of transport for liquid hydrogen rises from 5.89 to 7.37 CNY/kg (≈0.84–1.05 USD/kg), illustrating both the lower distance-sensitivity of cryogenic tankers and the high absolute cost of small-scale liquid-hydrogen logistics.[138] The accompanying qualitative assessment stresses that high-pressure tube trailers, though technologically mature and widely deployed, are suited mainly to short-range distribution to refuelling stations, whereas pipelines are preferable for long-distance, high-volume flows between inland production bases and coastal demand clusters. Engineering tables comparing gaseous, liquid and pipeline transport modes highlight trade-offs in volumetric density, pressure requirements, energy efficiency and safety constraints.

At the international frontier, imported hydrogen carried in liquid organic hydrogen carriers such as methylcyclohexane–toluene (MCH–TOL) appears potentially competitive with domestic green hydrogen in high-cost coastal regions. For a representative supply chain exporting hydrogen to China via MCH–TOL, the levelized cost of hydrogen at the exporter's plant gate lies between 16.49 and 21.35 CNY/kg (≈2.36–3.05 USD/kg), while the delivered cost at the Chinese terminal, including shipping, storage and dehydrogenation, is 26.02–28.59 CNY/kg (≈3.72–4.08 USD/kg). [139]

State Incentives for Hydrogen Cost Reduction

Beyond techno-economic fundamentals, the effective price of hydrogen in China is increasingly shaped by a dense layer of public support measures that target both capital expenditure and operating expenditure along the value chain. These

[138] Ibid.
[139] Zhang, Wenzuo, Xinying Li, Jiezhi Yang, Jianguo Liu, and Chuanbo Xu. 2023. "*Economic Analysis of Hydrogen Production from China's Province-Level Power Grid Considering Carbon Emissions*." Clean Energy 7(1): 30–40. P. 35. https://doi.org/10.1093/ce/zkac091.

policies are designed to close the cost gap between coal-based and green hydrogen and to accelerate deployment in priority end-use sectors relevant for transport.

A first pillar consists of CAPEX-oriented subsidies and investment support. System-dynamics simulations for China's green-hydrogen sector suggest that, in an early deployment phase, investment grants covering around 35–40% of initial electrolyser and storage-equipment costs can markedly improve project profitability and installed capacity growth over the first five years, especially when coupled with preferential corporate-income-tax rates for designated high-tech enterprises.[140] In the model, subsidy intensity is then gradually reduced by 5–10 percentage points every one to two years, so that support falls below 5% of CAPEX and phases out entirely after roughly 10–15 years, once economies of scale have lowered the LCOH.[141]

Concrete local policies illustrate how these principles are operationalised. The Changping District of Beijing, which positions itself as a hydrogen innovation hub, offers a suite of CAPEX-related measures: enterprises undertaking major hydrogen R&D projects can receive district-level top-ups equal to 10–20 % of their nationally or municipally funded project budgets, up to CNY 20 million per firm per year; firms purchasing fuel-cell and hydrogen components for large-scale applications can obtain a 5% subsidy on actual procurement expenditures above CNY 10 million, capped at CNY 10 million annually. The district also supports laboratory and testing-centre construction with lump-sum grants of CNY 200 million for national-level and CNY 20 million for municipal-level platforms, and it underwrites mergers, listings and dedicated hydrogen investment funds, thereby indirectly lowering financing costs for capital-intensive projects.[142]

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[140] Li, Jiaquan, Yi-Ming Wei, Lancui Liu, Xiaoyu Li, and Rui Yan. 2022. "*The Carbon Footprint and Cost of Coal-Based Hydrogen Production with and without Carbon Capture and Storage Technology in China*."Journal of Cleaner Production 362: 132514. P.5. https://doi.org/10.1016/j.jclepro.2022.132514.

[141] Ibid. P.5

[142] Beijing Changping District People's Government (北京市昌平区人民政府). 2023.《*昌平区促进氢能产业创新发展支持措施》[Support Measures for Promoting Hydrogen-Industry Innovation in Changping District]*. Beijing: Beijing Changping District Government.

The second pillar is production-side OPEX support linked either to hydrogen output or to electricity consumption. Because electricity accounts for 50–70% of green-hydrogen production cost, modest adjustments in the power tariff can translate into substantial changes in LCOH. Li et al. model three scenarios where the dedicated electricity price for hydrogen production is subsidised to 0.25–0.30 CNY/kWh compared with higher baseline tariffs; lower power prices significantly accelerate capacity build-up when combined with investment grants and tax relief.[143] In parallel, several "Three North" provinces have introduced direct per-kilogram subsidies for renewable-hydrogen production. Sinolink Securities' industry report documents production-side subsidies of 3–12 CNY/kg for projects in Inner Mongolia, Gansu, Jilin, Xinjiang and Dalian, explicitly calibrated so that subsidised green hydrogen reaches cost parity with coal-based hydrogen.[144]

RMI's green-hydrogen investment study provides further granularity by examining industrial offtake contracts. For the Ningdong coal-chemical base in Ningxia, a dedicated policy issued in 2024 offers a green-hydrogen consumption subsidy of 5.6 CNY/kg (about 0.8 USD/kg), up to CNY 5 million per enterprise per year and for a maximum of three years, for chemical plants replacing coal-based hydrogen or methanol feedstock with certified green hydrogen.[145] Building on this benchmark, the report assumes an "industrial green-hydrogen subsidy" that gradually declines towards zero by 2040 in its parity scenarios for steel, ammonia and methanol, where industrial users internalise a portion of the climate benefit while relying on policy support to bridge the interim cost gap. Together, these production-side subsidies can shave roughly 1 USD/kg or more off the effective cost

[143] Li, Jiaquan, Yi-Ming Wei, Lancui Liu, Xiaoyu Li, and Rui Yan. 2022. "*The Carbon Footprint and Cost of Coal-Based Hydrogen Production with and without Carbon Capture and Storage Technology in China*."Journal of Cleaner Production 362: 132514. P.5. https://doi.org/10.1016/j.jclepro.2022.132514.
[144] Sinolink Securities (国金证券). 2024. "*氢能&燃料电池行业研究——绿氢经济性可期，高碳场景替代加速 [Hydrogen & Fuel Cell Industry Research — Green Hydrogen Economics Improving, High-Carbon Scenario Substitution Accelerates]."* Industry Research Report, February 2024.
[145] Lu, Yujie, Nan Li, and colleagues. 2025. "*气候科技初创企业投资观察系列：绿氢产业各环节技术发展和投–融资趋势解析 [Climate-Tech Startup Investment Observation Series: Technology Development and Investment Trends Across the Green Hydrogen Value Chain]".* Beijing: 氢能源与燃料电池 / Hydrogen Energy & Fuel Cells.

of green hydrogen in targeted clusters, depending on baseline electricity prices and electrolyser utilisation rates.

A third layer of support targets infrastructure and downstream transport applications, thereby affecting the delivered hydrogen price facing mobility users. Using an evolutionary-game framework, the "Hydrogen refueling station subsidy strategy" study compares static and dynamic subsidy regimes for hydrogen refuelling stations and fuel-cell-vehicle purchases. In the preferred dynamic regime, average per-station capital subsidies in the first 40 decision periods are slightly above CNY 3 million (around 0.4 million USD) and then gradually decline as market volumes increase; compared with a static subsidy, this design raises average FCEV purchases by 27.8% and HRS construction effort by about 28–29%.[146] Changping's local rules again provide a concrete illustration: the district plans to support the construction of 10–15 hydrogen refuelling stations and oil–hydrogen hybrid stations in priority corridors, offering district-level co-funding equal to 20% of the municipal construction subsidy and, for stations that have been operating since 2022, an operating subsidy of 5 CNY/kg of dispensed hydrogen (about 0.7 USD/kg).[147] Additional vehicle-side incentives include mileage-based operating rewards of 0.2–0.5 CNY per kilometre for light- and heavy-duty FCEVs, capped at CNY 10,000–30,000 per vehicle per year, which effectively recycle a portion of station and production subsidies to fleet operators and lower total cost of ownership in logistics segments. RMI's policy inventory shows that similar combinations of fixed-asset grants, per-kilogram sales subsidies and toll-fee rebates for hydrogen trucks are now present in dozens of provinces, with some jurisdictions also subsidising distributed

[146] Wang, Yu, Chen Jia, and Chen Xue. 2021. *"Hydrogen Refueling Station Subsidy Strategy".* International Journal of Hydrogen Energy 46(63): 18455–18465.
[147] Beijing Changping District People's Government (北京市昌平区人民政府). 2023.《*昌平区促进氢能产业创新发展支持措施》[Support Measures for Promoting Hydrogen-Industry Innovation in Changping District]*. Beijing: Beijing Changping District Government.

fuel-cell generation and storage assets that share infrastructure with transport applications. [148]

Taken together, techno-economic cost drivers and layered subsidy instruments jointly determine hydrogen prices in China. Production-side LCOH for green hydrogen has already fallen to roughly 2.3–4.8 USD/kg in favourable inland locations, yet delivered prices in coastal demand centres still approach 7 USD/kg once storage, transport and retail margins are included, even after subsidies. Investment grants and concessional finance reduce upfront capital intensity for electrolysers and refuelling stations; production-linked per-kilogram subsidies and discounted electricity tariffs directly lower OPEX and LCOH; and vehicle- and infrastructure-side incentives compress the delivered price spread between fossil-based and green hydrogen faced by transport users. The differential between ex-factory and consumption prices thus reflects not only technical constraints in hydrogen logistics and the current spatial mismatch between resource-rich inland regions and coastal mobility demand, but also the design, duration and coordination of subsidy regimes—factors that will critically shape the economic viability of hydrogen-based transport in China over the coming decade.

4.1.5 Infrastructure Readiness and Spatial Integration

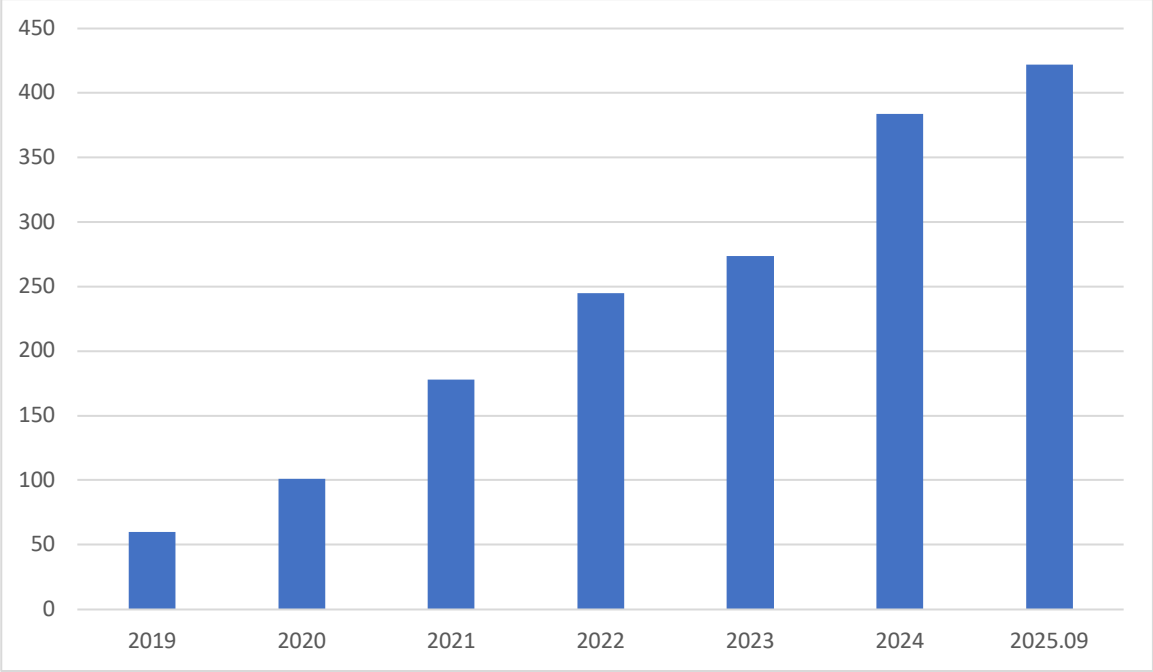
Hydrogen Refueling Station Network in China

Over the past decade, China has moved from a handful of demonstration sites to the world's largest network of hydrogen refueling stations, making refueling infrastructure a central pillar of its broader hydrogen-for-transport strategy. Data show that the number of operational HRS rose from about 60 stations in 2019 to 422 operational stations out of 567 completed by September 2025 (Figure 7). Over the

[148] Lu, Yujie, Nan Li, and colleagues. 2025. "*气候科技初创企业投资观察系列：绿氢产业各环节技术发展和投–融资趋势解析 [Climate-Tech Startup Investment Observation Series: Technology Development and Investment Trends Across the Green Hydrogen Value Chain]".* Beijing: 氢能源与燃料电池 / Hydrogen Energy & Fuel Cells.

same period, cumulative daily supply capacity increased from 20.8×10⁴ kg H_2/d to 35.8×10⁴ kg H_2/d. [149]

Figure 7. Number of HRS in operation in China

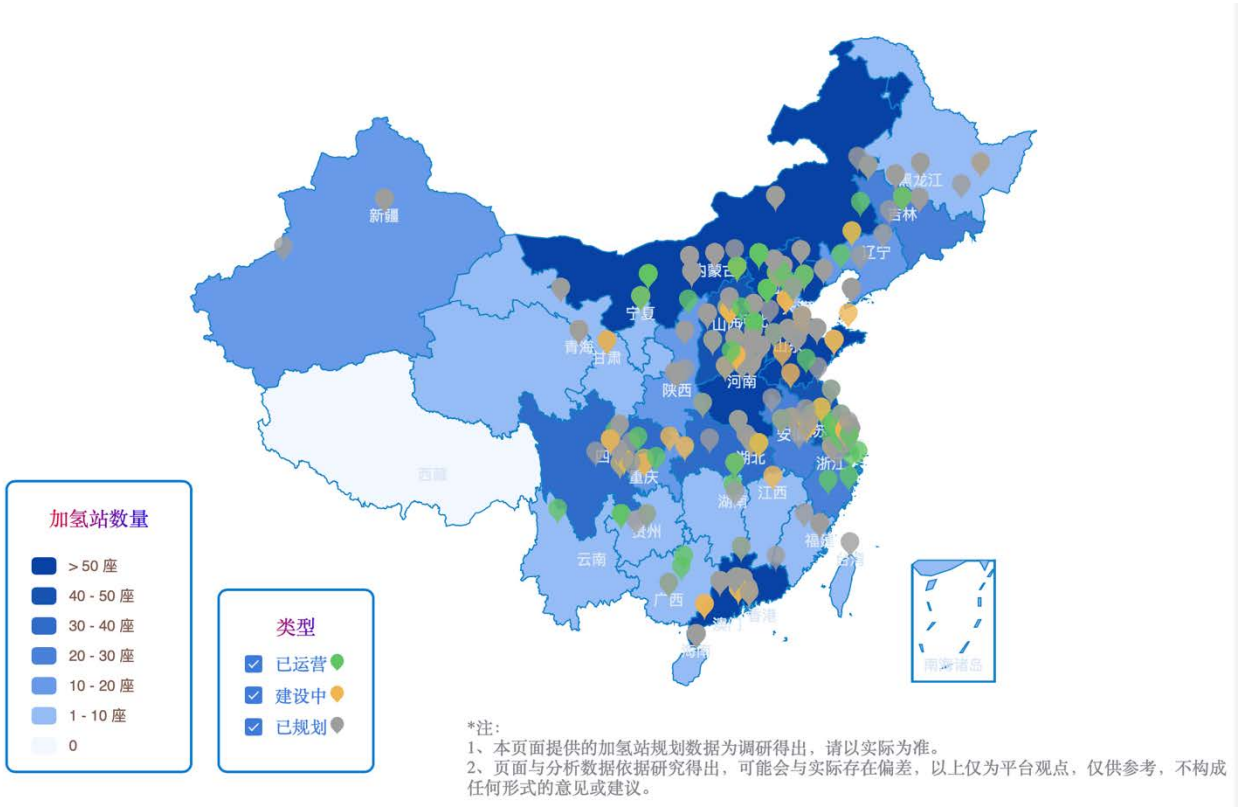


Source: Author, based on China Hydrogen Alliance Research Institute

The geographical pattern of this build-out is highly uneven and closely tied to demonstration programmes and industrial demand. By September 2025, the network had reached 31 provinces, with Tibet as the only remaining gaps; the top five provinces were now Guangdong, Hebei, Shandong, Henan and Zhejiang, with their combined share remained virtually unchanged at 45.8% (Figure 8).[150] This pattern points to a corridor-oriented development model. Stations are concentrated in coastal industrial clusters (Pearl River Delta, Bohai Rim, Yangtze River Delta) and selected inland logistics hubs, rather than being distributed evenly across the national territory.

[149] China Hydrogen Alliance Research Institute. 2025. "*氢能产业观察：2025 年 9 月刊 [Hydrogen Industry Observation: September 2025 Issue].*" Beijing: China Hydrogen Alliance Research Institute.
[150] Ibid.

Figure 8. Geographical distribution of hydrogen refueling stations in China (operational, under construction and planned)



Source: China H2 Data

Viewed against global benchmarks, this domestic expansion cements China's position as the single largest HRS market. The H2stations.org database compiled by Ludwig-Bölkow-Systemtechnik reports that 1,160 hydrogen refuelling stations were in operation worldwide at the end of 2024, 384 of which were located in China; in other words, China alone accounted for roughly one-third of all operational HRS globally.[151] H2stations.org data also suggests that in Europe and Japan a far larger share of HRS is designed around 70 MPa refuelling for passenger fuel cell vehicles, while only a subset is configured for heavy-duty refuelling. [152] In contrast, the prevalence of 35 MPa and high-capacity (>1,000 kg/d) stations in China reflects

[151] LBST (Ludwig-Bölkow-Systemtechnik GmbH). 2025. "*Milestone Reached: Over 1,000 Hydrogen Refuelling Stations in Operation Worldwide in 2024.*" Press Release, 11 February 2025. Munich: LBST / H2stations.org.
[152] Zero Emission Freight Initiative (ZEFI). 2025. *"氢燃料重卡的应用进展和推广建议研究报告 [Research Report on the Application Progress and Promotion Suggestions of Hydrogen Fuel Heavy Trucks]."* Beijing: Zero Emission Freight Initiative Secretariat, Smart Freight Centre China.

deliberate policy choices that prioritise buses and heavy-duty trucks over private cars, in line with national narratives that position fuel cells as a solution for "hard-to-electrify" segments of road transport.

Despite this impressive build-out, utilisation and economic performance remain problematic. ZEFI's fieldwork in major demonstration regions finds that many stations operate far below their technical capacity, with typical utilisation rates below 30% and some Guangdong and Hebei sites dispensing well under 100 kg/d, rendering them structurally loss-making.[153] High delivered hydrogen prices are a key driver: national price indices compiled by the China Hydrogen Alliance indicate retail prices in the range of roughly 45–55 CNY/kg in 2024–2025, even after a noticeable decline from earlier peaks, and logistics expenditures—compression, transport and storage—can account for 20–50% of terminal costs. Because large renewable hydrogen projects are concentrated in resource-rich north-west regions, whereas most HRS and vehicle fleets are situated in coastal and central provinces, spatial mismatches between production sites and demand centers further inflate logistics costs and complicate long-distance supply chains.

Hydrogen Transport and Storage Infrastructure

As mentioned above, China's hydrogen economy is fundamentally shaped by a structural spatial mismatch: large-scale renewable and by-product hydrogen production is concentrated in the resource-rich northern and western provinces, while most end-use demand—particularly in mobility, refining, and chemical industries—is located in the coastal metropolitan regions. This geographic imbalance makes long-distance transmission not merely an option but a necessary backbone of national hydrogen development. As multiple techno-economic studies demonstrate, dedicated hydrogen pipelines and hydrogen-compatible gas networks become the most cost-effective transport mode once flows reach industrial scale and

[153] Zero Emission Freight Initiative (ZEFI). 2025. *"氢燃料重卡的应用进展和推广建议研究报告 [Research Report on the Application Progress and Promotion Suggestions of Hydrogen Fuel Heavy Trucks]."* Beijing: Zero Emission Freight Initiative Secretariat, Smart Freight Centre China.

distances extend into the hundreds of kilometres, outperforming truck-based delivery in both efficiency and marginal cost.

Despite its importance China's dedicated hydrogen pipeline (HGP) network is underdeveloped and highly fragmented. The length of pure hydrogen pipelines in operation is only around 120 km, while approximately 1,328 km are under construction. A single cross-regional trunk line, the 400 km Wulanchabu–Beijing pipeline designed for up to 500,000 tonnes H_2 per year, links Inner Mongolia's wind and solar resources with the Beijing–Tianjin load centre; all other existing lines are short segments around refineries and chemical bases, typically 4–160 km in length. [154] According to the industry planning, China Petroleum Pipeline Engineering Corporation has outlined a 6,000 km integrated hydrogen pipeline network by 2050, explicitly designed to move hydrogen from the northwest and north to eastern coastal markets around Beijing, Tianjin and Shanghai. [155]

Table 2. Existing and Planned Hydrogen Pipelines in China

No.	**Pipeline Name**	**Status**	**Commissioning Year**	**Length (km)**	**Capacity (t H_2/year)**
1	Jinling–Yangzi	In operation	2007	32	40,000
2	Bailing–Changling	In operation	2014	42	44,200
3	Jiyuan–Luoyang	In operation	2015	25	100,400
4	Dingzhou–Gaobeidian	Under construction	2025	164.7	100,000
5	Shanghai	In operation	2023	4	5,040
6	Yumen Oilfield	In operation	2022	5.77	7,000

[154] Wu, Wei-Ping, Ke-Xing Wu, Wei-Kang Zeng, and Peng-Cheng Yang. 2022. "Optimization of Long-Distance and Large-Scale Transmission of Renewable Hydrogen in China: Pipelines vs. UHV." International Journal of Hydrogen Energy 47 (58): 24635–24650. https://doi.org/10.1016/j.ijhydene.2021.10.066

[155] Onyango, Daniel. 2023. "*China Plans 6,000-Kilometer Integrated Pipeline Network to Meet Soaring Hydrogen Demand."* Pipeline Technology Journal, June 9, 2023. Access at: https://www.pipeline-journal.net/news/china-plans-6000-kilometer-integrated-pipeline-network-meet-soaring-hydrogen-demand

7	Wuhai–Hohhot	Under construction	Dec. 2023	500	–
8	Wulanchabu–Beijing	Under construction	June 2027	400	100,000–500,000
9	Ningxia Energy and Chemical Base	In operation	2022	1.2	–
10	Shandong	Under construction	–	100	–
11	Damao	Under construction	–	159	100,000
17	Tongliao	Under construction	2025	4.7	–
18	Ningxia Ningdong Natural Gas Demonstration Project	In operation	2022	7.4	–

Source: Author, based on Internet research

Given the limited length of pure hydrogen pipelines, blending hydrogen into the existing natural gas network has emerged as a pragmatic bridge solution. A demonstration on the 397 km Ningxia Ningdong gas pipeline achieved stable operation with up to 24% hydrogen by volume, confirming both technical feasibility and safety over 100 days of continuous operation. With China's oil and gas grid reaching 185,000 km by 2022, a nationwide blending share of 20% could theoretically move more than 10 Mt of hydrogen annually, equivalent to over 560

TWh of green electricity, if separation technologies at the demand side mature sufficiently. [156]

Hydrogen storage in China is currently concentrated in above-ground compressed-gas tanks at refineries, industrial parks and hydrogen refuelling stations, complemented by limited amounts of liquefied hydrogen and metal-hydride or liquid-organic hydrogen carrier systems at the demonstration stage.[157] Large-scale geological storage is only beginning to emerge. In 2024 China started building its first deep underground cavern hydrogen storage facility, designed to store several thousand tonnes of renewable hydrogen at depths of more than one kilometre, signalling a shift towards seasonal and strategic storage options similar to European salt-cavern projects. [158]

Electrolysers as Core Supply-Side Infrastructure

Electrolysers are a foundational element of China's hydrogen infrastructure because they define where, at what scale and at what cost low-carbon hydrogen can be produced, thereby shaping all subsequent transport and storage needs. Analysing China's electrolyser technologies, manufacturing base and spatial deployment is therefore a necessary first step to assess the country's overall infrastructure readiness for scaling hydrogen use in the transport sector.

China's electrolyser segment has evolved from a niche equipment market into a central pillar of the country's hydrogen infrastructure, with manufacturing capacity, deployment volumes and technological performance all scaling rapidly. Patent data show that China has become the single largest locus of electrolyser-related invention activity, accounting for 6,383 out of 10,894 water electrolysis patent families

[156] Bai, Fanlong, Fuquan Zhao, Xinglong Liu, Zhexuan Mu, Han Hao, and Zongwei Liu. 2023. "*A Techno-Economic Analysis of Cross-Regional Renewable Hydrogen Supply Routes in China."* International Journal of Hydrogen Energy 48 (95): 37031–37044. https://doi.org/10.1016/j.ijhydene.2023.06.048
[157] Xie, Zhenyu, et al. 2024. "*A Review of Hydrogen Storage and Transportation.*" Energies 17 (16): 4070. Accessed November 17, 2025. https://www.mdpi.com/1996-1073/17/16/4070
[158] Wu, Jian. 2024. "*China Started Construction of Its First Deep Underground Cavern Hydrogen Storage Facility."* China Hydrogen Bulletin (Substack), January 24, 2024. Access at: https://chinahydrogen.substack.com/p/china-started-construction-of-its

published worldwide between 2005 and 2020, even if 97% of these filings are still aimed only at the domestic market.[159] This reading is consistent with market analysts' assessments that Chinese electrolyser systems are already 70–75% cheaper to purchase than Western equivalents while offering comparable efficiency, positioning China as a likely global cost setter if quality and reliability challenges can be systematically addressed. [160]

According to the 2025 China Green Hydrogen Industry Development Blue Book compiled by the Gaogong Hydrogen Power Industry Research Institute, by May 2025 China had already commissioned more than 1.2 GW of electrolyser capacity in operating green hydrogen projects, while projects under construction and formally announced plans together exceeded 110 GW of planned hydrogen production capacity. [161] The same report estimates that domestic electrolyser shipments in 2024 reached around 1.1 GW (including exports but excluding R&D prototypes) and are meant to accelerate to more than 22 GW by 2030, implying a compound annual growth rate above 60% and an expansion of the domestic electrolyser systems market from roughly CNY 2 billion in 2024 to over CNY 22 billion by 2030. [162] In global perspective, these volumes are systemically significant: by September 2024 the world had only about 1.75 GW of operating water-electrolysis capacity in total, of which roughly 1.15 GW—or 65%—was located in China, while Chinese plants accounted for around 40% of the 26 GW of global electrolyser manufacturing capacity that had reached final investment decision. [163]

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[159] International Renewable Energy Agency (IRENA) and European Patent Office (EPO). 2022. "*Innovation Trends in Electrolysers for Hydrogen Production: Patent Insight Report"*. Abu Dhabi and Munich: IRENA and EPO. Access at: https://www.irena.org/publications/2022/May/Innovation-Trends-in-Electrolysers-for-Hydrogen-Production

[160] Collins, Leigh. 2023. *"Chinese Are Catching Up Technologically': Longi's New Hydrogen Electrolyser Is More Efficient than Almost Anything Made in the West."* Hydrogen Insight, 21 February 2023. Access at: https://www.hydrogeninsight.com/electrolysers/chinese-are-catching-up-technologically-longi-s-new-hydrogen-electrolyser-is-more-efficient-than-almost-anything-made-in-the-west/2-1-1407074

[161] Gaogong Hydrogen Power Industry Research Institute (GGII, 高工氢电产业研究所). 2025. "*2025 中国绿氢产业发展蓝皮书 [2025 China Green Hydrogen Industry Development Blue Book]"*. Shenzhen: Shenzhen Gaogong Consulting Co., Ltd. P. 9

[162] Ibid. P. 13

[163] Asia Pacific Energy Research Centre (APERC). 2025. "*APERC Hydrogen Report 2024"*. Tokyo: Asia Pacific Energy Research Centre. P. 17-20. Access at: https://aperc.or.jp/file/2025/3/18/APERC_Hydrogen_Report_2024_final.pdf

From a technological standpoint, China's domestic electrolyser fleet remains dominated by alkaline systems, but PEM and advanced alkaline models are gaining ground. GGII estimates that alkaline units accounted for more than 91% of domestic shipments in 2024, yet PEM shipments almost tripled to around 90 MW, raising their market share from roughly 3% to 8% in a single year, reflecting batch deliveries to multi-megawatt wind-solar-to-hydrogen demonstration projects.[164] The appeal of PEM technology lies in its compact design, high current densities (above 2 A/cm²), rapid load-following capability and the production of very high-purity hydrogen, all of which are advantageous for coupling with variable renewables and supplying fuel-cell transport applications, even though reliance on noble-metal catalysts still makes PEM systems more expensive than alkaline units. At the same time, Chinese manufacturers are pushing down the specific electricity consumption of alkaline stacks: Longi's ALK Hi1 and Hi1 Plus series report full-load DC consumption as low as 4.0–4.3 kWh/Nm³, compared with a typical 4.5–4.6 kWh/Nm³ for mainstream alkaline and PEM units; Longi estimates that each reduction of 0.1 kWh/Nm³ lowers LCOH by roughly 1.8–2.2% and can cut initial equipment investment needs by 10–25%.[165] Such efficiency gains are particularly relevant for green hydrogen dedicated to transport, where electricity costs per kilogram of hydrogen are a major determinant of delivered fuel prices.

The industrial structure of China's electrolyser sector is highly concentrated but rapidly evolving as new entrants arrive from adjacent clean-energy value chains. A China Hydrogen Bulletin analysis of 2022–2023 shipments finds that the top three producers account for roughly 73% of the domestic market, led by Cockerill Jingli Hydrogen, with other leading positions occupied by firms such as Peric Hydrogen and Longi Hydrogen.[166] At the same time, Chinese solar and inverter champions are

[164] Gaogong Hydrogen Power Industry Research Institute. 2025. P. 16-18
[165] Jiaan Hydrogen Source (佳安氢源). 2023. *"深度分析！一文了解制氢电解槽国内竞争格局 [In-Depth Analysis: Understanding the Domestic Competitive Landscape of Hydrogen Electrolyser Manufacturing in One Article]*." Zhihu Zhuanlan, 5 May 2023. Access at: https://zhuanlan.zhihu.com/p/627021493
[166] China Hydrogen Bulletin. 2023. "*Top 3 Electrolyzer Producers Hold 73% China Market, New Enters Booming."* China Hydrogen Bulletin (Substack newsletter). Access at: https://chinahydrogen.substack.com/p/top-3-electrolyzer-producers-hold China Hydrogen

rapidly building gigawatt-scale lines: Sungrow has announced an expansion of electrolyser production capacity to around 3 GW in Hefei, while Trina Green Hydrogen has broken ground on a 1.5 GW alkaline electrolyser facility in Jiangsu. [167] [168]

Taken together, the evidence on refuelling stations, transport and storage and manufacturing capacity suggests that China has moved from pilot experimentation to an emerging but structurally uneven hydrogen infrastructure system. On the one hand, the rapid build-out of hydrogen refuelling stations, with a clear shift towards high-throughput 35 MPa sites serving buses and heavy-duty trucks, underpins China's quantitative lead in global HRS deployment and enables corridor-based hydrogen mobility in a growing number of coastal and central provinces. In parallel, China has built an electrolyser manufacturing base whose nameplate capacity already exceeds current domestic deployment needs, yet aligns with scenarios of rapid green hydrogen scale-up in power, industry and, eventually, transport. On the other hand, the network's concentration in a few urban–industrial clusters, combined with the early stage of dedicated pipeline and large-scale storage projects, means that hydrogen access remains highly segmented. Spatial modelling and policy planning consistently assume renewable and by-product hydrogen production in the resource-rich northwest and major transport and industrial demand in coastal metropolitan regions, so that long-distance transmission is not a marginal option but a structural condition for any large-scale hydrogen use in mobility and refining.

4.1.6 Market Uptake and Transport Implementation

This section assesses how far China has progressed in deploying hydrogen in the transport sector, focusing on (i) the evolution and structure of the fuel cell vehicle fleet, (ii) regional deployment patterns, (iii) the industrial ecosystem of vehicle and

[167] China Hydrogen Bulletin. 2023. "*Sungrow to Expand Electrolyser Production Capacity to 3GW."* China Hydrogen Bulletin (Substack newsletter). Access at: https://chinahydrogen.substack.com/p/sungrow-to-expand-electrolyser-production China Hydrogen

[168] China Hydrogen Bulletin. 2023. "*Trina Broke Ground for 1.5GW ALK Electrolyser Manufacturing Facility in Jiangsu.*" China Hydrogen Bulletin (Substack newsletter). Access at: https://chinahydrogen.substack.com/p/trina-broke-group-for-15gw-alk-electrolyser China Hydrogen

component manufacturers, (iv) the size of investments into hydrogen transportation projects, (v) the extent to which transport applications actually use low-carbon and green hydrogen, and (vi) early pilots in rail, shipping and aviation.

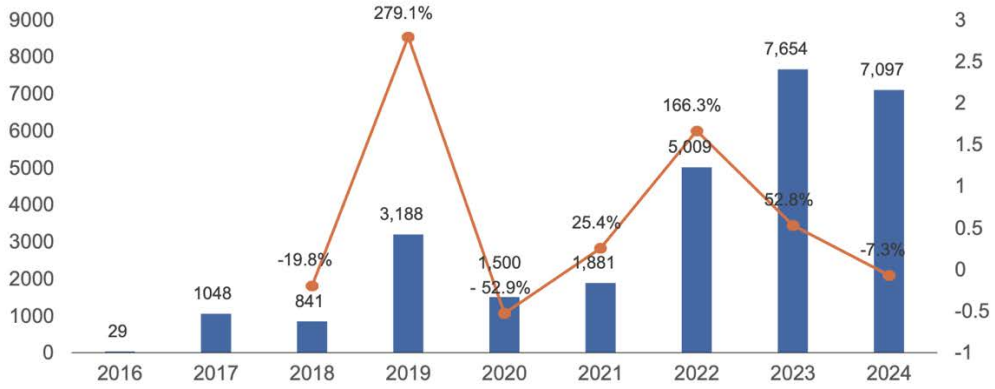
Fleet Evolution and Segment Structure

China's FCV market remains small in absolute terms and highly concentrated in commercial applications, but it has grown from a niche demonstration activity to a modest, policy-driven segment. According to the China Fuel Cell Vehicle Industry Development White Paper 2025, annual FCV sales peaked at 7,654 vehicles in 2023 and slipped slightly to 7,097 vehicles in 2024, bringing the cumulative stock to 28,247 vehicles (Figure 9). [169] According to the Global Hydrogen Review 2025 by the International Energy Agency, the global stock of fuel cell electric vehicles surpassed 100 000 units by 2024, which means that China accounts for roughly 27–30% of this global fleet. Despite this leading position, China remains significantly below its own policy target: the national Hydrogen Energy Industry Medium- and Long-Term Development Plan (2021–2035) set a goal of around 50 000 FCEVs by 2025, meaning current deployment reaches only about 56% of the intended level. [170]

[169] Wang, Shengke, Meimei Li, Siwen Wang, Yanxin Bao, Hao Wang, and Lei Chen. 2025. "*中国燃料电池汽车产业发展白皮书（2025 年）[China Fuel Cell Vehicle Industry Development White Paper 2025]".* Guangzhou: Xiangchenghui Research Institute (香橙会研究院). P. 33

[170] International Energy Agency (IEA). 2025. "*Global Hydrogen Review 2025".* Paris: International Energy Agency. P. 56. Access at: https://iea.blob.core.windows.net/assets/a6c466dd-b6f0-44bd-a60a-6940eccfb1c3/GlobalHydrogenReview2025.pdf.

Figure 9: Fuel Cell Vehicle (FCV) Sales in China



Source: China Fuel Cell Vehicle Industry Development White Paper 2025

More then that, FCVs remain a very small share of China's overall vehicle fleet and of new energy vehicle sales, which are dominated by battery-electric and plug-in hybrid cars. The White Paper 2025 shows that monthly NEV passenger car sales in 2024 routinely exceeded 700,000 battery-electric units and over 200,000 plug-in hybrids, while monthly FC passenger car sales typically remained in the single-digit or tens range. Hydrogen is yet a niche, targeted decarbonisation strategy in transport rather than a mass-market alternative to batteries.

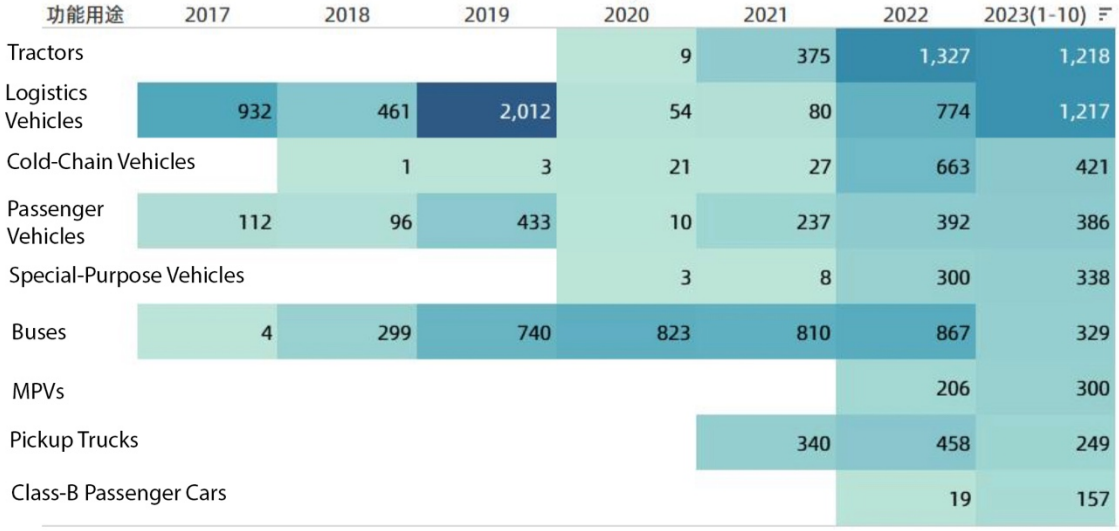
Both the industry-analyst reports from LeadLeo Research Institute and TrendBank emphasise that China has pursued a clear "commercial-vehicles first" (including light commercial vehicles, medium-duty and heavy-duty trucks) strategy in deploying fuel-cell vehicles. The available data show that in 2024 the dominant sub-segments were tractor units and special-purpose vehicles, which together accounted for 78.8 % of FCV sales (Figure 10). [171] [172] FC passenger cars remain marginal: in 2024, Haima's 7X FCV sold 22 units, Changan's Deep Blue SL03 sold 3 units, SAIC Maxus EUNIQ 7 sold 2 units, and Hongqi sold a single fuel cell sedan,

[171] LeadLeo Research Institute (头豹研究院). 2022. "*2022 China Hydrogen Industry White Paper: Hydrogen Energy Series [2022 年中国氢能行业白皮书：氢能系列]*". LeadLeo Research Institute. Access at: https://pdf.dfcfw.com/pdf/H3_AP202212081580936109_1.pdf.

[172] TrendBank (势银) and John Cockerill Jingli (考克利尔竞立). 2023. *"2023 TrendBank Hydrogen and Fuel Cell Industry Annual Blue Book [势银氢能与燃料电池产业年度蓝皮书（2023）]"*. TrendBank and John Cockerill Jingli. Access at: https://www.vzkoo.com/document/202401037c6b94ff254c418dc220f769.html.

each tied to small demonstration programmes with specific system suppliers. As a result, FC passenger cars account for only a negligible share of total FCV sales. [173]

Figure 10: Annual FCEV Sales by Vehicle Segment in China (2017–2023)



功能用途	2017	2018	2019	2020	2021	2022	2023(1-10)
Tractors				9	375	1,327	1,218
Logistics Vehicles	932	461	2,012	54	80	774	1,217
Cold-Chain Vehicles		1	3	21	27	663	421
Passenger Vehicles	112	96	433	10	237	392	386
Special-Purpose Vehicles				3	8	300	338
Buses	4	299	740	823	810	867	329
MPVs						206	300
Pickup Trucks					340	458	249
Class-B Passenger Cars						19	157

Source: TrendBank. 2023

The pattern — heavy bias toward high-utilisation commercial vehicles rather than passenger cars — is rooted in both policy design and techno-economic reality. On the policy side, China's deployment strategy kicks off in the segments where utilisation is high, operational profiles are predictable (fixed routes, depot refuelling) and business models (logistics fleets, municipal fleets) can internalise hydrogen costs. Passenger cars, by contrast, face a fragmented demand base, weak hydrogen refuelling infrastructure, and much stronger competition from battery-electric vehicles.

Regional Deployment Patterns and Demonstration Clusters

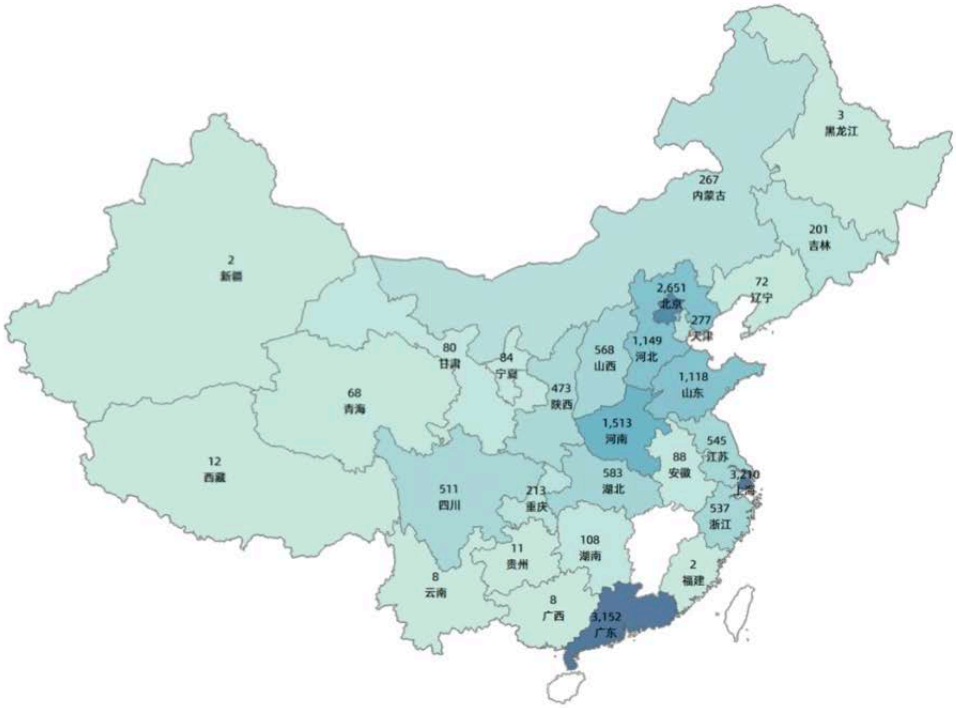
China's hydrogen vehicle deployment also exhibits distinctive spatial and institutional patterns that go beyond simple vehicle counts. Provincial sales data for 2024 show a highly uneven geography: a handful of leading provinces each deploy

[173] Wang, Shengke, Meimei Li, Siwen Wang, Yanxin Bao, Hao Wang, and Lei Chen. 2025. "*中国燃料电池汽车产业发展白皮书（2025 年）[China Fuel Cell Vehicle Industry Development White Paper 2025]*". Guangzhou: Xiangchenghui Research Institute (香橙会研究院). P. 35

on the order of several hundred to more than 1 300 fuel cell vehicles, while many others remain at single-digit or zero annual sales. This distribution mirrors the structure of China's five national fuel cell demonstration city clusters. By the end of 2024, these clusters had collectively deployed 15 393 FCVs, equivalent to only 47.4 % of their aggregate four-year target of 32 455 vehicles. Within this total, performance has diverged sharply: the Beijing–Tianjin–Hebei cluster over-fulfilled its quota with 5 767 vehicles (108.8 % of target), the Shanghai cluster reached 3 526 vehicles (70.5 %), and Henan achieved 2 513 vehicles (56.5 %), whereas the Hebei and Guangdong clusters remained far behind at 25.3 % and 16.3 % of their respective objectives.[174] This pattern underlines a key original feature of China's hydrogen transport policy: deployment is driven not only by central targets but by the capacity of individual provincial governments and local industrial ecosystems to orchestrate vehicles, hydrogen supply and infrastructure at scale, which some clusters manage much more effectively than others.[175]

[174] Xiangchenghui Research Institute (香橙会研究院) and Shanghai Qingduo Big Data Technology Co., Ltd. (上海氢多大数据科技有限公司). 2025. *"纯电重卡和氢能重卡的市场竞争分析[Market Competition Analysis of Battery-Electric and Hydrogen Heavy-Duty Trucks]"*. Shanghai: Xiangchenghui Research Institute.
[175] Wang, Shengke, Meimei Li, Siwen Wang, Yanxin Bao, Hao Wang, and Lei Chen. 2025. "*中国燃料电池汽车产业发展白皮书（2025 年）[China Fuel Cell Vehicle Industry Development White Paper 2025]"*. Guangzhou: Xiangchenghui Research Institute (香橙会研究院). P. 38-44

Figure 11: FCV Stock by Province and Municipality in China (Units, 2023)



Source: TrendBank. 2023

A second distinctive characteristic is the way large provincial pilots integrate hydrogen production, transport infrastructure and end-use into multi-scenario ecosystems. Shandong's "Hydrogen into Ten Thousand Homes" (氢进万家) science and technology demonstration project is emblematic. In its first phase (2021–2025), the project goes far beyond purchasing vehicles: it develops seven fuel cell powertrain platforms (10–200 kW) for buses, heavy 49-tonne trucks, port tractors and 4.5–7.5-tonne logistics vehicles, achieving hydrogen consumption figures better than competing products—for example, 4.45 kg/100 km for buses and 8.81 kg/100 km for 49-tonne trucks—and extending first-fault mileage beyond 18 000 km. At the infrastructure level, Shandong has built the Jinan–Qingdao "hydrogen highway" with five 35 MPa stations capable of around 30 refuellings and 200 kg per station per day. [176]

[176] Ibid.

Interestingly, “non-cluster” regions have become more important over time. In 2024, these non-demonstration areas accounted for 29.6% of annual FCV sales (2,099 vehicles) and 29.3% of cumulative stock (8,290 vehicles), reflecting the emergence of independent industrial and logistics users outside the original pilot architecture. This shift suggests that hydrogen transport is gradually diversifying beyond the initial cluster-based governance model, even though it still depends heavily on local subsidies and industrial policies.

Vehicle OEMs and Fuel Cell Suppliers

China’s hydrogen vehicle industry is characterised by a relatively concentrated group of leading vehicle manufacturers embedded in a broader and still fluid ecosystem of fuel cell system integrators and component suppliers. According to the China Fuel Cell Vehicle Industry Development White Paper 2025, around 45 OEMs delivered fuel cell vehicles in 2024, but market leadership is sharply skewed: the top ten OEMs accounted for 5,168 vehicles, or 72.8% of total FCV sales, while the top five alone captured 50.5%. Within this group, Yutong (宇通) ranked first with 1,145 vehicles and a 16.1% market share, followed by Beiqi Foton (北汽福田) with 764 vehicles (10.8%) and Shaanxi Automobile (陕西汽车) with 671 vehicles (9.5%). Smaller bus, truck and special-purpose vehicle manufacturers populate a long competitive tail, each contributing limited volumes to demonstration projects or regional pilots.

Figure 12: Industrial Value Chain of China's Hydrogen Mobility Sector

Source: TrendBank. 2023

The patterns on the vehicle side are closely mirrored by those in the fuel cell system segment. China Fuel Cell Vehicle Industry Development White Paper 2025 reports that in 2024 approximately 60 system companies shipped fuel cell systems for vehicles. Yihuatong (亿华通, also known as SinoHytec) led the market with 1,328 systems and an 18.7% share, followed by Refire (重塑能源) with 1,260 systems (17.8%), Guohong Hydrogen Energy (国鸿氢能) with 623 systems (8.8%) and Guohydrogen Technology (国氢科技) with 541 systems (7.6%). The top five system integrators together accounted for 58.5% of system shipments, confirming that a small group of specialised firms dominate powertrain supply even as dozens of smaller companies remain active at the margins. [177]

Patent and innovation data reinforce the picture of a concentrated, yet still evolving, leadership group. WIPO's patent landscape for hydrogen fuel cells in transportation identifies FAW Group, Dongfeng Motor, SAIC, Beiqi Foton and Yutong among the most active Chinese patent filers for vehicle fuel-cell

[177] Wang, Shengke, Meimei Li, Siwen Wang, Yanxin Bao, Hao Wang, and Lei Chen. 2025. "*中国燃料电池汽车产业发展白皮书（2025 年）[China Fuel Cell Vehicle Industry Development White Paper 2025]*". Guangzhou: Xiangchenghui Research Institute (香橙会研究院). P. 36-38

technologies, with companies such as SinoHytec and Refire playing a central role as technology partners in key demonstration projects, including the Beijing–Zhangjiakou Winter Olympics corridor. [178]

Investment Scale and Project Economics in China's Green Hydrogen Sector

China's green hydrogen build-out is increasingly shaped by the scale and structure of capital flowing into electrolysers, storage and transport infrastructure. The 2024 Hydrogen "Specialized, Sophisticated, Distinctive and Innovative" Investment and Financing Report compiled by the China Hydrogen Alliance estimates that, based on disclosed deals, hydrogen-sector financing in China between 2020 and 2023 reached a cumulative RMB 20 billion, with both the number of transactions and total volumes roughly doubling over this period.[179] In 2024 alone, nearly 90 individual hydrogen financing deals were recorded, with disclosed amounts exceeding RMB 5 billion, and the majority of transactions concentrated in early rounds (angel and Series A), which together accounted for more than 60% of all deals. Investors have thus far focused on upstream and midstream segments—water electrolysis, solid-state storage and fuel cell applications—while refuelling infrastructure attracts fewer but larger follow-on rounds due to high technical and operational entry barriers. A wave of sizeable equity financings and IPOs among fuel cell and component manufacturers during 2012–2022, including multiple single deals in the RMB 200–400 million range and the RMB 1.351 billion IPO of SinoHytec (亿华通), indicating that hydrogen has already become a recognised asset class in China's high-tech capital markets.

Green Hydrogen Projects for Transport Offtake

[178] World Intellectual Property Organization (WIPO). 2022. "*Global Challenges in Focus: Progress in Hydrogen Fuel Cell Technology Development and Deployment in China"*. Geneva: WIPO. Access at: https://www.wipo.int/edocs/pubdocs/en/wipo-pub-rn2022-4-en-global-challenges-in-focus.pdf.
[179] China Hydrogen Alliance Research Institute (中国氢能联盟研究院). 2024. "*2024 Hydrogen "Specialized, Sophisticated, Distinctive and Innovative" Investment and Financing Report [2024 氢能"专精特新"投融资报告]"*. Beijing: China Hydrogen Alliance Research Institute.

From a decarbonisation perspective, the key question is not merely how many FCVs are on the road, but to what extent they are supplied by low-carbon hydrogen. The 2025 China Green Hydrogen Blue Book refines this picture: in 2024, over 50% of commissioned green hydrogen projects by number targeted transport applications, but they represented only about 31% of electrolyser capacity; in the pipeline of under-construction and planned projects, the capacity share of transport falls further to around 3%, as large chemical and industrial projects dominate. [180]

In practical terms, the green-hydrogen transport projects that do exist in China today are tightly clustered around heavy industry and port logistics rather than generic long-haul corridors. A widely cited case is Jinnan Steel Group (晋南钢铁集团) in Shanxi: the plant's coking units generate around 73 000 t/yr of by-product hydrogen in coke-oven gas with a hydrogen content of about 61.7%. To date, part of this stream has been upgraded to chemical-grade hydrogen for ethylene glycol production, but Jinnan is progressively diverting purified hydrogen into a transport chain centred on fuel-cell heavy-duty trucks operating on internal short-haul routes for ore, coke and finished steel. By the end of 2023, the company had deployed 400 fuel-cell trucks without relying on national purchase subsidies and built a 6 t/day hydrogen refuelling station—currently the largest such facility in China—with plans to expand capacity to 9 t/day (around 500 truck fills). In parallel, Jinnan and China Huaneng are developing a 1.3 GW "PV-to-hydrogen" complex (300 MW already grid-connected in 2023), which is expected to raise green-hydrogen output from roughly 8 000 t/yr in the first phase to about 40 000 t/yr by 2030, turning the steelworks into an integrated hub where green hydrogen feeds both metallurgical processes and zero-emission transport. [181]

[180] Gaogong Hydrogen Energy Industry Research Institute (GGII, 高工氢电产业研究所). 2025. 2025 China Green Hydrogen Industry Development Blue Book (2025 中国绿氢产业发展蓝皮书). Shenzhen: Gaogong Hydrogen Energy Industry Research Institute. P. 14

[181] Wu, Jian. 2023. "*JINNAN Steel Group to Deploy 10,000 Hydrogen Heavy-duty Truck by 2025*." China Hydrogen Bulletin (newsletter on Substack), April 21. Access at: https://chinahydrogen.substack.com/p/jinnan-steel-group-to-deploy-10000.

A further illustration of how hydrogen transport is being anchored in specific regional ecosystems comes from Zhengzhou, the core city of the Henan hydrogen demonstration cluster. In November 2023, Zhengzhou Public Transit received a batch of 100 hydrogen fuel cell buses, the largest single deployment of FCEV buses in China that year, bringing the city's fleet to 423 fuel cell buses with a cumulative operational mileage of 43 million km and an estimated 45,852 tonnes of CO_2 abatement. As the hub of the Henan cluster, which aims to deploy 5,000 FCEVs by 2025, Zhengzhou had already reached around 1,300 FCEVs in operation by late 2023 and had built 19 hydrogen refuelling stations, with an ambitious 100 stations by 2025. [182]

Beyond Road Transport: Rail, Shipping and Aviation Pilots

Hydrogen applications beyond road vehicles are still at a demonstration stage but illustrate China's intent to position hydrogen for multi-modal decarbonisation. The world's first commercially-operated hydrogen tram line, located in the Gaoming district of Foshan in Guangdong province, China, commenced service in December 2019. Built as a demonstration of hydrogen-fuel-cell vehicle technology in rail transit, the 6.5 km line cost approximately USD 118 million (CNY 838 million) and was operated by Gaoming Modern Rail Transit Construction Investment Co., Ltd. However, operations were suspended on 6 August 2024 due to persistently low passenger volumes and rising operating costs. [183]

China's first hydrogen-powered urban train, developed by CRRC Changchun, completed testing in March 2024 in Jilin province, reaching a speed of 160 km/h and achieving a full-system verification. The train features an integrated hydrogen fuel-

[182] China Hydrogen Bulletin. 2023. "*100 Fuel Cell Buses Were Delivered to Zhengzhou, 1,300 FCEVs Are in Operation.*" China Hydrogen Bulletin (Substack newsletter). Access at: https://chinahydrogen.substack.com/p/100-fuel-cell-buses-were-delivered.
[183] Yicai Global. 2024. "*World's First Hydrogen-Powered Tram Line Halts Operations in China due to Few Passengers."* Access at: https://www.yicaiglobal.com/news/worlds-first-hydrogen-tram-line-halts-operations-in-china-due-to-few-passengers.

cell propulsion system free from overhead catenary supply and is designed for operation in low-temperature northeast China. [184]

In the maritime domain, in May 2022 China began constructing its first hydrogen fuel cell workboat certified by the China Classification Society, a key milestone for maritime safety and insurance acceptance. In December 2024 China launched its first hydrogen-powered container ship in Jiaxing, Zhejiang province. The vessel measures 64.5 m in length, carries 64 standard containers (~1,450 t), is powered by two 240 kW hydrogen fuel-cell systems and has a hydrogen storage capacity of 550 kg, enabling an operational range of about 380 km. The ship is claimed to reduce ~700 t CO_2 annually compared to a conventional vessel. [185]

Aviation and drone applications are also visible in the corpus but remain peripheral. In January 2025, a ton-class liquid-hydrogen-powered vertical take-off and landing drone completed its maiden flight in Baoji, Shaanxi Province. [186] Earlier, a Chinese hydrogen-fuelled internal combustion engine aircraft completed a maiden flight in Shenyang in February 2024.[187] The four-seat aircraft used a hydrogen-ICE powertrain rather than a fuel-cell stack and marked a domestic milestone in hydrogen aviation.

Across the corpus in this chapter, several consistent patterns emerge. First, China has succeeded in building a sizeable, predominantly domestic industrial ecosystem for hydrogen transport—covering stacks, systems, balance-of-plant components, storage and refuelling equipment—well ahead of mass-market demand. Second, real-world FCV deployment remains modest, with under 30,000 vehicles on the road by 2025 and annual sales plateauing around 7,000 units, far below the

[184] Xinhua. 2024. *"China's First Independently Developed Hydrogen-Powered Urban Train Completes Test."* Access at: https://english.www.gov.cn/news/202403/22/content_WS65fcd624c6d0868f4e8e554b.html.
[185] Global Times. 2024. *"China launches hydrogen-powered container ship, capable of carrying 64 standard containers."* Access at: https://www.globaltimes.cn/page/202412/1325383.shtml.
[186] Xinhua. 2024. "*China Develops Four-Seat Hydrogen Combustion Aircraft*." Access at: https://www.chinadaily.com.cn/s/202402/02/WS65d5ecc7498ed2d7b7ea7fb8/china-develops-four-seat-hydrogen-combustion-aircraft.html
[187] H2-View. 2024. "*Chinese hydrogen ICE-powered aircraft completes maiden flight — reports*". Access at: https://www.h2-view.com/story/chinese-hydrogen-ice-powered-aircraft-completes-maiden-flight-reports/2105596.article/.

levels implied by early projections of 50,000 vehicles by 2025 and over half a million by 2030. Third, hydrogen transport is heavily skewed toward commercial applications—buses, logistics trucks, heavy-duty vehicles and special municipal fleets—where hydrogen can exploit its comparative advantages in range and refuelling, while passenger FCVs remain a marginal niche.

In terms of decarbonisation, green hydrogen still accounts for only a small share of the hydrogen consumed by transport. While over half of newly commissioned green hydrogen projects by number in 2024 were aimed at transport, they represented only roughly one-third of electrolyser capacity, and the share falls to just a few per cent in the project pipeline as large chemical and industrial projects dominate. The bulk of hydrogen used in transport therefore continues to be grey rather than strictly green, even though industrial strategy documents frame FCVs as a flagship “deep decarbonisation” option for mobility. Overall, this specific market situation is central to understanding China’s evolving motives and instruments in hydrogen-based mobility, and it provides a crucial point of contrast with Japan’s approach in later chapters.

4.2 Japan

4.2.1 Regulatory and Institutional Framework

The intellectual and institutional foundations of Japan's hydrogen policy were laid in the 2000s through METI-led strategic plans for fuel cells, which identified FCVs as a key application for achieving energy security and industrial competitiveness, with climate benefits secondary at that stage. [188]These plans were operationalised through technology roadmaps and R&D support, but remained programmatic and lacked statutory force.

A qualitative shift came with the adoption of the Basic Hydrogen Strategy (NHS) in 2017, often described in Japanese specialist literature as the world's first comprehensive national hydrogen strategy.[189] The NHS framed hydrogen as a pillar of the "hydrogen society" concept and articulated three principal motives: enhancing energy security by diversifying away from imported fossil fuels; maintaining industrial leadership through first-mover advantage in fuel cells, hydrogen carriers, and infrastructure; and contributing to long-term decarbonisation. [190]

On the transport side, the 2017 NHS and the associated "Strategic Roadmap for Hydrogen and Fuel Cells" set explicit deployment targets: around 200,000 FCVs and 320 hydrogen refuelling stations by around 2025, rising to about 800,000 FCVs and 900 HRS by 2030.[191] The roadmap also recognised trucks and buses as priority segments for heavy-duty fuel cells over the medium term and called for corridor-based planning of HRS networks along expressways and in major metropolitan areas.

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[188] Behling, Noriko, Mark C. Williams, and Shunsuke Managi. 2015. "*Fuel Cells and the Hydrogen Revolution: Analysis of a Strategic Plan in Japan.*" Economic Analysis and Policy 48. P. 207–210.

[189] Hashimoto. 2021. "*Formulation of the World's First Basic Hydrogen Strategy*" (世界に先駆けた水素基本戦略の策定). Journal of the Hydrogen Energy System (水素エネルギーシステム) 46 (2). P. 123-125

[190] Council for Renewable Energy, Hydrogen and Related Ministers. 2017. "*Basic Hydrogen Strategy (水素基本戦略)*". Tokyo: Government of Japan.

[191] Hydrogen and Fuel Cell Strategy Council (水素・燃料電池戦略協議会). 2019. "*Strategic Road Map for Hydrogen and Fuel Cells: Action Plan for the Realization of a Hydrogen Society (水素・燃料電池戦略ロードマップ～水素社会実現に向けた産学官のアクションプラン～)*". Tokyo: Ministry of Economy, Trade and Industry

Although legally non-binding, these numerical targets became a core reference point for subsequent ministerial policies and regional visions.

Embedding Hydrogen in the 2050 Carbon-Neutrality and Growth Agenda

Japan's 2020 pledge to achieve carbon neutrality by 2050 re-situated hydrogen within a broader growth-oriented green transformation. The "Green Growth Strategy through Achieving Carbon Neutrality in 2050" designates hydrogen as one of fourteen priority industrial fields and stresses its dual role as both decarbonisation tool and engine of new investment and export opportunities. For transport, the strategy highlights FCVs, fuel-cell buses and trucks, and hydrogen or ammonia use in shipping and aviation as "next-generation" pillars alongside battery electric vehicles. [192]

The Green Growth Strategy also introduced macro-level quantitative aspirations for hydrogen use. It envisages hydrogen and ammonia supplying around 10% of Japan's total energy by mid-century, implying hydrogen-equivalent demand on the order of tens of millions of tonnes and signalling that domestic renewable resources alone will be insufficient. This high import dependence—unlike China's more domestically anchored supply strategy—has shaped Japan's strong emphasis on international supply chains, certification, and trade rules. [193]

Scale-Up: the 2023 Revision of the Basic Hydrogen Strategy

In June 2023, the Council for Renewable Energy, Hydrogen and Related Ministers adopted a revised Basic Hydrogen Strategy that reorients policy from demonstration to full-scale introduction. The revision significantly raises the ambition for hydrogen and ammonia supply, targeting roughly 30 million tonnes of

[192] Government of Japan. 2020. "*Green Growth Strategy through Achieving Carbon Neutrality in 2050*". Provisional translation. Tokyo. P. 7-9
[193] Osaki, Yuma, and Llewelyn Hughes. 2025. "*Japan: Putting Hydrogen at the Core of Its Decarbonisation Strategy*." In The Geopolitics of Hydrogen. Volume 2: Major Economies and Their Strategies, edited by Raimund Quitzow and Yana Zabanova, 105–123. Cham: Springer. P. 113-114

hydrogen-equivalent demand by 2030, 120 million tonnes by 2040 and 200 million tonnes by 2050, counting derivatives such as ammonia and synthetic fuels. [194]

Given limited domestic renewable potential, the strategy explicitly positions imports as central: Japan is to become a "global hydrogen hub" by establishing long-term supply chains with resource-rich partners, using multiple carriers (liquid hydrogen, ammonia, and liquid organic hydrogen carriers such as methylcyclohexane) and combining electrolysis-based production with fossil-based hydrogen plus carbon capture.[195] This technology-agnostic stance contrasts with the EU's stronger focus on renewable hydrogen and creates a structural tension between Japan's energy-security motive (diversified imports, broad eligibility) and its climate motive (deep life-cycle emission reductions), a tension highlighted by critical analysts.

The revised strategy retains the earlier FCV and HRS deployment goals but adds more emphasis on heavy-duty and commercial vehicles. It highlights fuel-cell trucks and buses in logistics and regional public transport as priority early markets and calls for the designation of "priority areas" where infrastructure and fleets are co-deployed. This shift reflects both learning from under-utilised passenger-car-focused stations and the recognition that decarbonising freight and bus networks offers higher emission-reduction leverage per HRS.

Legal Consolidation: the Hydrogen Society Promotion Act

A defining institutional development is the 2024 Hydrogen Society Promotion Act ("Act on Promoting the Supply and Use of Low-Carbon Hydrogen and Derivatives for Smooth Transition to a Decarbonised Growth-Oriented Economic Structure"). The Act elevates hydrogen policy from ministerial strategies to a statutory framework, clarifying the responsibilities of the national government, local

[194] Council for Renewable Energy, Hydrogen and Related Ministers. 2023. "*Basic Hydrogen Strategy (水素基本戦略)*". Tokyo.
[195] Konovalov, Dmytro, Ignat Tolstorebrov, Yuhiro Iwamoto, and Jacob Joseph Lamb. 2025. "*Hydrogen and Japan's Energy Transition: A Blueprint for Carbon Neutrality.*" Hydrogen 6 (3).

authorities and business operators in securing stable supply and promoting use of "low-carbon hydrogen etc." [196]

The accompanying Basic Policy for Promoting the Supply and Use of Low-Carbon Hydrogen introduces explicit life-cycle–based carbon-intensity criteria for hydrogen and its derivatives, drawing on the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) methodology. Rather than relying on colour labels, it defines "low-carbon" status through quantitative emission thresholds and thereby aligns Japan's regime with emerging international certification practices; the detailed design and implications of these thresholds are examined in the subsequent subsection on sustainability standards. [197]

Transport-Specific Instruments: From Passenger FCVS to Commercial Corridors

Within this statutory and strategic envelope, transport-specific policies refine the focus on segments and geographies. The Automobile Division of METI and the Hydrogen and Ammonia Division of ANRE issued "Application Guidelines for Priority Areas for Promoting the Introduction of Fuel Cell Commercial Vehicles (First Round)" in March 2025. The guidelines invite local governments and consortia of vehicle manufacturers, logistics operators and energy companies to apply for designation as priority areas, where fleets of fuel-cell trucks and buses and HRS are co-deployed with national and local subsidies. [198]

Subsidies in these schemes typically cover part of vehicle purchase costs and HRS capital expenditures, while operating support can be provided via the CfD

[196] Agency for Natural Resources and Energy (ANRE, 資源エネルギー庁). 2024. "*Hydrogen Society Promotion Act*" Ministry of Economy, Trade and Industry (METI).
[197] Agency for Natural Resources and Energy. 2024. "*Basic Policy for Promoting the Supply and Use of Low-Carbon Hydrogen, etc. (低炭素水素等の供給及び利用の促進に関する基本方針)*". Tokyo: Ministry of Economy, Trade and Industry (METI).
[198] Ministry of Economy, Trade and Industry (METI), Manufacturing Industries Bureau, Automobile Division, and Agency for Natural Resources and Energy, Hydrogen and Ammonia Division. 2025. "*Application Guidelines for Priority Areas for Promoting the Introduction of Fuel Cell Commercial Vehicles (First Round) (第 1 回燃料電池商用車の導入促進に関する重点地域募集要領)*". Tokyo: METI.

scheme where hydrogen costs remain significantly above diesel or LNG benchmarks. The guidelines also require applicants to present credible demand aggregation, refuelling-network layouts, and safety management plans, thereby embedding spatial planning and risk governance into project selection. This move towards competitive, criteria-based selection marks a gradual shift from blanket subsidies for early passenger FCVs towards more performance-oriented industrial policy.

Regional Strategies and Centre–Local Alignment

Subnational governments have been active laboratories for hydrogen-for-transport policy, often anticipating national narratives. Fukushima Prefecture's "Fukushima Plan for a New Energy Society" (2016) positioned hydrogen as a symbol of post-disaster reconstruction, with plans for large-scale renewable hydrogen production and demonstration of fuel-cell buses, forklifts and HRS around the Tokyo 2020 Olympics. [199]

Hokkaido's "Hydrogen Society Realization Strategy Vision" and its revised Hydrogen Supply Chain Construction Roadmap set out a path toward "Zero-Carbon Hokkaido," emphasising hydrogen production from abundant renewables, use in buses, trucks and port equipment, and export-oriented supply chains toward Honshu and overseas.[200] Hyogo Prefecture's Hydrogen Society Promotion Vision similarly targets deployment of FCVs, buses and forklifts around Kobe Port and industrial zones, combined with pioneering work on liquid hydrogen imports. [201]

These regional visions share several traits. First, they frame hydrogen mobility not only as a decarbonisation tool but also as a branding device for local "hydrogen hubs" and as a way to leverage existing industrial strengths—e.g. Kawasaki Heavy Industries in Hyogo or renewable resources in Hokkaido. Second, they rely heavily

[199] Council for Realizing the Fukushima Plan for a New Energy Society. 2016. "*The Fukushima Plan for a New Energy Society.*" Fukushima Prefecture.
[200] Hokkaido Government. 2020. "*Hokkaido Hydrogen Society Realization Strategy Vision (Revised Edition) (北海道水素社会実現戦略ビジョン（改定版）).*" Sapporo: Hokkaido Government.
[201] Hyogo Prefectural Government. 2019. "*Hyogo Hydrogen Society Promotion Vision (兵庫水素社会推進構想)*". Kobe: Hyogo Prefectural Government.

on national funding programmes (such as NEDO and, more recently, the Green Innovation Fund) and on alignment with national targets for FCVs and HRS. Third, they often use transport projects—bus routes, logistics fleets, port vehicles—as visible anchors for broader hydrogen ecosystems that also include power generation and industrial uses.

This centre–local dynamic is less hierarchical than in China: Japanese prefectures have considerable agenda-setting power but depend on national co-funding and certification rules, especially once the Hydrogen Society Promotion Act links access to CfD support to compliance with low-carbon thresholds.[202]

Table 3. Major national hydrogen policy documents in Japan relevant to transport

Year	Document (type)	Legal force	Key transport-related content
2014–2015	Strategic Roadmap for Hydrogen and Fuel Cells (METI)	Programmatic roadmap	Identifies FCVs and HRS as core applications; outlines phased diffusion and infrastructure deployment. (Behling, Williams, and Managi 2015, 207–210)
2017	Basic Hydrogen Strategy (NHS)	Cabinet-approved strategy	First comprehensive national hydrogen strategy worldwide; sets FCV targets (200,000 by ~2025, 800,000 by 2030) and HRS targets; frames hydrogen as pillar of "hydrogen society."
2020	Green Growth Strategy through Achieving Carbon Neutrality in 2050	Government growth strategy	Designates hydrogen and fuel ammonia as growth sectors; highlights FCVs, fuel-cell buses/trucks, and hydrogen use in shipping/aviation as next-generation mobility pillars.
2023	Revised Basic Hydrogen Strategy	Updated government strategy	Raises hydrogen-equivalent demand targets to ~30 Mt (2030), 120 Mt (2040), 200 Mt (2050); emphasises imports, low-carbon standards based on IPHE methodology, and heavy-duty FCVs/logistics corridors.
2024	Hydrogen Society Promotion Act + Basic Policy	Statute + basic policy	Creates legal framework for "low-carbon hydrogen etc." with quantitative CO_2-intensity thresholds; establishes CfD scheme for hydrogen,

[202] Osaki, Yuma, and Llewelyn Hughes. 2025. "*Japan: Putting Hydrogen at the Core of Its Decarbonisation Strategy*." In The Geopolitics of Hydrogen. Volume 2: Major Economies and Their Strategies, edited by Raimund Quitzow and Yana Zabanova, 105–123. Cham: Springer. P. 113-119

			with 15-year support and JOGMEC as implementing agency.
2025	Priority Areas for Fuel-Cell Commercial Vehicles (Guidelines)	Ministerial implementation guideline	Launches competitive selection of regions where FC trucks and buses and HRS are co-deployed with national and local subsidies, linking infrastructure planning to fleet aggregation.

Japan's regulatory and institutional framework for hydrogen in transport is now anchored in a combination of cabinet strategies and a dedicated statute that defines low-carbon hydrogen, creates a CfD scheme, and links access to support with carbon-intensity thresholds. The regime reflects a distinct configuration of motives: strong import dependence, industrial-policy ambitions in hydrogen carriers and infrastructure, and a commitment to climate goals that is mediated by relatively flexible sustainability criteria. Although it is necessary to notice that Japanese think-tanks and scholars have raised concerns that the country's hydrogen regime, as currently configured, risks allocating large fiscal resources to relatively inefficient decarbonisation pathways, especially fossil-based hydrogen and ammonia in power generation, while electrification and direct renewable use remain underutilised. [203]

4.2.2 Sustainability Assurance and Certification

For much of the 2010s, Japan promoted "clean hydrogen" in broad terms without strict criteria, implicitly including various production pathways (electrolysis, fossil with CCS, etc.) as long as they promised lower emissions. Recognizing the need for a consistent definition, the Japan Hydrogen Association (JH2A) – a leading industry body – proposed a quantitative standard in early 2023. JH2A advocated a 70% reduction in life-cycle CO_2 emissions compared to conventional steam methane reforming of natural gas. This proposal fed into government deliberations and was largely adopted in Japan's Revised Basic Hydrogen Strategy (June 2023), which for

[203] Renewable Energy Institute (自然エネルギー財団). 2022. "*Re-examining Japan's Hydrogen Strategy: Moving beyond the "Hydrogen Society" Fantasy*". Tokyo: Renewable Energy Institute. P. 5-9

the first time set an emission-intensity benchmark to label "low-carbon hydrogen".[204]

Under the Basic Hydrogen Strategy 2023 and the subsequent Hydrogen Society Promotion Act (2024), Japan defines "low-carbon hydrogen" as hydrogen (or its carriers like ammonia, synthetic methane, e-fuels) that emits no more than a specified amount of CO_2 per unit production. Although the Act left the exact number to ministerial orders, an Interim Summary Report released by the government in January 2024 explicitly cited 3.4 kg-CO_2 per kg H_2 as the indicative threshold. By October 2024, METI and MLIT issued a Basic Policy and accompanying Standard to implement the Act, confirming the carbon intensity limits for each fuel.[205] These figures align with the 70% emission reduction philosophy – essentially requiring that grey hydrogen's ~10–11 kgCO_2/kg footprint be cut by about two-thirds to qualify.

Importantly, Japan's standard is technology-agnostic. It does not mandate renewable energy use or a particular pathway, but simply sets a carbon intensity ceiling. This was a deliberate choice to maximize flexibility in sourcing low-carbon hydrogen. As analysts note, the 3.4 kg-CO_2 benchmark allows hydrogen produced from fossil fuels with carbon capture (so-called "blue hydrogen") to count as low-carbon alongside renewable ("green") hydrogen. Japanese policymakers saw this as pragmatic: it enables imports of affordable hydrogen from countries like Australia, the U.S. or Canada, where large blue hydrogen projects are expected to produce at scale. This contrasts with the European Union's approach of prioritizing strictly renewable-sourced hydrogen in its transport fuel targets. At 3.4 kgCO_2/kg, Japan's allowance is also slightly looser than the EU's taxonomy definition of low-carbon H_2 (3.0 kgCO_2/kg) and much higher than the UK's standard (2.4 kgCO_2/kg). Thus,

[204] Council for Renewable Energy, Hydrogen and Related Ministers. 2023. "*Basic Hydrogen Strategy (水素基本戦略)*". Tokyo.
[205] Agency for Natural Resources and Energy. 2024. "*Basic Policy for Promoting the Supply and Use of Low-Carbon Hydrogen, etc. (低炭素水素等の供給及び利用の促進に関する基本方針)*". Tokyo: Ministry of Economy, Trade and Industry (METI).

what Japan deems low-carbon hydrogen could have up to ~13% more emissions than the EU's label, and far more than truly "green" hydrogen which approaches zero.

System Boundary and Calculation Method

A critical aspect of any hydrogen GHG standard is the system boundary for emissions accounting. Japan's low-carbon hydrogen definition is assessed on a well-to-gate (WTG) basis for hydrogen and ammonia, meaning it includes all upstream emissions from resource extraction through production up to the factory gate where hydrogen or ammonia is produced. It does not, at present, include emissions from transport, distribution, or end-use. By contrast, for synthetic hydrocarbon fuels (e-fuels, e-methane), the Japanese standard uses a "whole supply chain" (well-to-wheel) scope. [206]

On the calculation methodology, Japan is aligning with international LCA practices. The Hydrogen Act explicitly calls for carbon-intensity reductions to be recognized "in light of internationally approved standards". [207] In effect, Japan measures life-cycle emissions per kilogram H_2 in a manner compatible with frameworks like the IPHE hydrogen emissions accounting guidance or ISO 14067 (carbon footprint of products). Indeed, to operationalize the 3.4 kg standard, the government will need to specify default emission factors, acceptable data sources, and calculation steps. Draft documentation suggests that standardized (secondary) data can be used for upstream processes, rather than requiring each project to obtain primary field data. This pragmatic approach lowers the burden on project developers, but as the Renewable Energy Institute points out, it also risks overlooking actual upstream emissions like fugitive methane if those default factors are too optimistic.

[206] Ishihara, Toshikazu. 2024. "*Addressing the Challenges of the Hydrogen Society Promotion Act: Transitioning Away from Imported Fossil Fuels*." Renewable Energy Institute. Access at: https://www.renewable-ei.org/en/activities/column/REupdate/20241226.php

[207] Bocobza, Julien, and Saori Takahashi. 2024. "*On the Path to Decarbonisation: Japan Enacts Its First Legislation on Hydrogen and CCS*." White & Case. Access at: https://www.whitecase.com/insight-alert/path-decarbonisation-japan-enacts-its-first-legislation-hydrogen-and-ccs#:~:text=than%20a%20certain%20amount%3B%20,set%20by%20the%20ministerial%20orders

[208] The implication is that a hydrogen producer could meet the 3.4 kg target on paper, yet real-world leaks or energy use in transport might be higher.

Japan's approach to certification thus leans heavily on government oversight, rather than market-driven certificates. METI and MLIT will evaluate proposals and presumably require documentation of how the carbon intensity will be achieved and measured. The law also calls for a code of conduct for hydrogen suppliers, which could include reporting and transparency obligations. While details on verification procedures are still emerging, the framework suggests that once a project is approved and producing, the government (or its designated agencies) will monitor performance against the low-carbon criteria. This could involve audits or requiring third-party LCA reports for the hydrogen produced. Compliance is incentivized rather than compulsory: companies are not punished for high-carbon hydrogen, but they cannot benefit from Japan's massive hydrogen support programs unless they meet the low-carbon standard.

In parallel to carbon accounting, Japan has technical standards ensuring the quality of hydrogen as a fuel. To use hydrogen in fuel cell vehicles or power generators, the hydrogen must meet purity specifications (absence of impurities like sulfur, moisture, etc.). Japan has adopted standards equivalent to the ISO 14687 fuel quality standard, defining grades of hydrogen suitable for PEM fuel cells. These industrial standards ensure any hydrogen delivered to vehicles is 99.97% pure with trace contaminant limits, which is crucial for performance and durability. While these purity standards are not about carbon footprint, they form part of the broader "hydrogen product" definition infrastructure**.**

Notably, Japan's policy does not create a separate label for "renewable hydrogen" or impose an exclusive renewable requirement at this. All hydrogen meeting the 3.4 kg threshold is grouped as low-carbon, whether the CO_2 cuts come

[208] Ishihara, Toshikazu. 2024. "*Addressing the Challenges of the Hydrogen Society Promotion Act: Transitioning Away from Imported Fossil Fuels*." Renewable Energy Institute. Access at: https://www.renewable-ei.org/en/activities/column/REupdate/20241226.php

from genuine renewable energy or from carbon capture. This reflects Japan's strategic choice to jump-start hydrogen use by any low-emission means available. However, it has also led to criticism that Japan is not distinguishing truly zero-carbon hydrogen from lower-cost, low-carbon options.

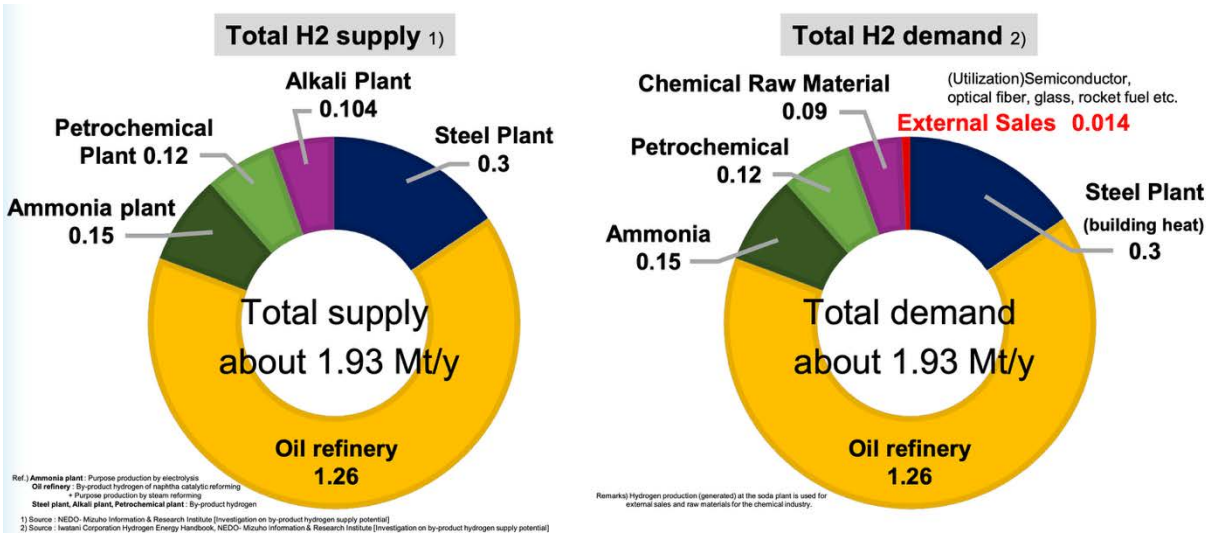
It's expected that Japan could, in the future, introduce a national renewable hydrogen certification or at least tighten the low-carbon standard. Indeed, Japanese climate policy observers argue that the current 3.4 kg-CO_2 threshold should be seen as a starting point – one that will need to become more stringent (and eventually oriented toward 100% renewables) for Japan to meet its 2050 net-zero goal.

4.2.3 Supply Structure and Sourcing Pathways

Japan's hydrogen economy still rests primarily on conventional industrial hydrogen rather than on new "green" supply streams. In practice, hydrogen functions as an internal process gas within refineries, steel mills, petrochemical complexes and chlor-alkali plants, rather than as a traded low-carbon energy carrier. Data compiled by the Japan Hydrogen Association indicate that total hydrogen supply is about 1.93 Mt per year, essentially equal to total demand because almost all production is consumed on-site in the facilities where it is generated (Figure 13).[209] Of this volume, roughly 1.26 Mt is associated with oil refining, 0.30 Mt with steel plants, and around 0.46 Mt with ammonia, petrochemical and alkali production, while only around 0.014 Mt is sold externally to sectors such as semiconductors and optical fibre manufacturing. According to JH2A, this entire domestic hydrogen supply is currently "grey", with approximately 99% self-consumed within the producing industries.

[209] Japan Hydrogen Association (JH2A). 2025. "*Hydrogen Distribution Strategy toward 2040: Section 3.2 "Hydrogen".* Tokyo: Japan Hydrogen Association. P. 4

Figure 13: Overview of Hydrogen Supply and Demand in Japan



Source: Japan Hydrogen Association. 2025

Japan NRG's survey of "green" hydrogen projects identifies a small but growing pipeline of domestic plants based on solar, wind, hydro and waste-to-energy, including IHI's Soma Green Energy Center in Fukushima and smaller projects such as eRex's 360 kW hydrogen power plant in Yamanashi Prefecture.[210] These facilities are primarily demonstration or early-commercial projects supplying local power or small industrial users rather than bulk commodity hydrogen. Their aggregate output remains a fraction of current industrial by-product supply, but they play an important role in maturing domestic engineering capabilities, grid integration solutions and business models.

On the blue hydrogen side, domestic potential is constrained by Japan's limited geological storage capacity for CO_2 and relatively modest domestic natural gas resources. The Hydrogen Factsheet highlights that both natural gas supply and CO_2 storage potential are "greatly limited due to geological conditions", which implies that large-scale domestic blue hydrogen will face structural constraints.[211]

[210] Japan NRG and Switzerland Global Enterprise. 2024. "*Japan: A Hydrogen Appreciation Society. Official Program*". Tokyo and Zürich: Japan NRG and Switzerland Global Enterprise. P. 15-16
[211] Sieler, Roman Eric, Lisa Cames, Bianca Schuster, Sören Borghardt, and Benjamin La Trobe. 2021. "*Hydrogen Factsheet – Japan*". Berlin: adelphi.

Nonetheless, government strategies and Japan NRG's market overview discuss several pilot-scale projects combining hydrogen production with CO_2 capture, often linked to ammonia production or industrial clusters.

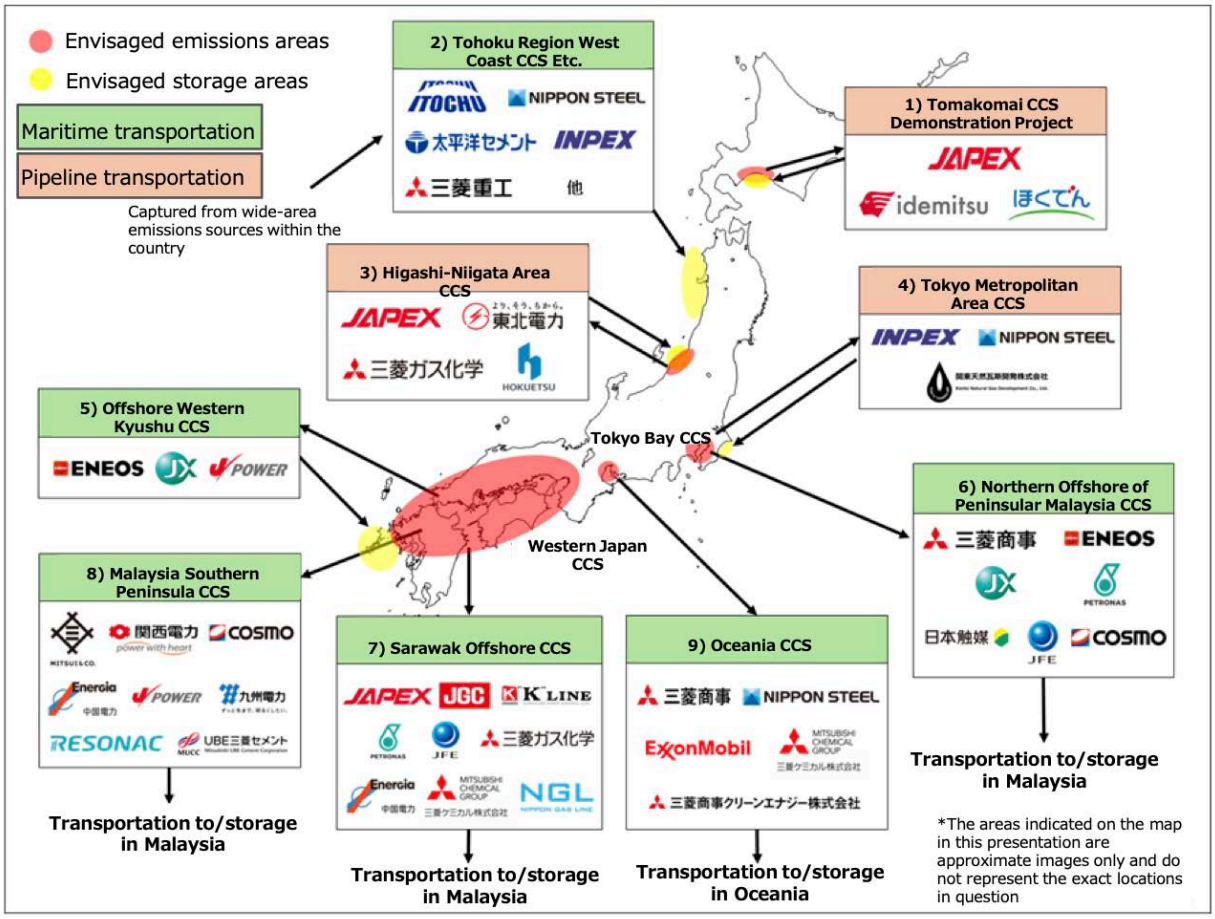
Regional Patterns and Key Industrial Actors

Spatially, Japan's emerging low-carbon hydrogen production is concentrated in a limited set of industrial and port regions. Demonstration projects linked to international hydrogen supply chains cluster around Kobe and Kawasaki, while Fukushima hosts the flagship FH2R and several research facilities.[212] Japan NRG's market overview highlights major corporate players—ENEOS, Iwatani, Kawasaki Heavy Industries, JERA, Kansai Electric, and others—whose projects are often anchored in regional industrial belts such as Kansai and the Tokyo Bay area.

At the same time, the Kansai region, including Osaka and Kobe, is being promoted by METI's regional bureaus and local governments as a hydrogen hub linked to Expo 2025 Osaka and to ongoing ammonia co-firing pilots in thermal power plants.[213] These clusters matter for transport decarbonisation because they co-locate production, import terminals and large potential off-takers such as ports, logistics operators and municipal bus fleets, thereby reducing distribution costs for mobility applications.

[212] Nagashima, Yoichi. 2020. "*Japan's Hydrogen Policy: Japan's Hydrogen Strategy and Its Implications for the Global Hydrogen Economy"*. Paris: Institut français des relations internationales (Ifri). P. 19-20
[213] Kansai Bureau of Economy, Trade and Industry (METI-Kansai). 2025. "*Hydrogen-Related Industries in Japan: Creating a Sustainable Future from Kansai to the World*". Osaka: METI-Kansai.

Figure 14: Map of CCS Projects in Japan for Potential Low-Carbon Hydrogen Production



Source: Kobayashi, Yoshikazu. 2025

Hydrogen Import Strategy and International Supply Chains

Japan's structural dependence on energy imports shapes its hydrogen sourcing strategy even more strongly than in many other economies. Hydrogen Council and Baringa's system-level analysis characterises Japan as an "islanded system" with around 88% of primary energy supplied by coal, gas or oil and more than 98% of fossil fuels imported; the country has minimal national gas grid infrastructure but the world's largest liquefied natural gas import capacity. [214] The Hydrogen Factsheet similarly underlines that Japan will be a net importer of hydrogen and is focusing on

[214] Hydrogen Council and Baringa. 2023. "*Hydrogen in Decarbonized Energy Systems*". Brussels: Hydrogen Council. P. 5

expanding international supply chains while positioning itself as an exporter of hydrogen-related technology rather than of the fuel itself. [215]

Japan has therefore moved early to establish international hydrogen and ammonia supply chains. Two government-backed pilot projects illustrate the approach. The AHEAD project between Brunei and Kawasaki uses an organic hydride (methylcyclohexane, MCH) route: natural gas-based hydrogen is produced in Brunei, converted into MCH, shipped to Japan and dehydrogenated in Kawasaki, with the toluene carrier recycled back to Brunei. After initial shipments in 2019, imported hydrogen has been used for power generation since 2020. [216] The HySTRA project between Australia and Japan, by contrast, develops a liquefied hydrogen chain based on lignite gasification in Australia, liquefaction and shipment to Kobe using the dedicated Suiso Frontier carrier; the commercial phase aims to add CCS to achieve "CO_2-free" hydrogen. [217] These pilots demonstrate the technical feasibility of long-distance hydrogen supply using both MCH and liquefied hydrogen, but they currently rely on grey or at best prospective blue hydrogen and operate at relatively small volumes.

More broadly, Japan is building a portfolio of potential suppliers across several regions. The Hydrogen Factsheet reviews memoranda of cooperation covering hydrogen, ammonia and CCS with Australia, Canada, Indonesia, the United States and Middle Eastern partners such as the United Arab Emirates, often involving joint feasibility studies on producing low-carbon ammonia for export to Japan (Figure 15).

[215] Sieler, Roman Eric, Lisa Cames, Bianca Schuster, Sören Borghardt, and Benjamin La Trobe. 2021. "*Hydrogen Factsheet – Japan*". Berlin: adelphi. P. 5
[216] Ibid. P. 19
[217] Clifford Chance. 2022. "*Focus on Hydrogen: Japan's Energy Strategy for Hydrogen and Ammonia*". London: Clifford Chance. P. 5

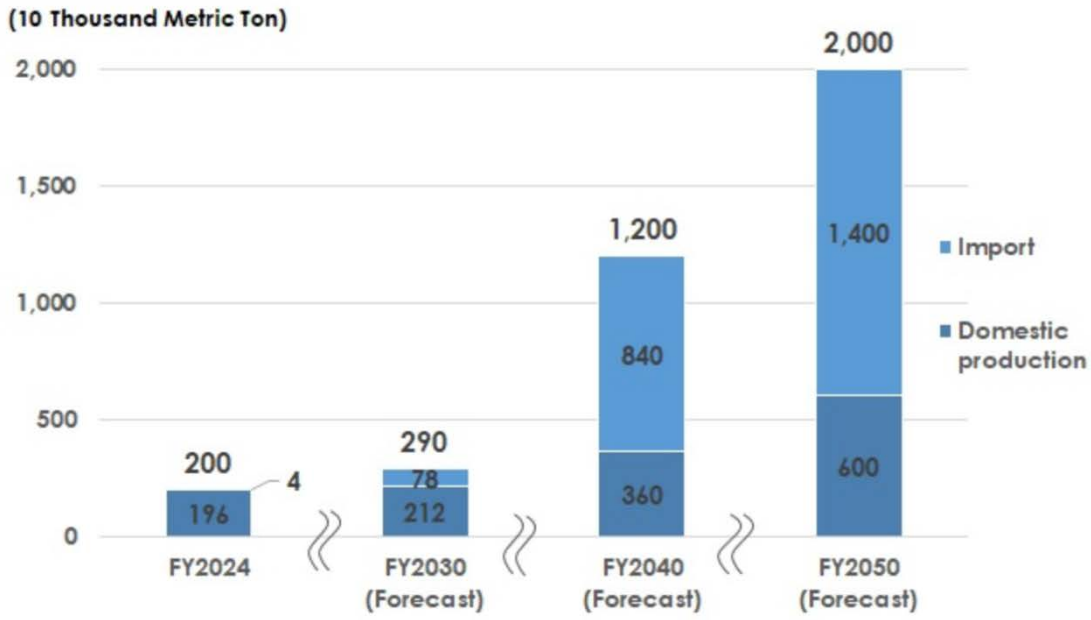
Figure 15: Countries with which Japan has signed H2 or ammonia accords

Source: Japan NRG and Switzerland Global Enterprise. 2024. P. 9

Yano's forecast in Figure 16 shows total hydrogen supply rising to 2.9 Mt by FY2030, 12 Mt by FY2040 and 20 Mt by FY2050, with imports increasing from 0.04 Mt (≈2%) in FY2024 to about 0.78 Mt (≈27%) in FY2030, 8.4 Mt (≈70%) in FY2040 and 14 Mt (≈70%) in FY2050.[218] This trajectory is broadly consistent with the updated national hydrogen strategy as summarised by APERC and Japan NRG, which envisages hydrogen and ammonia "available to Japan" reaching 12 Mt by 2040 and around 20 Mt by mid-century, and with system-level modelling by the Hydrogen Council that likewise treats Japan as structurally import-dependent in a net-zero scenario. [219]

[218] Yano Research Institute Ltd. 2025. "*Japan's Hydrogen Supplies Are Forecast to Reach 2.90 Million Metric Tons by FY2030 – Survey on Hydrogen Supply Market in Japan.*" Press release, September 17, 2025. Tokyo: Yano Research Institute.
[219] Asia Pacific Energy Research Centre (APERC). 2024. "*Hydrogen Supply, Demand and Trade in the APEC Region*." Tokyo: APERC. P. 24-26

Figure 16: Forecast of Hydrogen Supply Volume in Japan



Source: Yano Research Institute Ltd. 2025.

Implications for Low-Carbon Hydrogen Availability for Transport

From the perspective of transport decarbonisation, the key question is whether this evolving supply architecture will deliver sufficient volumes of genuinely low-carbon hydrogen at competitive cost and in the right locations. Government targets for the mobility sector are ambitious: METI aims for hydrogen consumption in mobility to reach about 80 000 t per year by 2030, supported by around 800 000 fuel cell vehicles (including 5 000 trucks) and 1 000 hydrogen refuelling stations.[220]

In terms of pure volumes, the planned expansion from roughly 2 Mt to about 3 Mt of hydrogen supply by 2030 appears sufficient to cover the mobility target of 80 000 t, which would represent only a few per cent of total demand, even if some additional hydrogen is required for buses, trucks, ships and trains. However, there are three structural constraints.

[220] Japan NRG and Switzerland Global Enterprise. 2024. "*Japan: A Hydrogen Appreciation Society. Official Program*". Tokyo and Zürich: Japan NRG and Switzerland Global Enterprise. P. 6

First, the low-carbon share of that 3 Mt remains uncertain. JH2A's current baseline is entirely grey hydrogen, and although policies such as the Hydrogen Society Promotion Act and its Basic Policy now define quantitative life-cycle emission thresholds for "low-carbon hydrogen etc.", the supply-side pipelines in the documents used here suggest that, by 2030, a non-trivial share of hydrogen and ammonia available to Japan will still be derived from fossil fuels with partial or planned CCS, especially in early import projects. This raises questions about how quickly truly low-carbon molecules can be scaled for transport in a way that is consistent with Japan's life-cycle-based standards.

Second, the domestic production base for green hydrogen remains small, with FH2R and similar plants operating at demonstration scale and limited additional electrolysis underway. For applications such as heavy-duty road transport in inland regions, reliance on imported hydrogen landing at a few coastal hubs may create additional distribution costs and infrastructure requirements. Hydrogen Council's system modelling emphasises that for an islanded system like Japan, scaling "last-mile" hydrogen distribution for zero-emission heavy-goods vehicles is a distinct challenge from designing the transmission-level energy system. [221]

Third, the economic and policy risks around large-scale hydrogen imports have not been fully resolved. Both APERC and IEEJ highlight that hydrogen project pipelines worldwide are subject to delays, FID uncertainty and cost overruns, while governments are beginning to recalibrate some targets in light of slower-than-expected progress. [222] Japan's own CfD and hub schemes are designed to mitigate these risks domestically, but the long-term stability of overseas projects, including CCS-enabled exports, remains outside Japan's direct control.

Taken together, the Japanese case reveals a distinctive supply and sourcing strategy for low-carbon hydrogen. The country starts from a large but fully grey

[221] Hydrogen Council and Baringa. 2023. "*Hydrogen in Decarbonized Energy Systems*". Brussels: Hydrogen Council. P. 8-9
[222] International Energy Agency (IEA). 2025. "*Global Hydrogen Review 2025*". Paris: IEA. P. 88-90

industrial hydrogen base, and it plans to overlay this with moderate domestic low-carbon production and very substantial imports, reaching 12 Mt by 2040 and roughly 20 Mt by 2050. For transport, this implies that physical availability of hydrogen is unlikely to be the primary bottleneck by 2030; rather, the key uncertainties lie in the carbon intensity of the available molecules, the spatial integration of supply hubs with mobility demand, and the durability of economic support mechanisms needed to make low-carbon hydrogen competitive with fossil fuels.

4.2.4 Economic Viability and Incentive Alignment

Japan's hydrogen strategy is unusually explicit about cost. Since the 2017 Basic Hydrogen Strategy the Ministry of Economy, Trade and Industry has treated hydrogen as both a decarbonisation tool and a traded fuel whose price must converge towards fossil alternatives if it is to scale in transport and power.[223] Yet most domestic and international analyses agree that hydrogen in Japan remains structurally expensive, especially for mobility.

Current Hydrogen Price Structure and Levelized Costs

When the "hydrogen society" narrative crystallised in the mid-2010s, retail prices at hydrogen refuelling stations were around ¥100 per normal cubic metre (Nm^3), or about US$0.90–1.00/$Nm^3$. [224] On an energy-equivalent basis this is several times more expensive than gasoline or diesel and poses an obvious barrier to fuel cell vehicle uptake.

Nagashima's station-level modelling highlights that even large stations with relatively high utilisation struggle to reduce supply costs below roughly half of this retail level, once compression, storage, land and labour are taken into account; small stations are clearly uneconomic without sizeable capital and operating support. [225]

[223] Ministry of Economy, Trade and Industry (METI). 2017. "Basic Hydrogen Strategy". METI.
[224] Nagashima, Monica. 2018. "Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications." Études de l'Ifri. Institut français des relations internationales (Ifri). P. 18
[225] Ibid. P. 26-32

This explains the persistent dependence on national subsidies and the formation of the JHyM consortium to pool investment and de-risk station operations.

For system-level LCOH, the Hydrogen Factsheet – Japan offers one of the most comprehensive comparative estimates across domestic and import-based supply chains. For Japan as the demand centre, the factsheet reports the following indicative LCOH ranges for generic low-carbon hydrogen:[226]

Table 4. Cost of low-carbon hydrogen in Japan (US$/kg H_2, including shipping for imports)

Year	**Baseline scenario**	**Optimistic scenario**	**Policy reference target**
2020	≈7.0–7.1		–
2030	≈4.9–5.5	≈3.7–4.8	≈3 US$/kg (≈¥30/Nm³)
2050	≈3.1–4.2	≈1.9–3.3	<2 US$/kg (≈¥20/Nm³)

These ranges already incorporate declining electrolyser CAPEX, higher load factors and cheaper renewables in exporting regions. Even the optimistic scenario suggests that achieving ≈US$3/kg by 2030 and <US$2/kg by 2050 will be challenging, especially once distribution and retail margins are added for transport use.

Domestic critical voices such as the Renewable Energy Institute (REI) argue that green hydrogen produced in Japan itself will remain significantly more expensive. Using government assumptions for electrolyser costs and realistic projections for domestic solar PV, REI estimates around US$4.5/kg for domestic green hydrogen in 2030—roughly 1.6 times higher than the implied government target of ≈US$2.7/kg (based on ¥30/Nm³).[227] The report attributes the gap mainly to

[226] Sieler, Roman Eric, Lisa Cames, Bianca Schuster, Sören Borghardt, and Benjamin La Trobe. 2021. "*Hydrogen Factsheet – Japan*". adelphi.
[227] Renewable Energy Institute. 2022. "*Re-examining Japan's Hydrogen Strategy: Moving Beyond the 'Hydrogen Society' Fantasy*". Renewable Energy Institute. P. 12-15

high renewable electricity prices, grid constraints and relatively slow deployment compared with Europe.

For the transport sector, the relevant metric is the delivered cost of hydrogen at hydrogen refuelling stations. Combining the H2 Factsheet's optimistic 2030 LCOH for imports (≈US$3.7–4.8/kg) with Nagashima's station-level analysis suggests that, without very high station utilisation and continued subsidies, retail prices are likely to remain well above gasoline or diesel on a per-kilometre basis by 2030. [228] [229]

Forward-Looking Cost Trajectories: Imported Supply

Because domestic renewables remain costly, policy documents and industry analyses converge on a supply strategy that leans heavily on imports. Early modelling focused on Australian coal-based hydrogen with carbon capture and storage, Norwegian natural gas–based hydrogen with CCS, and Middle Eastern oil-based hydrogen. Even in these resource-rich cases, delivered costs to Japan for low-carbon hydrogen around 2030 were projected at roughly US$0.22–0.29/Nm³. [230]

More recent work widens the lens to derivatives. The Hydrogen Council's Global Hydrogen Compass 2025 and APERC's 2024 report suggest that low-carbon ammonia imported into Japan for power co-firing is likely to cost around US$650–750/t in early projects, which remains well above the cost of unabated coal. [231] [232] The implication is that neither domestic nor imported low-carbon hydrogen will become "cheap" in Japan by itself; large-scale deployment requires policy instruments to bridge the gap to incumbent fuels.

[228] Nagashima. 2018. P. 30-33
[229] Sieler. 2021. P. 15-17
[230] Nagashima. 2018. P. 23-25
[231] Hydrogen Council. 2025. "*Global Hydrogen Compass 2025: Industry Progress and Lessons Learned from the First Wave of Mature Clean Hydrogen Projects*". Hydrogen Council.
[232] Asia Pacific Energy Research Centre (APERC). 2025. "*APERC Hydrogen Report 2024: Perspectives of Hydrogen in the APEC Region"*. Asia Pacific Energy Research Centre.

Domestic green hydrogen faces particular headwinds. REI stresses that unless Japan reforms grid access, accelerates solar and wind deployment and lowers financing costs, domestic green hydrogen will struggle to reach 30/20 yen/Nm³ price benchmarks even by 2050. [233] Liebreich's global analysis supports this general conclusion: Japan's electricity cost structure is not among the world's most favourable for ultra-low-cost electrolysis.[234]

For transport applications, this means that imported low-carbon hydrogen may not automatically deliver lower pump prices than domestic green hydrogen once shipping, liquefaction or conversion (e.g. to ammonia or methylcyclohexane) and reconversion are taken into account. Under realistic assumptions, both supply routes appear to require sustained government support if hydrogen is to gain market share in heavy-duty mobility.

National and Subnational Support Architecture: From Capital Subsidies to Price-Gap Contracts

In the 2010s, support concentrated on R&D and capital subsidies. Through the New Energy and Industrial Technology Development Organization (NEDO), the state financed large demonstration projects for hydrogen carriers and international supply chains, including liquefied hydrogen transport from Australia and the Fukushima Hydrogen Energy Research Field. In parallel, national programmes subsidised up to roughly half of HRS construction costs and part of operating costs, yet station economics remained weak, prompting the establishment of Japan H_2 Mobility (JHyM) in 2018 to coordinate private and public investment. [235]

A major turning point came with the 2020 Green Growth Strategy and the creation of the Green Innovation Fund (GIF), a ten-year ¥2 trillion programme managed by NEDO. Hydrogen and ammonia supply chains constitute one of its twelve priority fields, with several hundred billion yen earmarked for large-scale

[233] Renewable Energy Institute. 2022. P. 18-21
[234] Liebreich, Michael. 2023. "*Clean Hydrogen's Missing Trillions*." BloombergNEF.
[235] Nagashima. 2018. P. 30-32

low-carbon hydrogen and ammonia projects.[236] The GIF blends capital grants with performance-based payments linked to cost and emissions milestones, signalling a shift from pure RD&D to cost-oriented industrial policy.

Analyses by the Hydrogen Council describe the core instrument foreseen under the Act as a contract-for-difference (CfD)-type scheme administered by the Japan Organization for Metals and Energy Security. [237] Selected low-carbon hydrogen, ammonia and e-fuel projects would receive payments covering the difference between their actual cost and a reference price based on fossil fuel alternatives plus an implicit carbon price; if low-carbon fuels become cheaper, payments could reverse. Estimates by IEEJ slides suggest that on the order of ¥3 trillion could be mobilised over time for such price-gap contracts, in addition to the GIF. [238]

External observers interpret this as a qualitative shift. CSIS argues that Japan is moving from "subsidising hardware" to underwriting operating economics over long periods, thereby providing revenue certainty and enabling final investment decisions for large hydrogen projects.[239] JETRO similarly frames CfD-type support as essential for achieving the government's goal of reducing hydrogen prices from roughly US$1/Nm³ in the late 2010s to around US$0.30/Nm³ by 2030 and US$0.20/Nm³ by 2050, which roughly maps onto the 30/20 yen/Nm³ targets in official strategies. [240]

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[236] Ministry of Economy, Trade and Industry (METI). 2021. *"Green Growth Strategy Through Achieving Carbon Neutrality in 2050 Formulated.*" Tokyo: METI.
[237] Hydrogen Council. 2025. "*Global Hydrogen Compass 2025: Industry Progress and Lessons Learned from the First Wave of Mature Clean Hydrogen Projects*". Hydrogen Council.
[238] Institute of Energy Economics, Japan (IEEJ). 2025. "*Hydrogen/CCUS Policy for 2025: Challenges toward Social Implementation*." Presentation by Yoshikazu Kobayashi at the 449th Forum on Research Work, 24 December 2024. Institute of Energy Economics, Japan.
[239] Nakano, Jane. 2021. "*Japan's Hydrogen Industrial Strategy."* Washington, DC: Center for Strategic and International Studies (CSIS)
[240] Japan External Trade Organization (JETRO). 2025. "*Japan's Hydrogen Revolution Attracts Global Players*." Japan Insight – Investing in Japan, February. Japan External Trade Organization. Access at: https://www.jetro.go.jp/en/invest/insights/japan-insight/japans-hydrogen-revolution.html

While national policy concentrates on large-scale supply chains and power-sector use, the Tokyo Metropolitan Government illustrates how sub-national authorities can experiment with more granular cost-bridging schemes for mobility.

TMG's 2024 English-language overview sets out a comprehensive "produce, carry, use" approach to hydrogen, underpinned by a hydrogen-related budget of about ¥20.3 billion for FY2024.[241] Key programmes include:

- In coordination with national schemes, TMG offers subsidies covering up to the full capital cost of large stations, with differentiated ceilings for medium and small HRS and higher rates for SMEs.
- TMG provides purchase subsidies for FC buses, trucks, forklifts and port/airport ground support equipment, closing part of the upfront cost gap vis-à-vis diesel technologies.
- Through its "Green Hydrogen Active User Certification System," TMG compensates certified users for the cost difference between domestically produced green hydrogen and a benchmark grey hydrogen price, with separate schemes for on-site and off-site use.

In the context of this thesis, Tokyo exemplifies how regional governments can directly target both capital and operating components of hydrogen cost for specific transport segments, thereby complementing the more generic national CfD and GIF frameworks.

Implications for Decarbonised Mobility

First, Japan's starting point is a high-cost hydrogen system. Historical retail prices around ¥100/Nm³, LCOH estimates of ≈US$5–7/kg in 2020 and ≈US$3.7–5.5/kg even in optimistic 2030 scenarios, and critical domestic assessments of

[241] Tokyo Metropolitan Government, Bureau of Industrial and Labor Affairs. 2024. "*TMG's Efforts to Expand and Promote the Use of Hydrogen Energy*". Tokyo: Tokyo Metropolitan Government.

domestic green hydrogen costs all point to persistent cost disadvantages relative to gasoline, diesel and LNG.

Second, Japanese policymakers have adopted explicit and ambitious numerical cost targets and embedded them into strategies and laws. The 17/12 yen/kWh benchmarks for hydrogen power and the 30/20 yen/Nm³ benchmarks for hydrogen as a commodity back-cast stringent LCOH requirements and shape project evaluation and industrial policy priorities.

Third, Japan has begun to shift from technology-centric to price-centric support instruments. The Hydrogen Society Promotion Act's CfD-type schemes, the Green Innovation Fund's performance-linked disbursements and TMG's operational subsidies and exchange pilots all indicate a move towards stabilising effective hydrogen prices for users rather than merely funding hardware.

The state's willingness to articulate aggressive cost targets and to deploy large-scale price-gap instruments will be decisive for whether low-carbon hydrogen can achieve meaningful penetration in transport, especially in heavy-duty segments.

4.2.5 Infrastructure Readiness and Spatial Integration

Japan's hydrogen infrastructure for transport has developed earlier and more visibly than in most countries, but remains uneven across three critical subsystems: hydrogen refuelling stations, transport and storage networks (including ports and prospective pipelines), and electrolyser capacity.

Hydrogen Refuelling Station Network

Japan began building an HRS network in the mid-2010s as part of its "hydrogen society" narrative, targeting fuel cell vehicles and buses ahead of most other countries.[242] Early stations were highly capital-intensive "first-of-a-kind"

[242] Isenstadt, A., & Lutsey, N. 2017. "*Developing hydrogen fueling infrastructure for fuel cell vehicles: A status update*". International Council on Clean Transportation (ICCT).

facilities clustered around the Tokyo–Nagoya–Osaka corridor and key metropolitan areas such as Fukuoka and Kobe, reflecting a strategy of showcasing technological leadership rather than maximising cost-effective coverage.[243] The creation of the Japan H_2 Mobility consortium in 2018 – pooling resources of automakers, gas utilities and trading houses – institutionalised this corridor-focused rollout model, with strong central government co-funding and standardised station designs.

Quantitatively, Japan has moved from several dozen commercial HRS in 2015 to one of the largest networks worldwide. Samsun et al. estimate that Japan already ranked among the top three HRS countries globally by 2021, with over 140 stations in operation or under construction[244]; Zhu shows that by end-2023 Japan operated roughly 160 HRS, placing it alongside China, Korea and Germany as one of four markets with more than 100 open stations.[245] However, growth has slowed relative to original ambitions: Japan's first Basic Hydrogen Strategy envisaged 320 HRS by 2025 and 900–1,000 by 2030, targets that current trajectories appear unlikely to meet.

Geographically, stations are heavily concentrated in a few prefectures. Metropolitan Tokyo and adjoining Kanagawa, Aichi (Nagoya) and Osaka prefectures (Figure 17) host dense clusters of HRS co-located with high-income FCV markets and existing city-gas infrastructure, while much of rural Japan has no access at all. [246] This pattern mirrors Japan's focus on passenger FCVs, company fleets and municipal fuel-cell buses, often serving showcase corridors (airport links, Olympic routes) rather than long-haul freight. Samsun et al. emphasize Japan's particularly high share of 70 MPa light-duty stations relative to heavy-duty dedicated infrastructure, in contrast to emerging European truck corridors.

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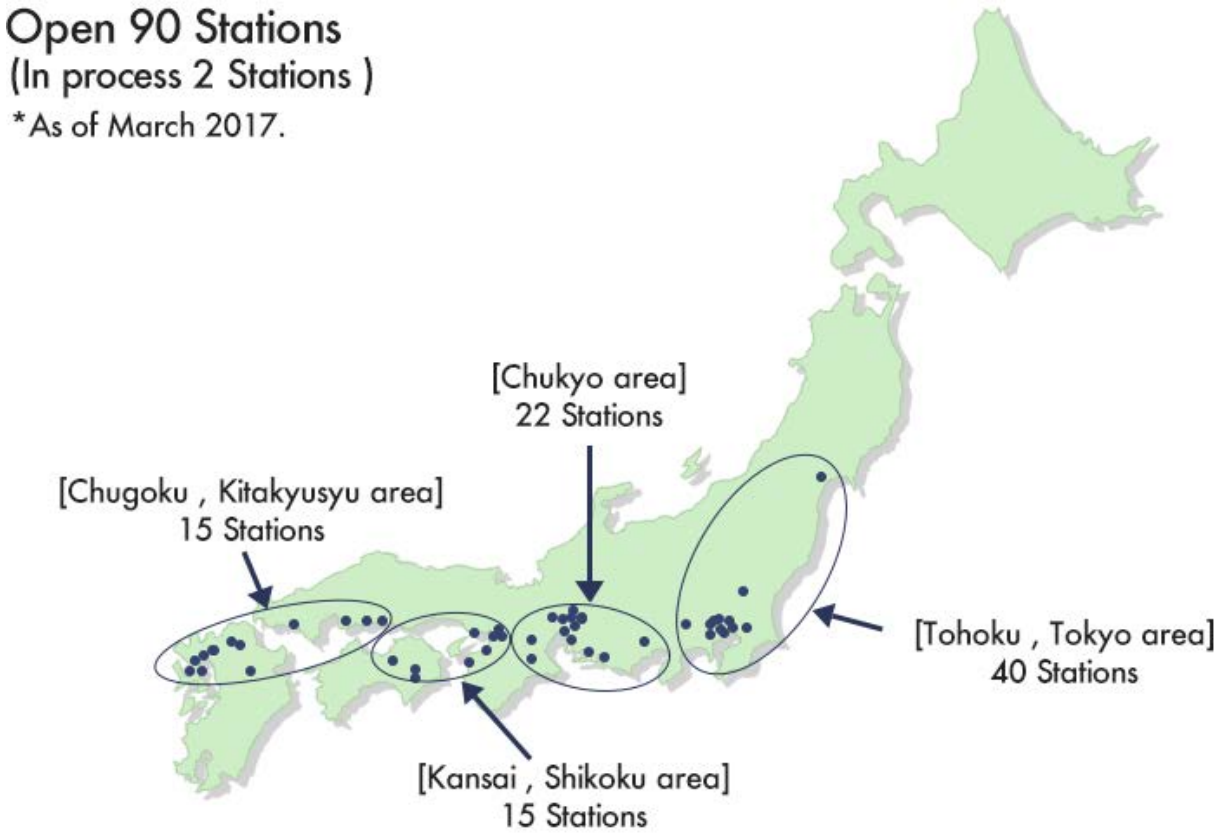
[243] Popov, S., & Baldynov, O. 2018. "*The Hydrogen Energy Infrastructure Development in Japan*". E3S Web of Conferences, 69, 02001. DOI: 10.1051/e3sconf/20186902001

[244] Samsun, R. C., Rex, M., Antoni, L., & Stolten, D. 2022. "*Deployment of Fuel Cell Vehicles and Hydrogen Refueling Station Infrastructure: A Global Overview and Perspectives*". Energies, 15(14), 4975. DOI: 10.3390/en15144975

[245] Zhu, S. 2024. "*Where are the world's 1,100 hydrogen refueling stations located*?" Interact Analysis (Commercial Vehicles Insight), August 2024

[246] Arias, J. 2019. "*Hydrogen and Fuel Cells in Japan*." EU-Japan Centre for Industrial Cooperation, Tokyo (Minerva Report)

Figure 17: Hydrogen Station Map in Japan as of March 2021



Source: Fuel Cell Commercialization Conference of Japan (FCCJ)

Station utilisation remains a structural weakness. Low FCV sales, driven by high vehicle prices and limited model diversity, mean that many stations operate at a fraction of their design throughput, inflating delivered hydrogen costs. [247] Hydrogen Council and McKinsey note that such under-utilisation is a central reason why hydrogen mobility infrastructure investments worldwide face an "investment gap" relative to announced projects, with HRS accounting for a large share of the missing capital. [248]

Social acceptance is a further constraint. Survey-based research in Japan shows that local support for HRS and related infrastructure is shaped less by abstract risk attitudes and more by perceived local benefits, fairness and trust in operators.

[247] Ohno, T., Nishida, Y., Ishihara, T., & Hirose, A. 2022. "*Moving Beyond the "Hydrogen Society" Fantasy: Re-examining Japan's Hydrogen Strategy*". Renewable Energy Institute
[248] Hydrogen Council & McKinsey. 2023. "*Hydrogen Insights 2023*". Industry report (May 2023) – Key data on H_2 deployment.

[249] Earlier work on public perception already identified safety concerns and lack of familiarity as barriers to station siting in Japanese municipalities. These findings reinforce that infrastructure readiness is not purely a question of physical assets but also of "social licence".

Looking ahead, the revised Basic Hydrogen Strategy and the 2024 Hydrogen Society Promotion Act envisage maintaining and modestly expanding the HRS network, but with more emphasis on multi-purpose hubs serving both mobility and nearby industrial users and with long-term revenue support through contract-for-difference mechanisms. In governance terms, this reflects a shift from purely technology-demonstration infrastructure towards integrating HRS into regional hydrogen hubs and national decarbonisation planning.

Transport and Storage Infrastructure: Pipelines, Logistics and Ports

Whereas European hydrogen visions often rely on repurposed gas pipelines, Japan's hydrogen transport infrastructure is dominated by trucked hydrogen and maritime supply chains rather than dedicated hydrogen pipelines. Existing hydrogen is produced mainly as by-product in petrochemical clusters and delivered via tube trailers or small-scale pipelines over short distances to refineries and industrial users; no nationwide hydrogen trunk pipeline network exists. [250] IEEJ explicitly frames "domestic transportation and storage" as a separate support category under the forthcoming CfD-like schemes, indicating that pipeline infrastructure is still at the planning rather than implementation stage. [251]

Policy documents and scenarios therefore largely envisage a port-and-hub model: hydrogen or derivatives such as ammonia and methylcyclohexane are imported by ship to industrial ports, then distributed regionally by truck or shorter

[249] Huan, N., Yamamoto, T., Sato, H., et al. 2025. "*Value perceptions outweigh contextual orientations in local support for hydrogen infrastructure*". Communications Earth & Environment, 6(1), Article 3029.
[250] Popov, S., & Baldynov, O. 2018. "*The Hydrogen Energy Infrastructure Development in Japan*". E3S Web of Conferences, 69, 02001. DOI: 10.1051/e3sconf/20186902001
[251] Institute of Energy Economics, Japan (IEEJ). 2024. "*Hydrogen/Ammonia Policy Challenges for 2024 (Summary)*". IEEJ, February 2024

pipelines. Japan's long-term carbon-neutrality strategy assumes substantial imports of low-carbon hydrogen from North America, Australia, the Middle East and Africa, leveraging established LNG port infrastructure and new liquid hydrogen, ammonia or LOHC terminals. Mizuho Bank's analysis of Japan–Africa green hydrogen cooperation similarly treats export ports in Namibia and other African states and import terminals in Japan as the backbone of future trade, not transcontinental pipelines.[252]

Empirical work on hydrogen ports confirms that, while Japan is considered a frontrunner, actual port-side readiness remains low. Chen et al. combine interviews and surveys in Japan and Australia and find that Japanese ports such as Kobe, Yokohama and Kawasaki are engaged in demonstration projects for liquid hydrogen and ammonia bunkering, but score modestly on infrastructure sufficiency, workforce training and standardisation compared with what would be required for large-scale trade. The study stresses that integration of port hydrogen facilities with hinterland demand – including fuel supply for heavy-duty trucks and port equipment – is still nascent, and that port authorities perceive regulatory uncertainty and social acceptance as key barriers. [253]

Real-world demonstrations illustrate both the potential and limits of current infrastructure. The Suiso Frontier project – the world's first liquefied hydrogen carrier developed by Kawasaki Heavy Industries – completed pilot shipments from Australia to Kobe, requiring the construction of dedicated LH_2 liquefaction, storage and regasification facilities at both ends of the supply chain. [254] While technologically successful, the demonstration highlighted the high CAPEX and energy losses of LH_2 chains, reinforcing the attractiveness of ammonia and LOHC imports on cost grounds in the medium term.

[252] Mizuho Bank Industry Research Division. 2023. "*How Japan Can Win the Global Competition for Hydrogen: Mizuho's vision for a hydrogen supply and demand structure*". (Private and confidential report)
[253] Chen, P. S.-L., Fan, H., Enshaei, H., et al. 2024. „*Opportunities and Challenges of Hydrogen Ports: An Empirical Study in Australia and Japan*". Hydrogen, 5(3), 436–458. DOI: 10.3390/hydrogen5030025
[254] Hydrogen Council. 2022. "*Toward a new era of hydrogen energy: Suiso Frontier built by Japan's Kawasaki Heavy Industries*". Case Study, Oct 4, 2022

From the perspective of transport decarbonisation, the current infrastructure mix implies that hydrogen fuel for vehicles in Japan will, for the foreseeable future, often arrive as imported molecules into major ports and then be trucked to HRS in metropolitan regions, rather than being produced at scale near demand centres and distributed via pipelines. Nevertheless, recent policy developments push in the direction of more coherent hub-and-spoke networks. The Hydrogen Society Promotion Act and associated Basic Policy envisage publicly supported "hydrogen hubs" combining import terminals, storage, distribution pipelines and end-users, including mobility applications, with revenue support for both domestic and overseas production plus marine transport. In this model, dedicated hydrogen pipelines may emerge within regional hubs – for example, between port terminals, industrial estates and logistics centres – but not as a nationwide backbone akin to gas grids in Europe.

Electrolyser Deployment

Electrolysers occupy a dual role in Japan's hydrogen infrastructure: as physical assets producing green hydrogen and as a technology domain in which Japanese firms seek to maintain global competitiveness. Yet, despite strong R&D capabilities, Japan's installed electrolysis capacity remains modest relative to its hydrogen demand ambitions.

Sieler et al. estimate that, as of 2021, Japan had only around 19 electrolysis plants with a combined capacity of roughly 12 MW, mostly small demonstration units integrated into power-to-gas or microgrid projects. The flagship exception is the Fukushima Hydrogen Energy Research Field (FH2R) in Namie, where Asahi Kasei installed a 10 MW alkaline water electrolysis system in 2020 – then one of the world's largest single units – powered mainly by local solar PV and grid-balancing electricity. [255] FH2R is explicitly framed as a testbed for coupling large-scale

[255] Sieler, R. E., Cames, L., Schuster, B., Borghardt, S., & La Trobe, B. 2022. „*Hydrogen Factsheet – Japan*". adelphi (Germany)

electrolysis with variable renewables and market-based power system operation, but it is not a commercial source for nationwide hydrogen supply.

IEEJ points out that Japan's Basic Hydrogen Strategy seeks to expand the share of Japanese electrolysis equipment in global markets, yet acknowledges that European and Chinese manufacturers currently dominate order books for large projects. [256] At the same time, hydrogen governance analyses emphasise that electrolysers are central to the new support schemes introduced under Japan's Hydrogen Society Promotion Act. Osaki and Hughes describe how the Act's CfD-style mechanism is designed to support both domestic and overseas low-carbon hydrogen projects, including electrolysis, with "production base development" funds explicitly targeting domestic transport and storage infrastructure. [257]

Electrolyser infrastructure also interacts with the HRS network. Locating electrolysers near refuelling stations offers the prospect of decentralised green hydrogen supply, reducing transport costs and demonstrating truly low-carbon mobility. However, given high electricity prices, grid carbon intensity and limited space in dense Japanese cities, most existing stations rely on delivered hydrogen produced elsewhere.

Across the three subsystems, Japan's hydrogen infrastructure readiness for transport is relatively advanced but unbalanced. The HRS network is among the world's largest but geographically concentrated, under-utilised and dependent on public funding and social acceptance, with corridor-based deployment outpacing true nationwide coverage. Transport and storage infrastructure prioritise maritime imports and port-centric hydrogen hubs over domestic pipelines, embedding Japan's traditional import dependence in a new carrier mix of liquid hydrogen, ammonia and LOHCs. Electrolyser deployment, finally, remains limited to a few flagship projects

[256] Institute of Energy Economics, Japan (IEEJ). 2024. "*Hydrogen/Ammonia Policy Challenges for 2024 (Summary)*". IEEJ, February 2024

[257] Osaki, Y., & Hughes, L. 2025. "*Japan: Putting Hydrogen at the Core of Its Decarbonisation Strategy*". In R. Quitzow & Y. Zabanova (Eds.), The Geopolitics of Hydrogen. Springer, Cham. DOI: 10.1007/978-3-031-84022-7_5

such as FH2R and small-scale demonstrations, leaving domestic green hydrogen production a secondary pillar relative to imported supply despite strong technological capabilities.

4.2.6 Market Uptake and Transport Implementation

Japan has been one of the earliest and most visible proponents of a "hydrogen society", with transport positioned from the outset as a flagship end-use. The Basic Hydrogen Strategy adopted by the Ministry of Economy, Trade and Industry in 2017 set explicit numerical targets for 800,000 fuel cell electric vehicles and roughly 900 hydrogen refuelling stations by 2030, embedding hydrogen mobility in a broader narrative of energy security, industrial competitiveness and climate mitigation.[258] At the same time, critical observers have pointed out that the realised market remains modest relative to these ambitions and that hydrogen in transport competes with more mature battery-electric and efficiency options. This section situates Japan's hydrogen vehicle market within that broader policy trajectory, examining (i) the evolution and structure of the hydrogen vehicle fleet, (ii) spatial distribution and regional policy "hotspots", (iii) lead firms and industrial coalitions, (iv) investment patterns and economic viability, and (v) emerging multi-modal pilots in rail, maritime and aviation.

Evolution and Structure of the Hydrogen Vehicle Fleet

Japan's hydrogen vehicle fleet remains very small in absolute terms and almost negligible relative to the country's 78 million-strong vehicle stock, but it is one of the largest and most diversified hydrogen fleets globally. The most consistent recent snapshot comes from the International Energy Agency's Technology Collaboration Programme on Advanced Motor Fuels (IEA AMF). Its 2024 country report for Japan, based on data from the Automobile Inspection & Registration Information Association (AIRIA) and the Agency for Natural Resources and Energy, records 8,051 fuel cell vehicles in operation as of March 2023. Of these, 7,748 were

[258] Ministry of Economy, Trade and Industry (METI). 2017. "Basic Hydrogen Strategy". Tokyo: METI, October.

passenger vehicles, 102 trucks, 160 buses and 41 special vehicles, such as refuse trucks or other specialised fleets. [259]

Back-casting from these values illustrates the slow but steady expansion of the fleet and the subsequent stagnation. Japan had deployed around 5,170 FCVs in 2020, implying growth of roughly 55% over three years to just above 8,000 vehicles by early 2023.[260] Global deployment studies by Samsun and co-authors similarly show Japan as an early leader with 3,700–5,000 FCVs in the late 2010s, but overtaken in absolute numbers by Korea and China during the 2020s. More recent market data, however, point to very weak incremental growth after 2021. According to Japan Automobile Dealers Association (JADA) statistics reported by Hydrogen Insight and summarised by Erofeev, annual FCEV car sales fell from 2,464 units in 2021 to 848 in 2022 and just 422 in 2023, an 83% drop over two years. [261]

Within this small national total, the Tokyo Metropolitan Government has emerged as the single most important regional cluster. TMG statistics show 1,539 registered FCVs in Tokyo alone as of end-March 2023 (about one fifth of the national fleet), reflecting a decade of targeted subsidies to households, car-sharing operators and corporate fleets. The same dataset records 109 fuel cell buses in operation in Tokyo by November 2023, while international reviews of fuel cell bus deployment report around 120 FCBs for Japan as a whole at the end of 2022, confirming that Tokyo accounts for the bulk of the national fuel cell bus fleet. For light and medium commercial hydrogen vehicles, TMG reports 39 light-duty fuel cell trucks operating in the Tokyo area by late 2023, in addition to demonstration

[259] International Energy Agency (IEA), Advanced Motor Fuels Technology Collaboration Programme (AMF TCP). 2024. "*Advanced Motor Fuels Annual Report 2024*". Paris: International Energy Agency. P. 80.
[260] Institute of Industrial Science, The University of Tokyo. 2025. "*Hydrogen: Energy Vital for Net Zero*." UTokyo-IIS Possible Future online magazine, 2 September 2025. Accessed at: https://magazine.iis.u-tokyo.ac.jp/en_article/p_2870
[261] Erofeev, Yury. 2024. "*Sales of Hydrogen Cars in Japan Have Fallen by 83% over the Past Two Years*." Medium, January 22, 2024. Access at: https://medium.com/@erofeev.yury/sales-of-hydrogen-cars-in-japan-have-fallen-by-83-over-the-past-two-years-370236fd27d5

garbage trucks and forklifts, indicating that the modest national volumes of fuel cell trucks are highly concentrated in a few metropolitan logistics corridors. [262]

Taken together, these sources provide a coherent order-of-magnitude estimate: Japan currently operates on the order of eight thousand road-going hydrogen fuel cell vehicles across all categories, with passenger cars (primarily the Toyota Mirai and a small number of Honda Clarity and imported Hyundai Nexo vehicles) comprising roughly 96 % of the fleet, and several hundred vehicles distributed across buses, trucks and special applications.[263] Despite Japan's early framing of itself as a "hydrogen society", the absolute numbers remain extremely low relative to battery electric vehicles and to the government's own target of 800,000 passenger FCEVs on the road by 2030, which implies two orders of magnitude growth from today's fleet.

Lead Firms, Vehicle Platforms and Industrial Coalitions

Japan's hydrogen transport trajectory is strongly shaped by the strategic choices of a small set of lead firms – above all Toyota – and by a dense web of industrial coalitions that seek to spread the risks of high-capex hydrogen technologies across multiple actors. Toyota's long-standing fuel cell research programme underpins most of the country's on-road hydrogen vehicles: the Mirai passenger car, the Sora fuel cell bus, fuel cell forklifts, and stacks supplied for trains, trucks and marine applications. Toyota explicitly presents its fuel cell system as a modular technology to be deployed across a diverse range of hydrogen applications.

The centre of gravity of industrial strategy is now shifting from passenger cars to commercial vehicles. Recognising that light-duty consumer FCEVs have not achieved mass-market adoption, Toyota, Isuzu and Hino established Commercial

[262] Tokyo Metropolitan Government (TMG), Bureau of Industrial and Labor Affairs. 2023. "*Tokyo Metropolitan Government's Efforts to Expand and Promote the Use of Hydrogen Energy*." Tokyo: Tokyo Metropolitan Government. Access at: https://www.tokyo-h2-navi.metro.tokyo.lg.jp/assets/pdf/torikumi/situation/torikumi_english_202312.pdf

[263] King, Logan. 2024. "*Tokyo Opts for Hydrogen and Promotes Fuel Cell Commercial Vehicles*." Hydrogen Today, April 10, 2024. Access at: https://hydrogentoday.info/en/tokyo-hydrogen-vehicles/

Japan Partnership Technologies (CJPT) to co-develop light-duty fuel cell trucks explicitly "for the mass market".[264] Under a joint initiative announced in July 2022, the three companies and CJPT committed to planning and developing small fuel cell trucks for urban logistics, arguing that high utilisation and depot-based refuelling make this segment more suitable for hydrogen than private cars. TMG's hydrogen strategy document shows these CJPT light-duty trucks as core beneficiaries of its "Early Implementation Project for ZEV Trucks", which provides purchase subsidies of up to 13 million yen per vehicle and aims to create early hydrogen freight corridors in and around Tokyo. By late 2023, TMG reported 39 light-duty fuel cell trucks in operation in the metropolitan area, indicating that the coalition between CJPT and the city government has begun to translate into real, if still modest, deployments. [265]

For the heavy-duty segment, Isuzu Motors and Honda Motor Co. have formed a separate strategic alliance that treats fuel cells as a key technology for decarbonising long-distance trucking. In December 2023 the companies began public-road demonstration testing of the GIGA Fuel Cell heavy-duty truck, co-developed using Honda's fuel cell systems and Isuzu's truck platform.[266] In their joint statements, Isuzu and Honda explicitly argue that fuel cells are "effective in achieving carbon neutrality for heavy-duty trucks, which require high efficiency for long-distance driving and large load capacity" – a line of reasoning that mirrors international techno-economic assessments distinguishing trucks from passenger cars.

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[264] Isuzu Motors Limited, Toyota Motor Corporation, Hino Motors, Ltd., and Commercial Japan Partnership Technologies Corporation (CJPT). 2022. "*Isuzu, Toyota, Hino, and CJPT to Promote Planning and Development of Mass-Market Light-Duty Fuel Cell Electric Trucks*." Toyota Global Newsroom, 19 July 2022. Access at: https://global.toyota/en/newsroom/corporate/37544772.html

[265] Tokyo Metropolitan Government (TMG), Bureau of Industrial and Labor Affairs. 2023. "*Tokyo Metropolitan Government's Efforts to Expand and Promote the Use of Hydrogen Energy*". Tokyo: Tokyo Metropolitan Government, p. 9. Access at: https://www.tokyo-h2-navi.metro.tokyo.lg.jp/assets/pdf/torikumi/situation/torikumi_english_202312.pdf

[266] Honda Motor Co., Ltd., and Isuzu Motors Limited. 2023. "*Isuzu and Honda Begin Demonstration Testing Today of Fuel Cell-Powered Heavy-Duty Truck on Public Roads in Japan*." Honda Global Newsroom, 22 December 2023. Access at: https://global.honda/en/newsroom/news/2023/c231222eng.html

Toyota-group company Hino Motors is simultaneously preparing to launch Japan's first mass-produced heavy-duty fuel cell truck, the Profia Z FCV. According to industry reporting, Hino plans to release the Profia Z FCV in late 2025, positioning it as Japan's first commercial hydrogen-powered truck, with support from Toyota's fuel cell technology.[267] The Profia Z FCV is designed for regional and long-haul distribution and will compete directly with battery-electric and diesel trucks in the domestic market.

Industrial coalitions extend beyond manufacturers to include local governments and service operators. In the taxi segment, for example, Toyota and TMG agreed in 2025 to promote fuel cell taxis in Tokyo. The city set a goal of deploying 600 fuel cell taxis by 2030–2031 and 10,000 commercial FCEVs by the mid-2030s, while Toyota committed to supplying 200 Crown FCEVs as taxis in the first phase and TMG pledged subsidies to bridge the price gap with conventional vehicles. [268]

Investment Patterns and Economic Viability

Japan's investment pattern in hydrogen transport is characterised by large, multi-level public spending on RD&D, infrastructure and operating subsidies, combined with innovative risk-sharing instruments such as CfD-style price support. The scale of committed and actual public investment is very large relative to the small size of the FCEV fleet. National strategy documents speak of more than JPY 15 trillion in expected hydrogen investments and create a JPY-trillion-scale CfD facility, while NEDO alone deployed close to JPY 30 billion for hydrogen and fuel cell RD&D in FY2019 and continues to fund large projects such as FH2R. [269]

[267] Parikh, Sagar. 2025. "*Hino Unveils Japan's First Mass-Produced Fuel Cell Heavy-Duty Truck*." electrive.com, 23 September 2025. Access at: https://www.electrive.com/2025/09/23/hino-unveils-japans-first-mass-produced-fuel-cell-heavy-duty-truck/

[268] Toyota Motor Corporation. 2025. "*Toyota Joins TOKYO H2 Project Aiming to Make Tokyo a Global Leader in Hydrogen*." Toyota Global Newsroom, 3 September 2025. Access at: https://global.toyota/en/newsroom/corporate/43271693.html

[269] Hara, Daishu. 2020. "*Hydrogen and Fuel Cell Development in Japan: NEDO's Role and Programs.*" Presentation at the 8th FC (Fuel Cell) International Meeting, Fuel Cell Development Information Center (FCDIC),

Empirical evidence indicates that even with generous subsidies, FCEVs are not yet cost-competitive with BEVs or high-efficiency hybrids in light-duty segments. Nishitateno quantifies that a Mirai remains roughly 35–47% more expensive than directly competing electrified models after applying national and Tokyo subsidies, and notes that adoption has been "notably sluggish" relative to BEVs and PHEVs. [270] On the infrastructure side, off-site HRSs require around USD 3.3 million in upfront investment and USD 220,000 per year in operating costs; even with two-thirds of these costs subsidised, low station utilisation implies long payback periods and significant residual risk for private operators. The Japanese case therefore illustrates a governance model where economic viability is not yet a precondition but an aspirational outcome of sustained public investment—an important contrast point for the cross-country comparison in later chapters.

Beyond Road Transport: Rail, Maritime and Aviation

Japan's hydrogen strategy has also extended beyond road vehicles into rail, maritime transport and aviation, motivated both by the search for new demand and by the desire to demonstrate integrated hydrogen supply chains. In rail, Toyota and East Japan Railway Company (JR East) developed the HYBARI fuel cell hybrid train. According to Toyota's 2020 announcement, HYBARI combines hydrogen fuel cells with lithium-ion batteries and has been tested on non-electrified lines with a view to potential commercial operation in the 2030s.[271] While the train consumes relatively modest volumes of hydrogen compared to heavy-duty truck fleets, it plays an important signalling role: it demonstrates that fuel cell systems can be integrated into rolling stock and that hydrogen can serve as an alternative to full electrification on low-density regional lines.

Tokyo, 25 February 2020. New Energy and Industrial Technology Development Organization (NEDO). Access at: https://www.fcdic.jp/pdf/FC%20International%20Meeting/The%208th%20FC%20International%20Meeting/%281%29Dr.%20DHara%20Taishu%20NEDO.pdf

[270] Nishitateno, Shuhei. 2025. "*Hydrogen Infrastructure, Fuel Cell Electric Vehicles, and Indirect Network Effects: Evidence from Japan*". RIETI Discussion Paper Series 25-E-045, May 2025. Tokyo: Research Institute of Economy, Trade and Industry (RIETI). Access at: https://www.rieti.go.jp/jp/publications/dp/25e045.pdf

[271] Toyota Motor Corporation. 2020. "*Japan's First Hydrogen Fuel Cell Train 'HYBARI' Starts Operation*." Toyota Global Newsroom, 8 October 2020. Access at: https://global.toyota/en/newsroom/corporate/33954855.html

Maritime pilots have focused on both hydrogen as cargo and hydrogen as fuel. Kawasaki Heavy Industries' Suiso Frontier project realised the world's first liquefied hydrogen carrier and completed a demonstration voyage between Australia and Japan, showcasing the technical feasibility of long-distance LH_2 shipping.[272] The vessel is part of a broader value-chain demonstration including liquefaction, loading and unloading infrastructure, which aligns with Japan's strategy of importing large volumes of hydrogen from resource-rich partners. While the initial hydrogen cargo for Suiso Frontier was not low-carbon, the project is significant for hydrogen mobility because it validates a logistical option for future imports to feed domestic transport demand.

On the fuel side, Kawasaki Heavy Industries announced in 2025 that, together with Yanmar, it had successfully demonstrated the world's first operation of a compact marine hydrogen engine under the IHPS project.[273] The demonstration involved a hydrogen-fuelled internal combustion engine for small vessels, providing a technological basis for future hydrogen-powered coastal and harbour boats. Hydrogen Council notes that such pilot projects are proliferating globally, but that Japan remains distinctive in its focus on integrating marine engines with upstream LH_2 or ammonia supply chains, a strategy that mirrors its broader emphasis on carrier-based hydrogen imports. [274]

The aviation sector represents the most nascent but symbolically important extension of Japan's hydrogen mobility agenda. A Reuters report from March 2024 describes a planned multi-trillion-yen programme in which the Japanese government will support the development of next-generation passenger aircraft with reduced environmental impact, explicitly including hydrogen and electric propulsion

[272] Kawasaki Heavy Industries, Ltd. 2019. "*Suiso Frontier: World's First Liquid Hydrogen Carrier Ship Completes Demonstration Voyage*." Kawasaki Global News, 12 November 2019. Access at: https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20191112_8603)
[273] Kawasaki Heavy Industries, Ltd. 2025. "*Kawasaki Heavy and Yanmar Successfully Demonstrate World's First Operation of Marine Hydrogen Engine (Compact PureFuel Engine) – IHPS Project*." Press Release, 20 October 2025. Access at: https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20251020_8887
[274] Hydrogen Council. 2024. "*Hydrogen Insights 2024*". London: Hydrogen Council and McKinsey & Company, September 2024. P. 29-31

concepts alongside sustainable aviation fuels (SAF).[275] In parallel, Japan Airlines (JAL) announced in November 2023 that it had signed a series of agreements with foreign partners to study hydrogen-electric and fuel cell-powered aircraft, focusing on issues such as safety, certification and ground infrastructure requirements at Japanese airports.[276] Although these initiatives are at an exploratory stage, they place hydrogen firmly within the portfolio of decarbonisation options for Japanese aviation, complementing the government's efforts to scale up domestic SAF production.

Interim Assessment

Industrially, Japanese firms such as Toyota, Honda, Isuzu and Kawasaki have developed a wide range of fuel cell, vehicle and shipping technologies, supported by targeted R&D programmes and roadmaps from NEDO and other agencies. Spatially, deployment has clustered in a handful of metropolitan regions where local governments and firms have the capacity to co-invest and experiment.

At the same time, empirical evidence shows that the indirect network effects between vehicles and refuelling infrastructure have so far been weaker than anticipated, especially for passenger cars. Critical analyses argue that part of Japan's hydrogen mobility agenda has been driven by industrial and diplomatic motives – such as showcasing technology at the Olympics or securing roles in future global supply chains – rather than by least-cost decarbonisation of domestic transport. The recent policy pivot toward heavy-duty trucks, buses and multi-modal pilots in rail, maritime and aviation can thus be read as an attempt to realign hydrogen transport with segments where its techno-economic fundamentals are stronger and where

[275] Reuters. 2024. "*Japan to Support Next-Generation Passenger Aircraft Development*." Reuters, 27 March 2024. Access at: https://www.reuters.com/business/aerospace-defense/japan-support-next-generation-passenger-aircraft-development-2024-03-27/

[276] Japan Airlines Co., Ltd. (JAL). 2023. "*JAL Signs Agreements to Advance Development of Hydrogen-Electric Aircraft*." Press Release, 16 November 2023. Access at: https://press.jal.co.jp/en/release/202311/007757.html

Japan's industrial assets – in fuel cell stacks, marine engines and airframe R&D – can be leveraged more effectively.

4.3 Cross-Case Comparative Assessment

4.3.1 Policy Architecture, Legal Force and Certification

Converging Strategic Choices

Both countries have adopted top-level strategies that frame hydrogen as integral to long-term decarbonisation and industrial competitiveness. In China, the Hydrogen Energy Industry Medium- and Long-Term Development Plan (2021–2035) and the New Energy Vehicle Industry Development Plan set indicative FCV deployment goals, call for integrated "oil–gas–hydrogen–electric" networks, and explicitly position transport as an early anchor market within a broader energy transition. In Japan, the Basic Hydrogen Strategy (2017), its 2023 revision and the Green Growth Strategy through Achieving Carbon Neutrality in 2050 specify targets for FCVs and HRS and present hydrogen as a pillar of the "hydrogen society" and green growth.

In both cases, hydrogen-for-mobility is closely tied to industrial strategy. Chinese documents emphasise localisation of key components (stacks, membranes, bipolar plates, compressors) and link vehicle and HRS support to domestic equipment upgrading. Japanese strategies similarly connect FCVs and hydrogen infrastructure to maintaining competitive advantage in fuel cells, hydrogen carriers and engineering services. In this sense, hydrogen transport policy in both countries functions as a bridge between climate goals and techno-industrial upgrading.

On sustainability assurance, convergence is evident in the decision to move away from purely qualitative notions of "clean hydrogen" toward quantified, life-cycle–based thresholds. China's group standard T/CAB 0078-2020 defines low-carbon, clean and renewable hydrogen through specific kg CO_2-equivalent per kg H_2 values calculated on a life-cycle basis, while Japan's Hydrogen Society

Promotion Act and Basic Policy define “low-carbon hydrogen etc.” through a numerical carbon-intensity ceiling informed by international LCA practice. In both regimes, compliance with these criteria is increasingly a condition for accessing major financial-support schemes, whether in the form of pilots, subsidies or contracts-for-difference.

These common choices mean that in both China and Japan, hydrogen-for-mobility is governed through strategic, centre-guided frameworks that combine deployment targets, industrial ambitions and an emerging sustainability metric, rather than being left to fragmented R&D or demonstration programmes.

Vertical Design and Sectoral Scope: Centralised Targets vs Statute-Centred Focus

Despite this convergence, the vertical design and sectoral scope of hydrogen policy differ substantially.

On the Chinese side, hydrogen is embedded in a broad, hierarchical decarbonisation architecture. The Energy Law elevates hydrogen to the legal status of an energy source and provides statutory hooks for market entry, grid interaction and safety governance. The hydrogen industry plan and NEV plan then specify roles for hydrogen across multiple sectors: transport, power, steel, refining, ammonia and methanol. Additional guidance for green and low-carbon industrial transformation, major technical equipment, and raw-materials standardisation extends hydrogen-related rules into diverse regulatory domains.

Crucially, this occurs within the frame of the “dual-carbon” goals—peaking CO_2 before 2030 and achieving carbon neutrality by 2060. Hydrogen-for-mobility is therefore one strand in a system-wide decarbonisation project, not the sole or dominant use case. The same value chains and standards that support hydrogen use in trucks and buses are intended to underpin hydrogen metallurgy, refinery decarbonisation and integration with high-renewable power systems. By 2024–2025,

this has crystallised into a thick body of regulation: hundreds of subnational policies (plans, fiscal measures, management rules), inter-ministerial opinions on transport–energy integration, and a national pilot programme that spans production, logistics, storage and end-use.

Japan's architecture is thinner in volume but sharper in legal focal points and more strongly branded around mobility. A small number of Cabinet-level strategies — the Basic Hydrogen Strategy, the Green Growth Strategy and their revisions — define hydrogen's role for energy security, green growth and 2050 carbon neutrality. The 2024 Hydrogen Society Promotion Act then provides a dedicated statutory backbone for "promoting the supply and use of low-carbon hydrogen and derivatives for a decarbonised growth-oriented economic structure". This Act mandates the government to issue a Basic Policy, define low-carbon criteria and establish support schemes such as CfDs.

While Japanese documents also envisage hydrogen and ammonia in power generation and industrial processes, the narrative focus is narrower: hydrogen is framed as a discrete growth field, and fuel-cell mobility — especially FC buses, trucks and port applications — is repeatedly highlighted as a flagship domain where Japan can showcase integrated supply chains, imported low-carbon hydrogen and advanced FC technology. In other words, Japan's hydrogen regime is more statute-centred and mobility-visible, whereas China's is more plan-centred and system-integrated across the energy–industry nexus.

Centralised Objectives, Decentralised Implementation

Both countries combine central steering with regional roles, but the balance between hierarchy and discretion is different.

China operates a model that can be characterised as centralised in targets, decentralised in implementation. National bodies (NDRC, NEA, MIIT, the Ministry of Transport and others) formulate plans, catalogues and standards, define national

FCV and HRS targets, and issue integrated guidance on transport–energy infrastructure. The NEA's hydrogen pilot programme adds an additional layer, spelling out project categories, application requirements, and safety and supervision arrangements, and assigning provincial agencies concrete responsibilities for siting, land, power interfaces and monitoring.

Provinces and municipalities then translate these objectives into their own plans and instruments. Shanghai, Beijing–Tianjin–Hebei, Shandong, Guangdong, Sichuan, Liaoning and others deploy distinct mixes of capital grants, operating subsidies, toll exemptions, industrial-localisation incentives and safety rules that reflect their comparative advantages (e.g. port logistics, heavy industry, renewable resources). Yet this experimentation is framed by central evaluation cycles, template-based reporting and, in some cases, the possibility of losing pilot status or funds. The result is a strong vertical hierarchy in objective-setting and oversight, combined with regional diversity in policy instruments and project portfolios.

Japan's centre–local interaction is more negotiated and bottom-up. Prefectural and municipal governments – for example in Fukushima, Hokkaido and Hyogo – have developed their own hydrogen "visions" that explicitly link regional reconstruction, renewable resource endowments or port infrastructure to demonstration of FC buses, trucks and port equipment. These regional strategies often pre-date or parallel national documents and are used to position localities as "hydrogen hubs".

The central government, for its part, sets overarching targets and rules (including the low-carbon hydrogen definition) and controls the main funding channels (NEDO-led projects, Green Innovation Fund programmes, CfDs). Implementation in transport hinges on competitive selection: guidelines for "priority areas for promoting the introduction of fuel-cell commercial vehicles" invite local governments and consortia of manufacturers, logistics firms and energy companies to apply for designation, presenting corridor plans, fleet aggregation and safety

management schemes. Access to support depends on satisfying these criteria, but there is less evidence of direct, hierarchical performance management akin to China's evaluation of pilots against centrally designed templates. Japan's regime is thus centralised in rule-setting and budgetary power but more discretionary in local uptake, relying on voluntary alignment and project-based selection rather than mandated implementation quotas.

Sustainability Standards: Thresholds, Boundaries and Governance

The two certification regimes further illustrate both convergence and divergence.

China's group standard T/CAB 0078-2020 creates a three-tier system of "low-carbon", "clean" and "renewable" hydrogen, all defined by life-cycle emissions per kilogram of H_2. It uses relatively wide system boundaries (from feedstock extraction to on-site storage/transport), sets thresholds at 14.51 kg CO_2e/kg for "low-carbon" and 4.9 kg CO_2e/kg for "clean/renewable", and assigns certification to accredited third-party bodies with on-site audits, batch tracking and an explicit ban on using external offsets. The design is MRV-heavy and cross-sectoral: transport is one of several end-uses that can later build on this labelling.

Japan instead adopts a single threshold for "low-carbon hydrogen etc." under the Hydrogen Society Promotion Act and Basic Policy: about 3.4 kg CO_2/kg H_2. For hydrogen and ammonia, this is assessed on a well-to-gate basis (excluding downstream logistics and use); for synthetic hydrocarbons, a full supply chain boundary applies. The standard is deliberately technology-neutral, allowing both renewable and fossil-based (with CCS) pathways as long as calculated emissions stay below the 3.4 kg limit. Verification is predominantly state-centred: ministries and implementing agencies review carbon-intensity claims in the context of CfD and subsidy applications rather than via a separate certification market.

Numerically, Japan's 3.4 kg benchmark is stricter than China's 4.9 kg CO_2e/kg "clean/renewable" threshold, and far below China's "low-carbon" level, even though Japan uses a somewhat narrower boundary. To receive major support in Japan, hydrogen must therefore meet a more demanding nominal standard, while China relies on looser numerical thresholds but tighter third-party MRV embedded in a wider GHG accounting system. In both countries, the formal integration of these certificates into fleet-level transport reporting and target-tracking is still incomplete; the key difference is that Japan already uses its threshold as a hard gatekeeper for CfD-type schemes, whereas China's labels currently play a more foundational, cross-sector role with only gradually emerging links to transport-specific incentives.

Comparative Assessment

Taken together, the comparison suggests that China and Japan share a strategic convergence in treating hydrogen-for-mobility as a planned, centre-guided domain with explicit targets, emerging LCA-based sustainability criteria and strong industrial-policy overtones. At the same time, they have adopted contrasting governance models.

China's regime is broad, hierarchical and system-integrated. Hydrogen is woven into a multi-sector 2030/2060 decarbonisation project, governed through the Energy Law, national plans and dense standardisation work, and pushed into hundreds of provincial and municipal measures under strong central supervision but with significant room for regional experimentation.

Japan's regime is narrower in document volume but more statute-centred and mobility-visible. A small number of Cabinet strategies and the Hydrogen Society Promotion Act provide clear legal focal points; hydrogen is framed as a discrete growth field; and fuel-cell mobility is repeatedly used as a showcase for low-carbon hydrogen imports and domestic technology.

For the decarbonisation of transport, these designs imply that China is building hydrogen as a system resource whose governance is shared with other hard-to-abate sectors and rolled out through vertically disciplined but locally variable implementation. Japan, by contrast, is constructing a legally concentrated, import-oriented and mobility-centric regime in which a single carbon benchmark acts as the main gatekeeper for state-backed hydrogen use in trucks, buses and related applications. Subsequent sections examine how these upstream differences translate into supply strategies, cost profiles, infrastructure build-out and market uptake.

4.3.2 Supply Strategy and Economic Viability

From Grey Industrial Base to Low-Carbon Supply

On the Chinese side, the sheer scale of existing production defines the starting point. China already accounts for roughly one third of global hydrogen output, with total production estimated at around 36.5 Mt in 2024. The current mix is overwhelmingly fossil-based with only around 1% from electrolysis. The medium- and long-term strategy is not to replace this system with green hydrogen wholesale, but to gradually decarbonise and diversify it from within. Official roadmaps envisage renewable hydrogen reaching on the order of 100 Mt by 2060, so that most incremental growth comes from low-carbon pathways.

Japan's hydrogen balance looks similar in structure but a lot smaller in scale. Total hydrogen supply is currently around 1.93 Mt per year, essentially equal to demand because nearly all production is consumed on-site in refineries, steel mills and chemical plants. The Japan Hydrogen Association estimates that this supply is effectively 100% grey and 99% self-consumed. Domestic green-hydrogen projects – such as FH2R in Fukushima and several smaller electrolysis plants based on solar, wind, hydro or waste-to-energy – exist but remain small in aggregate and primarily serve as demonstration platforms rather than bulk commodity sources.

In contrast to China's "decarbonise a giant domestic base" approach, Japan's national hydrogen strategy assumes that it will become a structural net importer of low-carbon hydrogen and ammonia. Yano's forecast for hydrogen supply shows total volumes rising to about 2.9 Mt by FY2030, 12 Mt by FY2040 and 20 Mt by FY2050, with the import share increasing from roughly 2% in FY2024 to around 27% by FY2030 and approximately 70% by FY2040–2050 (Section 4.2.3). The updated Basic Hydrogen Strategy and related analyses treat Japan as an "islanded system" with limited domestic fossil and renewable resource endowments and therefore plan for a future in which most hydrogen and ammonia "available to Japan" originates abroad.

Critically, in both cases transport demand is small relative to system size. China's prospective FC truck and bus fleets could consume several hundred thousand tonnes of hydrogen annually by 2030, but this remains marginal against a 40–50 Mt hydrogen system. Japan's official target of about 80,000 tonnes of hydrogen consumption in mobility by 2030 likewise accounts for only a few per cent of projected total hydrogen use. For both countries, the question is therefore not whether there will be enough hydrogen in aggregate, but whether sufficient volumes of genuinely low-carbon hydrogen can be made available at acceptable cost and in the right locations for transport applications.

Supply Strategy: Self-Sufficiency with Marginal Imports vs Trade-Centred Sourcing

China's strategy is fundamentally domestic-resource-oriented. Policy documents and modelling exercises emphasise that China has vast potential for renewable generation in its western and north-western regions, combined with a large established base of coal- and gas-based hydrogen production that can be retrofitted with CCUS. International imports are present but framed as complementary options rather than a structural pillar. Early shipments of certified low-carbon blue ammonia from Saudi Arabia to Chinese petrochemical users,

memoranda of understanding around potential liquefied hydrogen exports from Russia's Sakhalin region, and prospective trade in green ammonia from Australia illustrate that China is willing to experiment with cross-border supply chains. Yet these flows are minuscule compared with total hydrogen consumption and target specific industrial users rather than transport.

Japan's strategy, by contrast, is explicitly trade-centred. Government-backed pilots such as AHEAD's methylcyclohexane chain from Brunei to Kawasaki and HySTRA's liquefied hydrogen shipments from Australia to Kobe were designed to test long-distance hydrogen logistics and to position Japanese firms as technology leaders in carriers, shipping and import terminals (Section 4.2.3). Beyond these pilots, Japan has signed a broad array of memoranda and framework agreements on hydrogen, ammonia and CCS with Australia, Canada, the United States, Indonesia and Gulf states. These arrangements aim to secure future supply of low-carbon ammonia and hydrogen, often with Japanese utilities or trading houses as offtakers.

Economic Viability: Cheap Domestic Fossil Base vs High-Cost Imported and Domestic Supply

China's cost structure is characterised by very low domestic costs for fossil-based hydrogen and still higher, but rapidly falling, costs for renewable hydrogen. Engineering-economic studies suggest that coal-based hydrogen without CCS remains the cheapest large-scale route, with levelised costs around 1.2–1.3 USD/kg on average and even lower in some provinces (Section 4.1.4). Current estimates put levelised costs for alkaline electrolysers in China at around 3.7 USD/kg and for PEM systems at over 5 USD/kg (Section 4.1.4). However, once storage, compression, potential liquefaction and long-distance transport to coastal demand centres are included, the delivered price of hydrogen can easily reach around 7 USD/kg. Logistics costs alone are non-trivial: tube-trailer transport adds on the order of 0.5 USD/kg per 100 km, while pipelines and liquid hydrogen have lower distance sensitivities but require high utilisation and large upfront investment.

Japan, by contrast, faces a situation in which hydrogen is structurally expensive across virtually all routes. When the "hydrogen society" narrative crystallised in the mid-2010s, retail prices at hydrogen refuelling stations were around 100 yen per normal cubic metre—equivalent to several times the per-kilometre cost of gasoline or diesel (Section 4.2.4). System-level LCOH estimates compiled in the Japanese chapter suggest that generic low-carbon hydrogen for Japan as a demand centre cost around 7 USD/kg in 2020 and is expected to fall only to roughly 4.9–5.5 USD/kg in baseline scenarios, or 3.7–4.8 USD/kg in optimistic scenarios, by 2030. Even by 2050, low-carbon hydrogen is projected at about 3.1–4.2 USD/kg in baseline and 1.9–3.3 USD/kg in optimistic cases. Imported low-carbon hydrogen and ammonia from resource-rich partners can, in principle, be produced at lower cost, but logistics, conversion (to ammonia or MCH) and reconversion for end-use erode much of this advantage. For mobility in particular, the relevant metric is the delivered price at the refuelling station, which, even under optimistic assumptions, is likely to remain higher than fossil alternatives without sustained policy support.

Incentive Design: Layered Domestic Subsidies vs Long-Term Price-Gap Contracts

Given these cost structures, both countries have developed extensive support architectures, but again with different emphases.

China's approach is layered and geographically differentiated. On the production side, simulation studies and local policies show the use of sizeable CAPEX subsidies—covering roughly 35–40% of initial investment for early electrolysis projects and then phasing down over 10–15 years—as well as preferential tax treatment, R&D grants and support for testing facilities (Section 4.1.4). Several inland provinces also provide direct per-kilogram subsidies for green hydrogen production, typically in the range of 3–12 CNY/kg, calibrated to bring renewable hydrogen close to cost parity with local coal-based hydrogen in targeted

industrial clusters. Additional consumption subsidies for industrial users, such as the 5.6 CNY/kg support for green-hydrogen feedstock in coal-chemical bases, further bridge the gap from the demand side.

For transport, local governments combine production-side support with infrastructure and vehicle incentives. Dynamic subsidy schemes for hydrogen refuelling stations offer declining capital grants of around 3 million CNY per station in initial phases, together with operating subsidies per kilogram of hydrogen dispensed. Some jurisdictions also provide usage-based incentives for FC trucks and buses and toll exemptions on key freight corridors. The resulting package does not aim at a single nationwide hydrogen price, but at creating pockets of local cost competitiveness in regions where renewable resources, industrial demand and freight flows coincide.

Japan's support architecture has evolved toward explicit price-gap instruments that reflect both high costs and import dependence. In the 2010s, policy focused on capital subsidies for refuelling stations and vehicles, and on R&D funding for large demonstration projects through organisations such as NEDO. With the 2020 Green Growth Strategy and the creation of the Green Innovation Fund, Japan committed around 2 trillion yen over ten years to support hydrogen and ammonia supply chains among other fields (Section 4.2.4). The fund blends capital grants with performance-linked payments, signalling a shift toward cost-oriented industrial policy.

The Hydrogen Society Promotion Act goes further by embedding a contracts-for-difference (CfD)-type mechanism into the core of the new support regime. Under this model, selected low-carbon hydrogen, ammonia and e-fuel projects receive payments that cover the difference between their actual cost and a reference fossil-fuel price plus a carbon value. Estimates cited in the Japanese chapter suggest that this CfD framework could mobilise on the order of several trillion yen of support over time, effectively underwriting operating economics for eligible projects.

Subnational authorities, particularly the Tokyo Metropolitan Government, complement national schemes with targeted capital and operating subsidies for specific transport applications. Tokyo's hydrogen programme, backed by a 2024 budget of about 20.3 billion yen, includes generous co-funding for large, medium and small HRS, purchase subsidies for FC buses, trucks and logistics equipment, and a "Green Hydrogen Active User Certification System" that compensates certified users for the price difference between domestic green hydrogen and a benchmark grey-hydrogen price (Section 4.2.4). Together, these instruments are designed not simply to stimulate technology deployment, but to stabilise effective hydrogen prices for end-users, especially in heavy-duty transport segments.

Comparative Implications for Decarbonised Mobility

From a mobility perspective, the comparison suggests that both countries can, in principle, secure sufficient hydrogen volumes for transport, but they do so under very different economic and strategic conditions.

China leverages a huge, relatively cheap domestic fossil base and vast renewable resources to build a primarily self-reliant low-carbon hydrogen system. Green hydrogen costs are already within a factor of two of coal-based hydrogen in favourable regions, and layered subsidies can narrow this gap further in selected clusters. The main challenges are spatial—moving hydrogen from inland renewable bases to coastal demand centres—and institutional, namely coordinating industrial, power and transport policies to prioritise low-carbon hydrogen use in segments where it delivers the greatest mitigation per unit of scarce green supply. For transport, this implies that hydrogen is likely to first become economically viable in regional freight corridors and industrial hubs where local production and demand can be tightly coupled, rather than across the national fleet.

Japan, by contrast, operates in a structurally high-cost environment and must import a large share of its low-carbon hydrogen and ammonia. Its response has been to set explicit price targets and to develop long-term price-gap contracts and subsidy

schemes that insulate project developers and, indirectly, transport users from the full volatility and cost of low-carbon hydrogen. The key uncertainties for mobility are thus less about aggregate supply than about the durability of support schemes, the realised carbon intensity of imported molecules, and the cost of last-mile distribution from coastal hubs to inland freight and bus networks.

4.3.3 Infrastructure Readiness and Market Uptake Performance

Hydrogen Refuelling Station Networks

China and Japan are among the world's four largest HRS markets, but their networks differ in scale, configuration and utilisation.

China has built the largest HRS network globally. The number of operational stations rose from roughly 60 in 2019 to 422 by September 2025. The top five provinces—Guangdong, Hebei, Shandong, Henan and Zhejiang—account for nearly 46% of stations, underlining the clustered, corridor-oriented nature of deployment around coastal industrial belts and selected inland logistics hubs rather than uniform national coverage. A high share of Chinese stations are configured as 35 MPa, high-throughput sites (>1,000 kg/d) tailored to buses and heavy-duty trucks, reflecting a deliberate "commercial vehicles first" strategy and alignment with demonstration city clusters.

Japan's network is smaller in absolute terms but earlier in inception and more passenger-car-oriented. By end-2023, around 160 stations were operational. The first Basic Hydrogen Strategy had envisaged 320 stations by 2025 and 900–1,000 by 2030; current trajectories fall short, with build-out clearly lagging original plans. Stations are heavily concentrated in a few metropolitan regions—Tokyo and Kanagawa, Aichi (Nagoya) and Osaka/Kobe—mirroring the geography of early fuel cell passenger car deployment and existing city-gas infrastructure. The technical focus is on 70 MPa stations for light-duty vehicles, with only a small subset designed primarily for heavy-duty fleets.

Despite their different profiles, both networks share two structural weaknesses. First, utilisation rates are low. In China, fieldwork in major clusters reports station utilisation often below 30% of technical capacity, with some Guangdong and Hebei stations dispensing well under 100 kg/d, leaving them structurally loss-making despite subsidies. In Japan, slow fuel cell vehicle sales mean many stations operate far below design throughput too, contributing to high delivered hydrogen prices and long payback periods even when capital costs are heavily subsidised.

Second, both networks are geographically uneven. In China, HRS density is high along selected "hydrogen corridors" such as the Pearl River Delta, the Yangtze River Delta and Beijing–Tianjin–Hebei, but extensive parts of the central and western hinterland lack refuelling options. In Japan, the urban bias is even stronger: large portions of rural territory remain effectively outside the hydrogen system. In both cases, this spatial pattern is rational from a cost perspective—concentrating limited vehicles and stations into dense corridors—but it also limits the range of feasible use cases and reinforces a focus on fleet-based, depot-centric operations, not dispersed private mobility.

Transport and Storage Backbones and Electrolysers

Infrastructure readiness also hinges on the backbone systems that move and store hydrogen and on electrolysers as core supply-side assets. Here, the contrast between China's nascent inland–coast pipeline vision and Japan's port-centric import model is particularly pronounced.

China's hydrogen geography is defined by a structural spatial mismatch: large-scale renewable and by-product hydrogen production is concentrated in northern and western provinces, while most end-use demand—especially in mobility, refining and chemicals—is located in coastal metropolitan regions. Long-distance transmission is therefore not optional but a necessary condition for large-scale hydrogen use in transport. Yet the dedicated hydrogen pipeline system remains embryonic: only around 120 km of pure hydrogen pipelines are currently in

operation, mostly short industrial lines around refineries and chemical bases, while roughly 1,300 km are under construction.

To bridge the gap in the interim, China is experimenting with hydrogen blending into the existing natural gas grid. A 397 km demonstration on the Ningxia Ningdong pipeline has shown stable operation with up to 24% hydrogen by volume for 100 days, suggesting that the 185,000 km national oil and gas grid could, in principle, carry several million tonnes of hydrogen annually. Storage infrastructure is also in transition: most hydrogen is currently stored in above-ground compressed tanks at industrial parks and HRS, with limited liquid hydrogen and liquid organic hydrogen carrier use.

Electrolysers are a central node in China's infrastructure story. By May 2025, more than 1.2 GW of electrolyser capacity had been commissioned in operating green hydrogen projects, while projects under construction and announced plans together exceeded 110 GW of planned hydrogen production capacity. China already hosts about two-thirds of global operating electrolysis capacity and roughly 40% of global manufacturing capacity that has reached final investment decision. The fleet is still dominated by alkaline systems (>90% of shipments in 2024), but PEM volumes are rising rapidly. This combination of manufacturing scale, deployment and efficiency gains positions China as a likely global cost setter for electrolysis equipment and provides a deep supply base for future transport-linked projects.

Japan's hydrogen backbone looks very different. There is no nationwide hydrogen pipeline grid, and domestic hydrogen is primarily transported by tube trailers. Instead, the system is increasingly conceptualised as a port-and-hub model: low-carbon hydrogen, ammonia or LOHCs are imported by ship to a small number of industrial ports (Kobe, Yokohama, Kawasaki, etc.) and then distributed regionally by truck and, eventually, short-distance pipelines. Port-side readiness remains partial: demonstration projects for liquid hydrogen and ammonia bunkering are in place, but

interviews and surveys highlight gaps in infrastructure sufficiency, workforce skills and standardisation relative to the volumes envisaged in long-term scenarios.

Electrolyser deployment in Japan is modest. As of 2021, around 19 plants with a combined capacity of roughly 12 MW had been installed, mainly in power-to-gas and microgrid projects. Japanese firms maintain strong R&D capabilities in electrolysers and aim to preserve export competitiveness, but installed capacity is far below domestic demand ambitions, and policy documents assume that most low-carbon hydrogen will be produced abroad and brought to Japan as molecules or derivatives.

Market Uptake: Fleet Structure, Geography and Industrial Ecosystems

Infrastructure readiness only translates into decarbonised mobility if vehicle fleets expand and actually use hydrogen at scale. On this dimension, both countries display significant ambition but modest realised uptake, with clear differences in segment focus and industrial organisation.

China's fuel cell vehicle fleet reached about 28,000 units by 2024, with annual sales peaking at 7,654 vehicles in 2023. This volume accounts for roughly 27–30% of the global FCV stock but falls well short of the national target of around 50,000 FCVs by 2025. More importantly, FCVs remain negligible compared with China's battery-electric vehicle boom: monthly NEV passenger car sales routinely exceed 700,000 BEVs and 200,000 plug-in hybrids.

The segment structure of China's FCV fleet is distinctive. In 2024, tractor units and special-purpose vehicles together accounted for nearly 80% of FCV sales, with buses and logistics trucks making up most of the remainder. Passenger FCVs are a rounding error—individual models sold only a handful of units each in that year. This heavy tilt toward commercial vehicles is consistent with a policy logic that prioritises high-utilisation fleets with predictable routes and depot refuelling, where hydrogen's high energy density can offset infrastructure costs.

Deployment is also geographically uneven and policy-driven. Five national fuel cell demonstration city clusters account for almost half of the FCV stock, yet their performance diverges markedly: some (e.g. Beijing–Tianjin–Hebei, Shanghai) over- or near-fulfil their vehicle quotas, while others lag behind. At the same time, non-cluster regions have begun to account for almost a third of annual sales and cumulative stock, indicating the emergence of independent hydrogen transport ecosystems around specific industrial users and logistics corridors.

Japan's FCV fleet is much smaller—around 8,000 vehicles as of early 2023—but more heavily skewed toward passenger cars. The vast majority (about 96%) are light-duty vehicles, primarily the Toyota Mirai, with only around a hundred trucks, roughly 160 buses and a small number of special vehicles. FCV car sales have collapsed in recent years, falling from 2,464 units in 2021 to 422 units in 2023, signalling that early consumer enthusiasm has not translated into sustained diffusion.

The spatial concentration of Japan's fleet is even more pronounced than China's: Tokyo alone hosts roughly one-fifth of all FCVs and around 100+ fuel cell buses, while remaining buses and trucks are clustered in a few metropolitan and logistics hubs. This clustering is closely tied to local subsidy schemes; the Tokyo Metropolitan Government, for example, offers generous purchase subsidies for FC buses, trucks and taxis and actively co-develops pilot logistics corridors with vehicle manufacturers.

Industrial ecosystems also differ. In China, around 45 OEMs sold FCVs in 2024, but the top ten manufacturers commanded nearly three-quarters of the market, and the top five fuel cell system integrators supplied almost 60% of the systems. A relatively consolidated group of bus and truck makers (Yutong, Beiqi Foton, Shaanxi Automobile) and system companies (Yihuatong/SinoHytec, Refire, Guohong) anchor a broader value chain of stack, membrane, compressor and storage suppliers.

In Japan, the industrial landscape is dominated by a small set of lead firms and coalitions. Toyota's fuel cell technology underpins most on-road applications (Mirai

cars, Sora buses, forklifts), while new alliances (CJPT for light-duty trucks; Isuzu–Honda for heavy-duty trucks) have emerged to reorient hydrogen toward commercial segments after disappointing passenger-car sales. Consortia such as Japan H_2 Mobility pool automaker, utility and trading-house capital to de-risk HRS investment. This coalition-based model spreads risk but also makes hydrogen mobility highly dependent on the strategic priorities of a few large incumbents.

Beyond Road Transport: Multi-Modal Pilots as System Signalling

Both China and Japan have sought to extend hydrogen's reach beyond road vehicles, using high-visibility pilots in rail, ports and aviation to signal long-term multi-modal roles.

In China, non-road applications include the world's first commercial hydrogen tram line, a hydrogen-powered urban train tested in Jilin at 160 km/h, and multiple maritime pilots including the first CCS-certified hydrogen fuel cell workboat and a hydrogen-powered container ship. Hydrogen-powered drones and experimental aircraft using hydrogen internal combustion engines further reveal an interest in embedding hydrogen in broader transport narratives, even though the associated hydrogen volumes remain small.

In Japan, rail and maritime pilots are similarly prominent but more tightly coupled to strategic narratives about import chains and technology export. The HYBARI fuel cell hybrid train demonstrates hydrogen as an alternative to catenary electrification on low-density regional lines. Kawasaki's Suiso Frontier liquefied hydrogen carrier, together with associated port infrastructure, showcases Japan's ambition to pioneer international LH_2 value chains. Compact marine hydrogen engines and early hydrogen aviation initiatives (including airline partnerships to study fuel cell aircraft and ground infrastructure) situate hydrogen within multi-decade visions of decarbonised shipping and aviation.

Comparative Assessment: Advanced but Unbalanced Systems

Comparing these elements, both China and Japan can be described as having advanced but unbalanced hydrogen mobility systems. Both have built substantial HRS networks, begun to assemble the backbone infrastructure for hydrogen production and distribution, and nurtured industrial ecosystems that can supply vehicles, stacks and key components. Both have also taken hydrogen beyond road transport into rail and maritime pilots, strengthening the narrative of hydrogen as a versatile decarbonisation vector.

Yet in both cases infrastructure has run ahead of market uptake, and the geographies of infrastructure and fleets are highly uneven. China's readiness is grounded in scale and manufacturing depth: a very large and growing network of HRS tuned to heavy-duty vehicles, a rapidly expanding electrolyser industry and early pipeline and storage projects that reflect a domestic, inland-to-coast integration logic. Market uptake is concentrated in commercial fleets within a handful of clusters and industrial ecosystems, and the link between these projects and truly low-carbon hydrogen remains partial.

Japan's readiness is grounded in early deployment, import-oriented hubs and highly visible multi-modal pilots. Its HRS network is dense in a few metropolitan areas but under-utilised and strongly dependent on public funding and social licence. FCV fleets remain small and passenger-heavy, with a late pivot toward commercial vehicles. Domestic electrolysis capacity is limited, and the transport system will depend heavily on the success of long-distance hydrogen and ammonia import chains.

These differences in infrastructure and market uptake are not purely technical; they reflect deeper strategic motives and institutional arrangements that will be taken up in the discussion and recommendation chapters.

5. DISCUSSION AND RECOMMENDATIONS

5.1 Motives in Motion: Two Models of Hydrogen-Based Transport Decarbonisation

Seen through the combined evidence from Chapters 2–4 and the wider literature, China and Japan have not simply adopted different policy mixes for hydrogen; they have assembled two stylised models of what hydrogen-based transport decarbonisation looks like in a large, industrialised economy.

In the Chinese case, the empirical chapters show hydrogen being woven into a broader developmental project. Central plans and strategies situate hydrogen within the "dual-carbon" goals and the upgrading of manufacturing, while sectoral and provincial documents reinterpret these overarching objectives for concrete local contexts. Hydrogen for transport enters this picture as one of several application fields that can absorb growing low-carbon hydrogen production. The result is a system-integrated developmental model in which hydrogen is treated less as an isolated policy problem and more as a cross-cutting industrial and infrastructural opportunity.

Several features of this model are particularly salient. First, governance relies on a dense but flexible hierarchy of plans, guidance documents and standards rather than a single hydrogen law. Central agencies define general objectives, principles and technical baselines, while provincial and municipal authorities experiment with specific combinations of vehicle subsidies, infrastructure support, land policies and demonstration zones. This multi-level configuration allows for rapid learning and local adaptation but also generates significant territorial variation in the generosity, design and enforcement of hydrogen-related measures. Second, sustainability assurance is introduced through group standards and labelling schemes that distinguish conventional, low-carbon and renewable hydrogen, yet life-cycle thresholds remain relatively permissive in practice, leaving ample space for fossil-based and CCS-enabled production to qualify as "low-carbon" in the near term.

Third, China's very large legacy production capacity in industrial hydrogen, particularly from coal and natural gas, keeps marginal hydrogen costs low in many pilot projects; this makes it easier to fill refuelling stations in demonstration clusters but delays the full internalisation of decarbonisation costs. Fourth, the spatial pattern that emerges is one of corridor- and cluster-based experimentation. Hydrogen refuelling stations, vehicle fleets and production assets concentrate in coastal and industrial regions where logistics demand is dense and where local governments have the fiscal resources and political incentives to sponsor ambitious projects. Within these clusters, hydrogen is used primarily in high-utilisation commercial segments—buses, medium- and heavy-duty trucks, port and special-purpose vehicles—rather than as a mass fuel for private cars.

Japan, by contrast, constructs hydrogen-for-mobility around a more sharply demarcated policy field, anchored in national strategies and dedicated legislation. From the early Basic Hydrogen Strategy onwards, hydrogen is framed as a response to the structural vulnerability of an energy system dependent on imported fossil fuels, as a means of decarbonising hard-to-abate sectors, and as a platform for preserving and extending Japanese technological leadership in fuel cells, gas turbines, specialised shipping and related equipment. The Hydrogen Society Promotion Act and related basic policies consolidate hydrogen's status as a distinct domain of intervention by providing a statutory basis for price-gap support mechanisms and for defining, in legal terms, what qualifies as "low-carbon" hydrogen. The resulting statute-anchored import–contract model places particular emphasis on creating long-term certainty for investors considering capital-intensive projects along international hydrogen and ammonia supply chains.

Within this model, the core institutional choices differ markedly from those in China. Governance places greater weight on formal legal instruments and on clearly codified eligibility criteria. Life-cycle assessment is embedded more explicitly into the design of support schemes, with national thresholds defined for well-to-wheel emissions that apply to both domestic and imported supply. The

supply strategy, given Japan's limited domestic fossil and renewable resource base, leans heavily on overseas production and shipping of low-carbon hydrogen and ammonia. The central state accepts that delivered costs will be structurally high and seeks to manage this by underwriting the price gap between fossil benchmarks and low-carbon alternatives over extended periods. In mobility, as the empirical chapters show, these choices translate into a refuelling network that is smaller but older than China's, initially built to support passenger fuel cell vehicles and later reoriented towards buses and logistics fleets in specific metropolitan and industrial corridors. The number of vehicles remains modest, and hydrogen's share of total transport energy use is small; nevertheless, hydrogen occupies a symbolically important position in Japan's decarbonisation narrative as an emblematic technology of the "hydrogen society".

5.2 Policy Implications from China and Japan for Hydrogen-Based Transport

Assessing these two models comparatively requires distinguishing between three dimensions: climate effectiveness, economic efficiency and governance robustness. Across all three, the empirical material suggests that the promise of hydrogen for transport is, at this stage, more conditional and context-dependent than many early policy narratives implied.

In terms of climate effectiveness, both regimes have so far delivered relatively modest direct emission reductions in transport when measured against their own long-term targets. The total number of fuel cell vehicles on the road remains low relative to overall fleets, and hydrogen accounts for only a minor fraction of energy use in road transport. More importantly, the quality of hydrogen matters at least as much as the quantity. In China, the continued reliance on by-product and coal-based hydrogen in many early projects, combined with relatively lenient thresholds for "low-carbon" labels and incomplete coupling between certification and support schemes, means that some hydrogen-for-mobility applications may offer only

marginal improvements over efficient diesel in well-to-wheel terms. The system is evolving towards tighter life-cycle assessment, but the trajectory is gradual. In Japan, the formal stringency of the low-carbon threshold and the clear well-to-wheel boundary create a more demanding baseline; yet the actual climate performance of imported hydrogen and ammonia hinges on the durability of CCS over decades and the control of upstream methane leakage abroad, issues over which Japanese regulators have only indirect influence. In both cases, therefore, hydrogen's climate contribution cannot be assumed; it depends on the degree to which sustainability assurance systems are progressively tightened and effectively enforced.

Economic efficiency presents a different pattern. China's developmental model benefits from lower marginal hydrogen costs in the short term because it can leverage existing industrial production, domestic equipment manufacturing and relatively inexpensive land and labour in many regions. This lowers barriers to piloting hydrogen in buses, trucks and port logistics. At the same time, the willingness to tolerate overbuilding and underutilised infrastructure as part of an industrial learning strategy carries the risk of stranded assets and long-term fiscal burdens if utilisation does not catch up. Japan's model internalises the reality that hydrogen is structurally costly in an energy-importing economy and responds by explicitly socialising part of these costs through long-term price-gap support. This gives private investors confidence to pursue large projects, but it does so by committing public resources to a technology whose future competitiveness relative to batteries, demand reduction and other options remains uncertain. In both regimes, hydrogen for mobility emerges as a relatively expensive instrument for abatement; its economic rationality is strongest where alternative decarbonisation options are limited by physics, infrastructure or timing, and weakest where batteries and efficiency can deliver similar climate benefits at lower system cost.

Governance robustness adds a further layer of differentiation. China's model displays a high capacity for rapid mobilisation and experimentation. Central planning organs and leading provinces can move quickly from strategic intent to

concrete projects, drawing on state-owned enterprises and local development coalitions. This adaptive capacity is a significant asset in a technological field characterised by uncertainty. At the same time, the combination of strong central signalling with intense local competition can lead to duplication and uneven sustainability enforcement, especially where local growth imperatives collide with national carbon targets. Mechanisms for ex-post evaluation and course correction exist but are not yet fully institutionalised across all regions. Japan's statute-anchored regime, in contrast, offers a high degree of legal clarity and predictability, particularly for international partners and capital-intensive upstream investments. Yet its very legalism can become a source of rigidity if cost assumptions or technological trajectories change faster than legislators are willing or able to amend primary instruments. The lesson here is that neither flexibility without discipline nor discipline without flexibility is sufficient; sustainable hydrogen-for-mobility regimes require both.

These comparative insights carry several implications. First, they suggest that hydrogen is unlikely to become a universal transport fuel even under very ambitious decarbonisation scenarios. Instead, it is more plausible to see hydrogen as a structurally niche technology whose rationale lies in specific segments: high-utilisation heavy-duty trucking on defined corridors, port and airport operations, certain rail and mining applications, and, in the longer term, the production of synthetic fuels for shipping and aviation. Both the Chinese and Japanese experiences underline that attempts to position hydrogen as a mass solution for light-duty transport face very strong economic and infrastructural headwinds. Second, the cases demonstrate that sustainability assurance cannot be an afterthought. If hydrogen is to contribute meaningfully to climate neutrality rather than only to industrial or security objectives, life-cycle carbon accounting and verification need to be integrated into policy design from the outset and tightened over time, including for imported molecules. Third, the analysis shows that the sequence in which infrastructure, supply and demand are developed matters. Building large refuelling

networks ahead of confirmed fleet demand, as both countries did in the early phases, tends to produce low utilisation and dependence on continuing subsidies; more cautious, corridor-based sequencing can mitigate these effects. Finally, the two models illustrate that the institutional embedding of hydrogen policy—whether more plan-based and experimental or more statute-centred and legally precise—shapes not only investor behaviour but also the ease with which governments can adjust course in response to new information.

5.3 Strategic Recommendations for Stakeholders

Against this background, the question is not whether hydrogen should play a role in transport decarbonisation, but how that role can be defined and governed in ways that are climatically credible, economically proportionate and institutionally resilient. The empirical and comparative findings of this thesis point towards several strategic directions, which differ in emphasis between China and Japan but share a common logic.

For China, the central strategic challenge is to align the developmental momentum of its hydrogen industry with the tightening requirements of the dual-carbon agenda. The existing model has been very effective at mobilising investment, building domestic manufacturing capacity and demonstrating hydrogen applications in heavy-duty fleets and industrial clusters. To make this compatible with long-term climate neutrality, central authorities will need to accelerate the shift from a quantity-oriented to a quality-oriented approach. This implies progressively tightening the carbon-intensity thresholds embedded in hydrogen standards, making access to transport-related subsidies contingent on verified life-cycle performance, and prioritising applications where hydrogen offers clear advantages over direct electrification. It also suggests a gradual move from infrastructure-led to demand-led planning, in which new stations and production assets are justified by concrete commitments from fleet operators and by integrated assessments of corridor-level demand. At the same time, central agencies can use their coordination role to diffuse

best practices and to constrain the most fiscally risky forms of local competition, without stifling the experimentation that has been a hallmark of China's approach so far.

For Japan, the key strategic issue is not how to start a hydrogen-for-mobility regime but how to recalibrate one that already exists under demanding fiscal and structural constraints. The statute-anchored import–contract model has succeeded in putting hydrogen firmly on the policy map, in establishing clear eligibility criteria and in catalysing a wave of large-scale project proposals domestically and abroad. The next phase requires a sharper focus on where hydrogen can realistically compete in the transport system and how its use can be justified to citizens facing higher energy costs. This points towards a more selective deployment strategy centred on segments that are difficult to decarbonise by other means and on geographies where hydrogen can piggyback on infrastructure built for industrial or power-sector uses. It also underscores the importance of enhancing the credibility and granularity of life-cycle governance for imported hydrogen and ammonia, including differentiated categories for truly renewable hydrogen and for higher-emission options, and robust verification arrangements with supplier countries. Finally, the Japanese case highlights the need to maintain flexibility within statutory schemes. Building explicit review clauses, adjustment mechanisms and sunset provisions into long-term support instruments would allow policy makers to respond to faster-than-expected cost declines in batteries, to changes in global fuel markets or to new evidence on CCS performance without jeopardising investor confidence.

Beyond the two core cases, the analysis offers a set of more general strategic lessons for other jurisdictions and for non-state actors. For governments considering hydrogen-for-mobility strategies, the Chinese and Japanese experiences serve as a reminder that technology-neutral slogans such as "hydrogen society" or "hydrogen economy" are insufficient guides for action. What matters is the concrete configuration of motives, institutions and infrastructures: how climate goals are balanced against industrial and security objectives; how legal and planning

instruments are combined; how costs and risks are distributed between taxpayers, consumers and firms; and how strictly life-cycle emissions are governed. Rather than attempting to replicate either model in its entirety, other countries can draw selectively on their elements. From China, they can learn the value of linking hydrogen to broader industrial and spatial development strategies and of using pilot programmes to discover where hydrogen actually works in practice. From Japan, they can learn the importance of legal clarity, of embedding sustainability criteria into support schemes, and of thinking from the outset about international supply chains and certification.

For industry, the main implication is that hydrogen for transport is unlikely to be a homogeneous, global mass market in the near term. Instead, it will consist of a patchwork of regional niches shaped by local resource endowments, infrastructure legacies, regulatory choices and corporate strategies. Vehicle manufacturers, logistics operators and hydrogen producers will therefore need to position themselves in specific segments and geographies rather than betting on universal adoption. Companies that can operate across both models—offering technologies and services that fit into China's system-integrated clusters and into Japan's import-oriented corridors, for example—may be better placed to survive policy shifts and demand fluctuations. At the same time, firms have a stake in the credibility of hydrogen as a climate solution; investing in transparent life-cycle accounting and in continuous improvement of carbon performance is not only a regulatory necessity but also a reputational asset.

Finally, for international organisations and standard-setting bodies, the juxtaposition of the Chinese and Japanese models underscores the importance of working towards some degree of convergence in life-cycle assessment methods, guarantees of origin, safety codes and refuelling protocols. As trade in low-carbon hydrogen and derivatives grows, and as more countries experiment with hydrogen in transport, the risk of fragmented and incompatible regimes will rise. Shared frameworks do not require identical policies, but they can lower transaction costs,

reduce the scope for carbon leakage and greenwashing, and make it easier to compare the effectiveness and efficiency of different national approaches.

6. LIMITATIONS AND FUTURE RESEARCH

6.1 Methodological Constraints

Any comparative study of an evolving socio-technical field such as low-carbon hydrogen must be read with an awareness of its boundaries. This thesis has sought to reconstruct and interpret two national approaches to hydrogen in transport with as much empirical and conceptual care as the available material allows, but its findings remain constrained by design choices, by the quality of underlying data, and by the speed with which the Chinese and Japanese regimes are changing.

The first limitation relates to the basic research design. The thesis adopts a qualitative comparative case-study approach focused on China and Japan, interpreted through the "Motives in Motion" framework and informed by documentary analysis and techno-economic reasoning. This design enables a rich, context-sensitive reconstruction of how climate, industrial and energy-security motives are translated into hydrogen-for-mobility strategies, but it necessarily restricts claims about generalisability. The results speak most directly to large industrialised economies with similar state capacities and industrial structures; extrapolation to other contexts requires caution and additional comparative work.

A second constraint is that the analysis remains essentially configuration-oriented rather than strictly causal in a narrow sense. The thesis links particular governance architectures, industrial strategies and cost structures to characteristic patterns of hydrogen deployment in transport, but it does not apply formal causal-inference tools or detailed process-tracing to individual policy instruments or episodes. The argument is strongest at the level of regimes and trajectories, and more tentative when it comes to the marginal impact of specific laws, subsidies or standards.

The study also relies predominantly on published documents and quantitative indicators rather than primary fieldwork. Official strategies, laws, standards,

industry reports and academic analyses provide a substantial evidentiary base, yet they cannot fully capture informal negotiation processes within ministries, firms and subnational governments, nor the everyday practices of actors implementing hydrogen projects. Interviews, participant observation or access to internal corporate and bureaucratic materials would likely reveal additional mechanisms and conflicts that here can only be inferred indirectly.

Finally, the temporal focus on roughly 2015 onwards is appropriate for an inquiry centred on contemporary decarbonisation strategies, but it condenses earlier phases of technology development, capability formation and policy experimentation into a relatively thin historical background. Some path dependencies in the Chinese and Japanese trajectories are therefore only sketched rather than reconstructed in detail.

6.2 Data Availability and Quality Issues

A second set of limitations concerns the empirical material itself. Hydrogen and fuel cell technologies remain emergent domains, and statistical and reporting practices are still fragmented. Core indicators such as the number and status of hydrogen refuelling stations, the size and composition of fuel cell vehicle fleets, or the scale and structure of hydrogen production often suffer from definitional inconsistencies between sources and between countries. Some datasets distinguish carefully between demonstration and commercial assets, public and captive infrastructure, or by-product and dedicated hydrogen; others aggregate across these categories. The thesis mitigates this problem by triangulating multiple sources and focusing on orders of magnitude and trends, but residual uncertainty is unavoidable, especially in side-by-side comparisons of China and Japan.

Economic data are even more constrained. Detailed information on capital and operating costs, price-gap support, offtake contracts and realised utilisation rates is frequently proprietary or only partially disclosed. Many cost figures in the literature rest on modelled assumptions rather than fully transparent project data. As a result,

the techno-economic elements of the analysis are indicative and comparative rather than precise: they help clarify relative differences in cost structures and risk allocation between the two models but cannot provide exhaustive bottom-up costings for specific projects or technologies.

Language also matters. The thesis draws extensively on Chinese- and Japanese-language sources, yet any cross-linguistic comparison entails risks of mistranslation, loss of nuance and selective emphasis. While English-language summaries and secondary analyses are used for cross-checking, they can themselves introduce interpretive biases or omit important details.

Finally, the policy and industrial landscape is evolving rapidly in both countries. New strategies, laws and project announcements appear continuously, and there is an inevitable lag before they are reflected in official statistics and scholarly work. The empirical picture in the thesis thus represents a moving target; some of the patterns it describes may be partly superseded as hydrogen policies and markets mature.

6.3 Directions for Further Study

These methodological and data-related limitations point towards several productive directions for future research. One obvious extension is comparative: applying the "Motives in Motion" framework to additional cases—such as the European Union, the United States, the Republic of Korea or Australia—would make it possible to test and refine the two stylised models identified here, to identify hybrid configurations that combine developmental and import–contract elements, and to distinguish context-specific from more general features of hydrogen-for-mobility governance.

Within China and Japan, further work could move to finer scales of analysis. Subnational studies could investigate why certain provinces, prefectures or metropolitan regions have become more prominent hydrogen hubs than others, how

local political economies and fiscal capacities shape the choice of segments and technologies, and how coordination actually functions between energy, transport and industrial policy at regional level. Firm-level research could similarly examine how vehicle manufacturers, energy companies, logistics operators and financiers interpret national hydrogen strategies and translate them into concrete investment and alliance patterns. Such work would benefit from mixed methods, complementing document analysis with interviews and, where possible, ethnographic observation of specific projects or programmes.

There is also considerable scope for more detailed techno-economic and systems modelling anchored in specific hydrogen-for-mobility configurations. Corridor- or hub-level models that integrate hydrogen supply chains, electricity systems and transport operations in China and Japan could quantify with greater precision the cost per tonne of CO_2 avoided, the sensitivity of project economics to fuel prices, carbon prices and utilisation, and the interactions between hydrogen deployment and power-system decarbonisation. Dynamic energy-system models could then explore how the role of hydrogen in transport changes under alternative technology and policy scenarios.

Finally, future research could expand the social and political dimensions that are only indirectly visible in this thesis. Public perceptions of hydrogen vehicles and infrastructures, the framing of hydrogen in media and political discourse, and the distributional implications of hydrogen subsidies and tariffs—who pays, who benefits, and who bears risk—are likely to become more salient as deployment scales up. These questions link hydrogen-for-mobility research to broader debates on just transitions and on the governance of technological uncertainty. Addressing them would not only deepen understanding of the Chinese and Japanese trajectories reconstructed here, but also help assess more generally under what conditions hydrogen can play a legitimate and durable role in decarbonised mobility systems.

7. CONCLUSION

This thesis intended to answer how China and Japan approach the development of low-carbon hydrogen in their transport sectors, and what these trajectories reveal about the wider governance of hydrogen-based mobility transitions. It did so by combining a comparative case-study design with the "Motives in Motion" framework, which traces how six dimensions of hydrogen governance – (1) policy architecture and legal force, (2) sustainability assurance and certification, (3) supply and sourcing strategies, (4) economic viability and incentives, (5) infrastructure readiness and spatial integration, and (6) market uptake and industrial implementation – jointly make visible the underlying motives of climate mitigation, energy security and industrial upgrading.

Across the six analytical lenses, several cross-cutting findings emerge. In terms of governance and legal force, China's plan-based regime excels at rapid mobilisation and flexible adaptation, but risks uneven enforcement and fiscally costly local competition. Japan's statute-centred regime offers strong signalling power and investor certainty, yet can become rigid if cost or technology trajectories shift faster than legislation. Sustainability assurance is more explicitly embedded in Japan's life-cycle thresholds and import rules, while China's standards and labelling schemes are evolving from relatively permissive baselines towards tighter low-carbon and renewable categories. On supply and sourcing, China leverages large domestic fossil and emerging renewable resources, using green hydrogen pilots and CCS-enabled projects to decarbonise parts of an already substantial industrial hydrogen base. Japan, with much more limited domestic resource endowments, has committed early to overseas low-carbon hydrogen and ammonia chains, accepting structurally high delivered costs and using price-gap contracts to underwrite them.

Economic viability and infrastructure readiness further differentiate the two models. Both countries have experienced the familiar problem of infrastructure running ahead of demand: hydrogen refuelling stations in China and Japan operate

at low utilisation rates, keeping fuel prices high and reinforcing dependence on public subsidies. In China, extensive support for domestic manufacturing has produced very rapid growth in electrolyser capacity and a refuelling network skewed towards 35 MPa, high-throughput stations serving buses and heavy-duty trucks along industrial corridors. Japan's HRS network is smaller in absolute terms but older, highly concentrated in a few metropolitan areas and heavily oriented towards 70 MPa passenger refuelling, with a belated pivot to buses and logistics fleets. Pipeline and storage systems remain embryonic in both cases, albeit with different spatial logics: inland-to-coast transmission and early geological storage projects in China versus port-centred import hubs and truck-based distribution in Japan.

Market uptake in road transport remains modest in both regimes when measured against long-term targets and against the scale of battery-electric diffusion. China has become the largest FCV market in absolute numbers, but with fewer than 30,000 vehicles deployed it still falls short of its own 2025 target and remains a small niche within a rapidly electrifying vehicle fleet. Deployment is heavily skewed towards high-utilisation commercial segments – buses, medium- and heavy-duty trucks, port and municipal vehicles – concentrated in a handful of demonstration clusters. Japan operates a smaller but more passenger-heavy fleet centred on the Toyota Mirai and a limited number of buses and trucks, with Tokyo emerging as the dominant regional hotspot. In both countries, hydrogen's share of overall transport energy use is negligible, and a significant share of hydrogen used in mobility is still grey or only partially low-carbon, even where policy narratives portray FCVs as flagship deep-decarbonisation options.

Beyond road transport, both cases demonstrate how hydrogen mobility is being extended symbolically and experimentally into other modes. China's hydrogen trams, urban trains, workboats and early aviation pilots, and Japan's HYBARI train, Suiso Frontier carrier, marine engines and nascent aviation initiatives, do not yet materially change national emissions trajectories. However, they play an important role in shaping expectations, normalising hydrogen in new

regulatory domains and strengthening industrial claims that hydrogen is a platform technology rather than a single-segment fuel. These pilots illustrate how state and corporate actors use multi-modal projects to anchor learning and justify the continued allocation of public and private capital to hydrogen even under significant uncertainty.

Taken together, the comparative analysis yields a set of broader substantive conclusions. First, it confirms that hydrogen's role in transport decarbonisation is structurally niche and highly context-dependent. In both China and Japan, the most plausible long-term rationale for hydrogen lies in specific segments – high-utilisation heavy-duty trucking, port and airport operations, selected rail and mining applications, and, indirectly, synthetic fuels for shipping and aviation – rather than in mass deployment for light-duty passenger cars. Second, it underscores that sustainability assurance cannot be an afterthought. If hydrogen is to contribute meaningfully to climate neutrality rather than primarily to industrial or security objectives, robust life-cycle accounting and verification, including for imported molecules, must be integrated into support schemes from the outset and tightened over time. Third, it highlights the importance of sequencing infrastructure, supply and demand. Building out extensive refuelling networks ahead of confirmed offtake, as both countries did initially, tends to lock in low utilisation and a long-term need for subsidies; more corridor-based, demand-led planning can mitigate these risks. Finally, the analysis shows that the institutional embedding of hydrogen policy – whether more experimental and plan-based or more statute-centred and legally precise – shapes both investor behaviour and the state's capacity to adjust course as new information emerges.

Methodologically, the thesis demonstrates the value and limits of a motive-centred, configuration-oriented comparison. The "Motives in Motion" framework makes it possible to move beyond simple score-card comparisons of targets and capacities and to reconstruct how different combinations of climate, industrial and security motives generate distinct institutional logics and deployment patterns. At

the same time, as Chapter 6 underlined, the absence of formal causal-inference tools, the reliance on documentary sources and the rapidly evolving nature of hydrogen statistics and policies constrain the precision and generalisability of the findings. The empirical picture captured here is necessarily a snapshot in time; future work will be needed to trace how the Chinese and Japanese regimes adapt as costs, technologies and international norms develop.

The comparative insights generated here speak not only to China and Japan but also to policymakers, firms and international organisations elsewhere. For governments, the central lesson is that adopting a "hydrogen strategy" is the beginning rather than the end of the policy challenge: what matters is how motives are prioritised, how life-cycle integrity is enforced, and how costs and risks are distributed across taxpayers, consumers and investors. For industry, the analysis reinforces that hydrogen for mobility will remain a patchwork of regional niches rather than a homogeneous global market, requiring careful positioning in specific segments and geographies. For international bodies, the juxtaposition of a system-integrated developmental regime and a statute-anchored import–contract regime underscores the urgency of converging at least partially on life-cycle methodologies, guarantees of origin and safety and refuelling standards to reduce transaction costs and guard against greenwashing.

Ultimately, the thesis suggests that hydrogen will become a meaningful element of decarbonised mobility only where political, institutional and industrial choices align it with genuinely hard-to-abate segments and with credible life-cycle climate limits. China and Japan illustrate two different ways of putting similar motives into motion under contrasting structural conditions. Neither model currently delivers transformative emission reductions in transport, but both generate valuable insights into what is feasible, what is risky, and what may be transferable to other contexts for building credible, differentiated pathways towards low-carbon mobility.

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ANNEXES

Annex 1.1 Key System Indicators for Hydrogen and Transport in China and Japan

Indicator	China	Japan
Annual hydrogen production (all routes)	≈36.5 Mt (2024)	≈1.9 Mt (~2024)
Share of electrolysis-based hydrogen	≈1% (early 2020s)	Very small, mostly demos (e.g. FH2R)
Fuel cell vehicles in operation	≈28,000 vehicles (2024)	≈8,000 vehicles (2023)
Dominant vehicle segments	Buses, medium- and heavy-duty trucks, special vehicles	Passenger cars (Mirai etc.) dominate; small fleets of buses and trucks
Operational hydrogen refuelling stations (HRS)	≈422 operational by Sept 2025	≈160 operational by end-2023
Dominant pressure / station type	35 MPa, high-throughput, commercial-vehicle oriented	70 MPa, passenger-car oriented
Main "low-carbon hydrogen" threshold	4.9 kg CO_2e/kg H_2 for "clean/renewable"; 14.51 kg CO_2e/kg for "low-carbon"	3.4 kg CO_2/kg H_2 for "low-carbon hydrogen etc."
Emission accounting boundary	Upstream LCA (feedstock, production, on-site storage/transport)	Well-to-gate for H_2 and NH_3; well-to-wheel for synthetic fuels
Levelized cost of grey coal-based hydrogen	≈0.9–1.5 USD/kg (coal without CCS)	Not a central focus; domestic grey used mainly as process gas
Levelized cost of green hydrogen (electrolysis)	≈2.35–4.8 USD/kg (ALK/PEM, regional spread)	≈4.5 USD/kg for domestic green H_2 around 2030 (REI estimates)
Delivered cost of imported low-carbon hydrogen	LOHC chains ≈3.7–4.1 USD/kg H_2 equivalent	Low-carbon imports ≈3.7–5.5 USD/kg by 2030 (optimistic)

Annex 2.1 China – Key Policy and Legal Instruments Relevant to Hydrogen for Transport

Year	Institution(s)	Instrument	Type	Legal force
2021	State Council / multiple ministries	New Energy Vehicle Industry Development Plan (2021–2035)	Industry development plan	Programmatic, guiding
2021	NDRC, NEA	Hydrogen Energy Industry Medium- and Long-Term Development Plan (2021–2035)	Sectoral development plan	Programmatic but binding for ministries/provinces
2022	NDRC, MIIT, others	Guidance for green and low-carbon transformation of steel industry	Sectoral guidance	Programmatic
2023	NDRC, NEA	Guidance for the petroleum refining and petrochemical sector	Sectoral guidance	Programmatic
2023–2024	MIIT	First-(Set) Major Technical Equipment Catalogue; Guidance Catalogue for Green and Low-Carbon Transformation Industries	Catalogues / guidance	Soft law with fiscal/insurance implications
2024	Standing Committee of the NPC (draft)	Energy Law	Basic law (draft)	High statutory force
2024	State Council / multiple ministries	Opinions on accelerating comprehensive green	Central Opinions	Binding direction for ministries/provinces

		transformation of economic and social development		
2024	Ministry of Transport and others	Action Plan for Large-Scale Equipment Renewal in the Transport Sector	Action plan	Programmatic
2025	Ten ministries including NDRC, NEA, MoT	Guiding Opinions on Promoting the Integrated Development of Transport and Energy	Guiding Opinions	Programmatic, with implementation obligations
2025	NEA	Notice on Organizing Hydrogen-Energy Pilots	Implementation notice	Binding for pilot regions
2020	China Hydrogen Alliance / CAP	T/CAB 0078-2020: Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen	Group standard	Voluntary but influential; referenced by policy

Annex 2.2 Japan – Key Policy and Legal Instruments Relevant to Hydrogen for Transport

Year	Institution(s)	Instrument	Type	Legal force
2014–2015	METI	Strategic Roadmap for Hydrogen and Fuel Cells	Technology /roadmap	Programmatic
2017	Cabinet / METI	Basic Hydrogen Strategy	National strategy	Cabinet-approved, high political authority
2020	Cabinet	Green Growth Strategy Through Achieving Carbon Neutrality in 2050	Green growth strategy	Cabinet-approved

2023	Council for Renewable Energy, Hydrogen and Related Ministers	Revised Basic Hydrogen Strategy	Updated strategy	Cabinet-approved
2023	JH2A (industry)	Proposal on quantitative criteria for “clean hydrogen”	Industry proposal	Non-binding
2024	Diet; METI, MLIT	Hydrogen Society Promotion Act (Act on Promoting the Supply and Use of Low-Carbon Hydrogen and Derivatives…)	Statute	Legally binding
2024	METI, MLIT	Basic Policy under the Hydrogen Society Promotion Act	Basic policy	Legally binding guidance under the Act
2020–	METI / NEDO	Green Innovation Fund (GIF)	Funding programme	Budgetary, with performance contracts
2025	METI (Automobile Division; Hydrogen and Ammonia Division)	Guidelines on Priority Areas for Promoting the Introduction of Fuel Cell Commercial Vehicles	Ministerial guideline	Programmatic but tied to subsidies
2016–	Prefectural governments (e.g. Fukushima, Hokkaido, Hyogo, Tokyo)	Regional hydrogen strategies and visions	Regional strategies	Soft law, linked to budgets