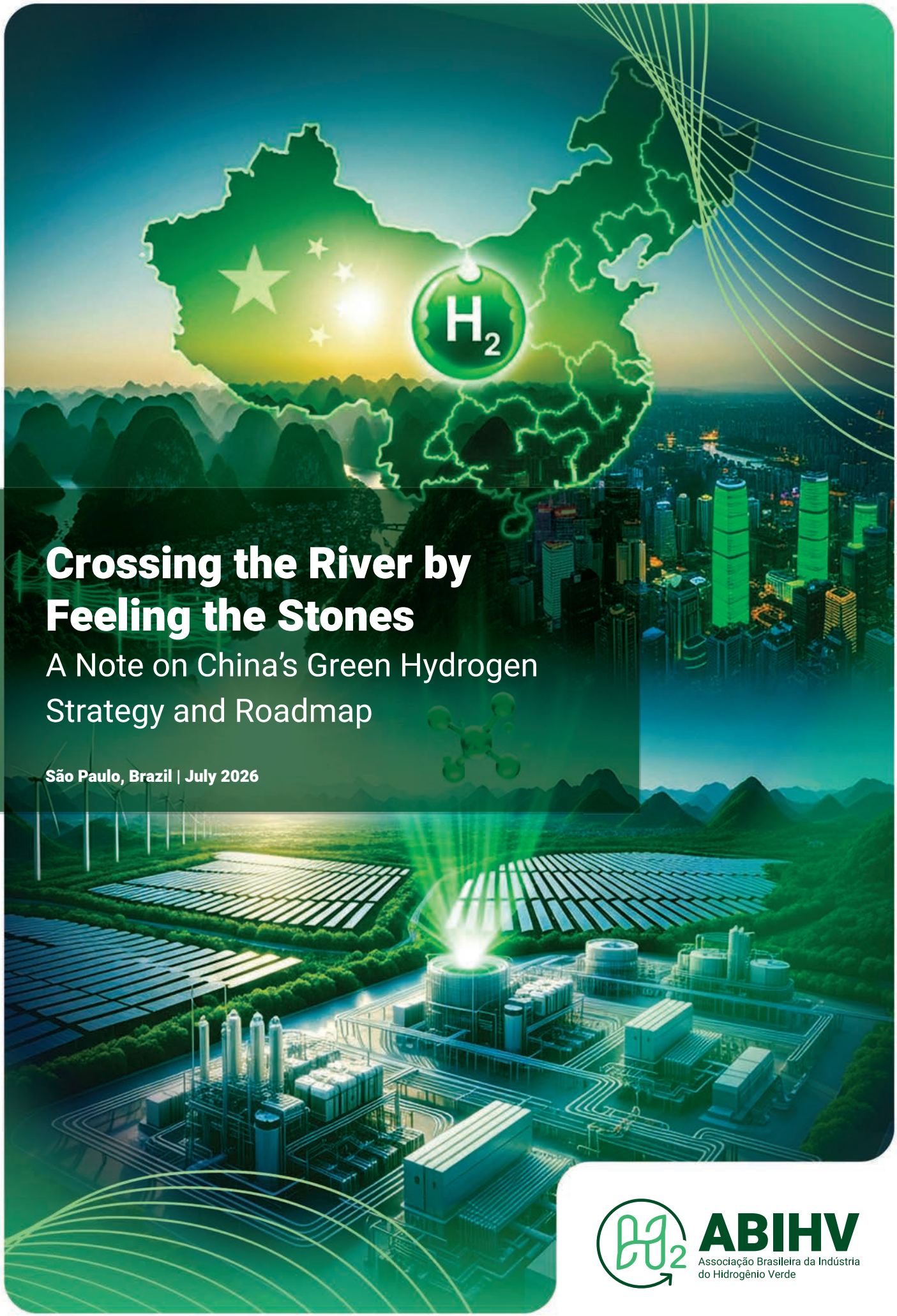


Crossing the River by Feeling the Stones

A Note on China's Green Hydrogen Strategy and Roadmap

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ABIHV
Associação Brasileira da Indústria do Hidrogênio Verde

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Executive Summary

The People's Republic of China is at a turning point in its trajectory of industrial modernization and energy transition. Hydrogen policy is not treated as an isolated sectoral agenda, but rather as a pillar of energy security, industrial competitiveness, and technological leadership in low-carbon solutions. The integrated analysis of official Chinese documents (2021–2035 Plan), sectoral studies (such as those by Boston Consulting Group/BCG and the Rocky Mountain Institute (RMI), in partnership with the China Hydrogen Alliance), and recent legal intelligence (the 2025 Energy Law and related regulatory reforms) reveals a deliberate strategy of "national floor + provincial ambition," designed to consolidate scale, reduce costs, and avoid distortions typical of subsidy cycles [1–4].

The central government established a conservative target of 100,000–200,000 t/year of renewable hydrogen production by 2025, along with approximately 50,000 fuel cell electric vehicles (FCEVs) and a pilot refueling network, in contrast to an already massive domestic market of approximately 34 Mt/year of hydrogen consumption, still predominantly fossil-based [2]. In parallel, provincial plans and industrial initiatives project a far more aggressive expansion, with combined targets reaching approximately 1.1–1.2 Mt/year of renewable hydrogen by 2025, led by regions such as Inner Mongolia, with a target of 480,000 t/year [2,5]. In practice, the national target functions as a "floor" for quality and coordination, while large-scale implementation occurs through decentralized competition and experimentation.

China organizes hydrogen development as a "tournament-style competition among regions." Resource-rich provinces (Inner Mongolia, Xinjiang, Gansu, Ningxia, Qinghai) compete for the role of major low-cost production hubs, while coastal industrial centers (Shanghai, Jiangsu, Zhejiang, Guangdong) compete for technological leadership, industrial value chains, and high-value applications (fuel cells, heavy logistics, chemicals, and steelmaking). This structure reduces the systemic risk of central planning: ssuccessful experiments are scaled up, advance in technological maturity, and are replicated nationwide, while failures remain contained at the regional level., while failures remain regionally contained. In simple terms, China operates a "championship" among provinces to accelerate the learning curve, consolidate standards, and rapidly internalize the supply chain [2,5].

This strategy is enabled by a decisive material foundation: over the past two decades, China has built the world's largest expansion of wind and solar energy, reducing the marginal cost of renewable electricity and creating the conditions for large-scale coupling with electrolysis (power-to-hydrogen) [2,3,6]. The analyzed documents frame this coupling not only as a hydrogen production pathway, but also as a mechanism for renewable integration, curtailment reduction, and monetization of structural generation surpluses, especially in the North and Northwest, directly linking hydrogen policy to the national grid strategy and regional industrial reconfiguration [2,3,5].

In the long-term horizon, Chinese industrial reports (such as Sinopec's China Hydrogen Energy Industry Outlook [1]) project that, by 2060, hydrogen demand in China could reach approximately 86 Mt/year, accounting for around 12% of final energy consumption with dedicated production increasingly based on non-fossil sources, especially renewables [1].

Within this framework, hydrogen is defined as a strategic emerging industry and treated as a driver of industrial and technological growth, alongside renewables, batteries, and other critical low-carbon value chains, reinforcing the structural — rather than marginal — nature of China's hydrogen policy in achieving its "Dual Carbon" goals [1,2].

Structural Foundations and Geopolitical Context

Energy Security and the "Dual Carbon" Targets

China is the world's largest importer of oil and gas and therefore faces significant strategic vulnerabilities, including in critical supply routes such as the Strait of Malacca. In this context, green hydrogen is treated as a vector for reducing exposure to fossil fuel volatility and geopolitical risks.

Beijing frames green hydrogen as an instrument of energy sovereignty. By converting the country's vast wind and solar resources — particularly in the North and Northwest — into a transportable molecule usable by industry, China reduces supply vulnerabilities, increases the resilience of its energy system, and lowers its exposure to fossil fuel volatility and geopolitical risks.

In practice, the strategy combines the accelerated expansion of renewables, electrolysis, and industrial logistics to transform an abundant resource — though geographically distant from major consumption centers — into high-value energy and chemical feedstock.

Since 2020, with the announcement of the "Dual Carbon" targets (peak emissions before 2030 and carbon neutrality by 2060), renewable hydrogen has been identified as indispensable for decarbonizing hard-to-abate sectors: steelmaking, cement, refining, petrochemicals, fertilizers, and heavy transport [6]. The centrality of the issue stems largely from the scale of China's current fossil-based hydrogen consumption, as shown in **Figure 1**.



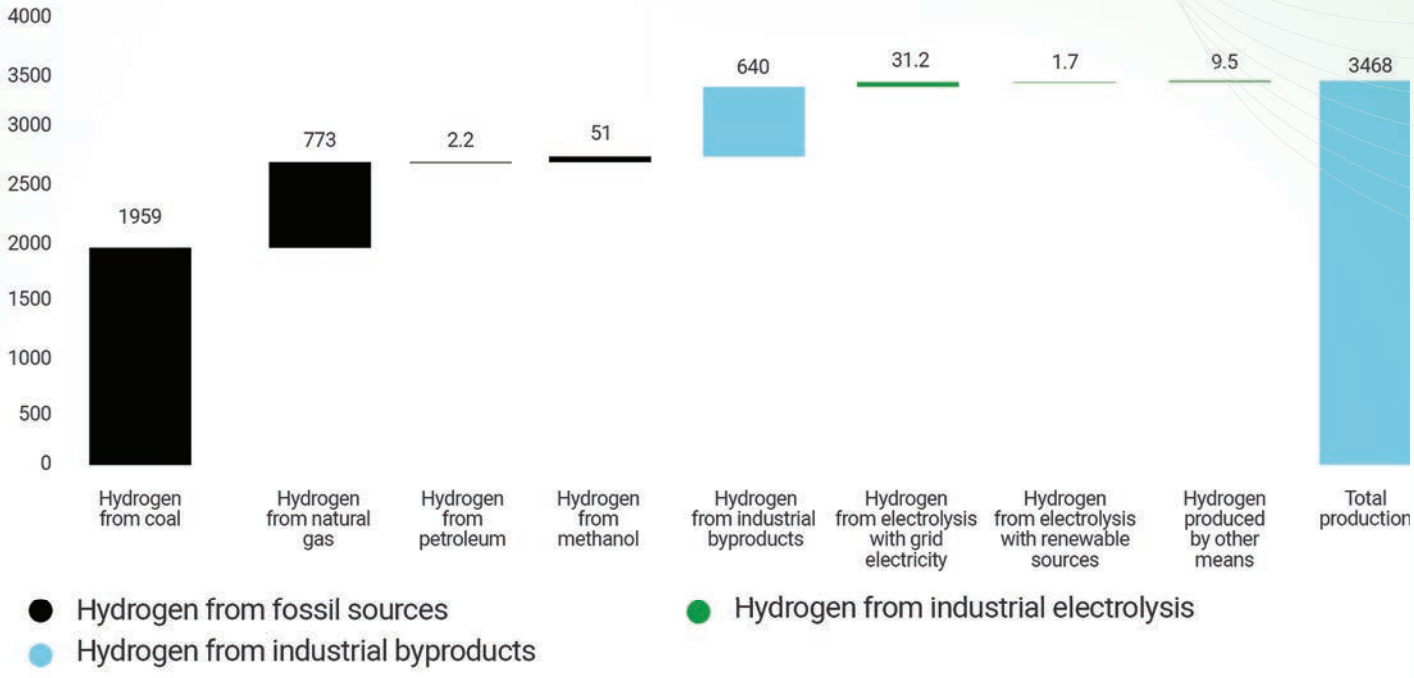


Figure 1. Hydrogen production in China by energy source in 2021. Source: Adapted from China Hydrogen Alliance and Accenture analysis [7]

From "Hazardous Chemical" to "Energy Resource"

Historically, hydrogen in China was treated primarily as a "hazardous chemical," which in practice imposed zoning restrictions, safety requirements, and limitations on the deployment of infrastructure outside industrial parks, including hydrogen refueling stations (HRSs) and distributed solutions. This framework acted as a material barrier to the growth of green hydrogen because it increased regulatory costs and reduced project location flexibility [2,5,7].

The turning point is clear: in recent sectoral planning, hydrogen is no longer viewed solely as an industrial input and is instead treated as a component of the future energy system, as well as a vector for enabling the low-carbon industrial transition.

This redefines the role of green hydrogen in Chinese energy policy, connecting renewable expansion, energy security, and industrial competitiveness.

By repositioning hydrogen as a "secondary energy carrier" and linking it more directly to energy planning, the Chinese strategy creates the institutional conditions for green hydrogen to move beyond a purely industrial issue and be treated within the framework of energy infrastructure and policy [2,3,7]

This shift gains legal consistency with the Energy Law of the People's Republic of China, in force since January 1, 2025 [8]. The legal interpretation consolidated in the *China Legal Briefing* indicates that the Law incorporates hydrogen into the set of strategic technologies within the energy sector and reinforces the role of the State in coordinating markets, infrastructure, and innovation, creating a legal umbrella to treat hydrogen as a regulated energy resource rather than merely a chemical input. For green hydrogen, this is particularly relevant because it reduces governance uncertainty and increases predictability for projects integrated with renewables, grids, and industrial applications.

In practice, this framework enables sector coordination around major state-owned enterprises (SOEs) and an expanded consortium involving research institutes, universities, and private companies, as summarized in **Figure 2** [4,9].



Figure 2. Ecosystem of the Chinese hydrogen consortium led by state-owned enterprises. Adapted from [9].

In practical terms, the importance of this regulatory change is that it shifts hydrogen's "institutional role" and unlocks scale. By bringing hydrogen closer to energy governance, it expands the space for major energy-sector players, facilitates licensing and infrastructure deployment in logistical and urban environments, and creates a more robust foundation for standardization and integration between renewable supply, transportation, and industrial consumption.

It is precisely this type of reclassification and harmonization that supports the transition from pilot projects to mass deployment and helps explain why China combines national caution with regional acceleration in building the green hydrogen economy [2,5,7].



National Roadmap 2021–2035: Phases and Targets

The interpretation of the National Roadmap 2021–2035 becomes clearer when one observes that China reached this plan after decades of incremental development of its hydrogen market. Today, the country accounts for the world's largest hydrogen consumption, supported by a mature base of predominantly industrial production and use. At the same time, this market is still largely supplied by gray hydrogen, while fuel applications remain limited, which helps explain why green hydrogen is treated as an ongoing transition rather than a fully consolidated reality.

Figure 3 summarizes this trajectory by combining the evolution of consumption with the sector's structural milestones. It highlights the transition from an initial phase focused on building the supply and consumption system, to a period of accelerated development within the context of industrialization and reform and opening-up, culminating in the most recent stage, in which the Dual Carbon targets and national plans begin to guide the transition toward a green, low-carbon, diversified, and higher value-added industry.

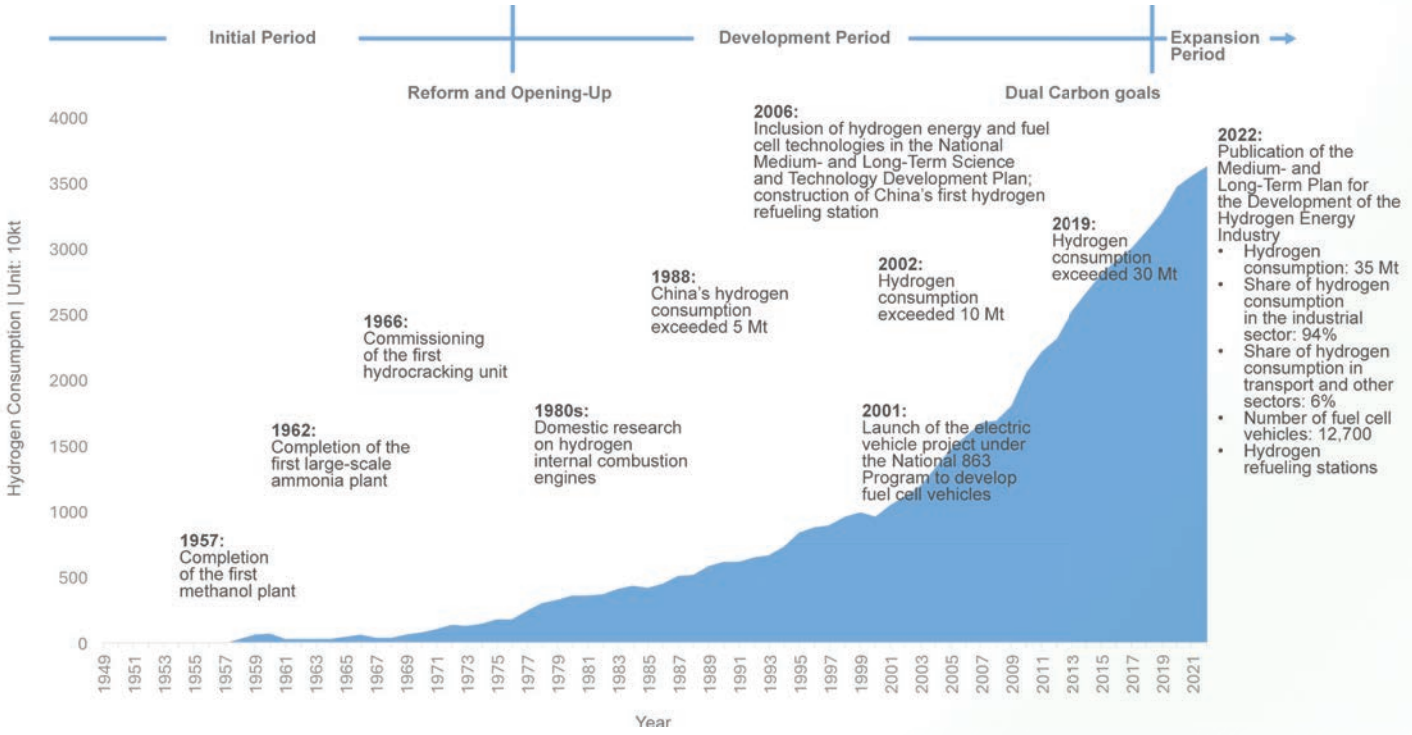


Figure 3. Trend in hydrogen consumption in China. Adapted from [1], approximate data.

This historical background is relevant because it helps justify the phased logic of the 2021–2035 Roadmap. The plan builds upon an existing industrial base and seeks to reorient it through policies, standards, and investments in innovation, promoting the integration of the entire value chain, from production to end use, with increasing emphasis on demonstration projects, infrastructure, and industrial and energy applications associated with green hydrogen.

The 2021–2035 Plan structures this trajectory into **three phases**, with targets designed to avoid the mistakes of overcapacity and uncontrolled subsidies previously observed in the solar and EV sectors [2].

Phase 1 – Incubation and Demonstration (by 2025)

Official targets for 2025:

Indicator	2025 Target (Plan)	Comment
Renewable hydrogen production	100–200 kt/year	<1% of current consumption (~34 Mt). A deliberately modest target aimed at focusing on technological demonstration and project quality.
FCEVs	~50,000 vehicles	Focus on commercial vehicles (buses, trucks, and logistics). Passenger cars continue to be dominated by Battery Electric Vehicles (BEVs).
Infrastructure	Pilot HRS network	Demonstration clusters in five major urban agglomerations (Beijing, Shanghai, Guangdong, Henan, and Hebei).
CO_2 reduction	1–2 Mt/year	Limited initial impact, but important as a proof of concept for industrial and transport decarbonization.



Transition Guideline: Control of Unabated Coal-Based Hydrogen

The Plan is explicit: pathways based on coal without carbon capture are no longer considered a regulatory priority. The new efforts of state-owned enterprises (SOEs) should instead be directed toward:

- Short Term: Projects involving carbon capture, utilization, and storage (CCUS).
- **Long Term: Full focus on electrolysis coupled with renewable energy sources.**

Impact: This signals strict control over fossil-based expansion and an accelerated transition toward low-carbon solutions.

At the same time, long-term scenarios do not assume an immediate abandonment of fossil-based pathways. Gray hydrogen production from coal is expected to peak around 2030 and then begin a gradual decline. This production will gradually be replaced by blue hydrogen (with CCUS) and, primarily, by renewable hydrogen. By 2060, hydrogen production is projected to consist of 7% fossil-based sources and 93% non-fossil sources, with renewable hydrogen accounting for more than 80% of the total, while blue hydrogen will maintain a residual role as a supply security measure.

This transition will be gradual, with blue hydrogen functioning as an intermediary between fossil and renewable sources. The focus is on implementing emerging technologies that enable a smooth shift toward a low-carbon economy while ensuring supply stability.

Hydrogen infrastructure, including large-scale storage and distribution networks, will be essential to enable this transition. The expansion of pipelines and refueling stations will be crucial to efficiently balance hydrogen production and consumption.

Finally, technological innovation, such as improvements in electrolysis and electrolyzers, will be central to reducing costs and increasing the competitiveness of renewable hydrogen, driving China's transition toward a low-carbon energy system [1].

Phase 2 – Commercialization and Parity (by 2030)

Although the national plan does not establish strict numerical targets for 2030, the combination of official documents and think tank analyses converges on three main axes:

"Renewable Hydrogen 100" Initiative

The Rocky Mountain Institute (RMI), in partnership with the China Hydrogen Alliance, proposes as a scale benchmark the installation of **100 GW of electrolyzer capacity by 2030**, which would be sufficient to produce approximately **7.7 Mt/year** of renewable hydrogen. This is a proposal and sector projection, serving as a reference for ambition and industrial sizing, rather than an official target of the national plan [3,6].

Industrial integration

Green hydrogen moves from a "pilot" stage to becoming a **standard input** in selected sectors, especially in the chemical industry and in hard-to-abate industrial applications, driven by decarbonization requirements and economic signals associated with the carbon market. In practical terms, the strategy seeks to normalize green hydrogen as a standard input in already established industrial chains before expanding to more diffuse uses [3].

Phase 3 – Systemic Diversification (by 2035)

By 2035, the goal is a mature hydrogen ecosystem, structured around:

Multisector applications: Beyond chemicals and transport, hydrogen is expected to be used in long-duration energy storage, distributed generation, and combined heat and power (CHP) systems in buildings and industries [3]. This reflects a shift from niche industrial use toward broader integration across the energy system.

Energy mix transformation: A significant increase is expected in the share of renewable hydrogen in final energy consumption, positioning it as a structural pillar of the green transition [2,3]. Policy roadmaps indicate hydrogen will progressively support electricity systems, industry, and transport as part of a more flexible low-carbon energy mix [3].

Legal and regulatory framework: This phase also requires a consolidated legal structure, including energy law updates and hydrogen-specific regulations covering standards, certification systems, and safety governance. The objective is to move from pilot regulation to a fully institutionalized market environment.

In an extended outlook toward 2060, reference scenarios project total hydrogen demand in China could reach around 86 Mt/year, with hydrogen accounting for approximately 12% of final energy consumption. In this context, production becomes deeply decarbonized, with about 93% of hydrogen coming from non-fossil sources and over 80% from renewable hydrogen, consolidating hydrogen as one of the core pillars of China's energy system [1].

As shown in **Figure 4**, long-term Chinese scenarios indicate that final energy consumption continues to grow in this decade, reaching a peak around **2030**. In the **Coordinated Development Scenario (CDS)**, total final energy consumption would increase from approximately **3.176 billion tonnes of coal equivalent (btce) in 2020** to about 3.644 btce in 2030, before gradually declining to approximately **2.738 btce by 2060**.

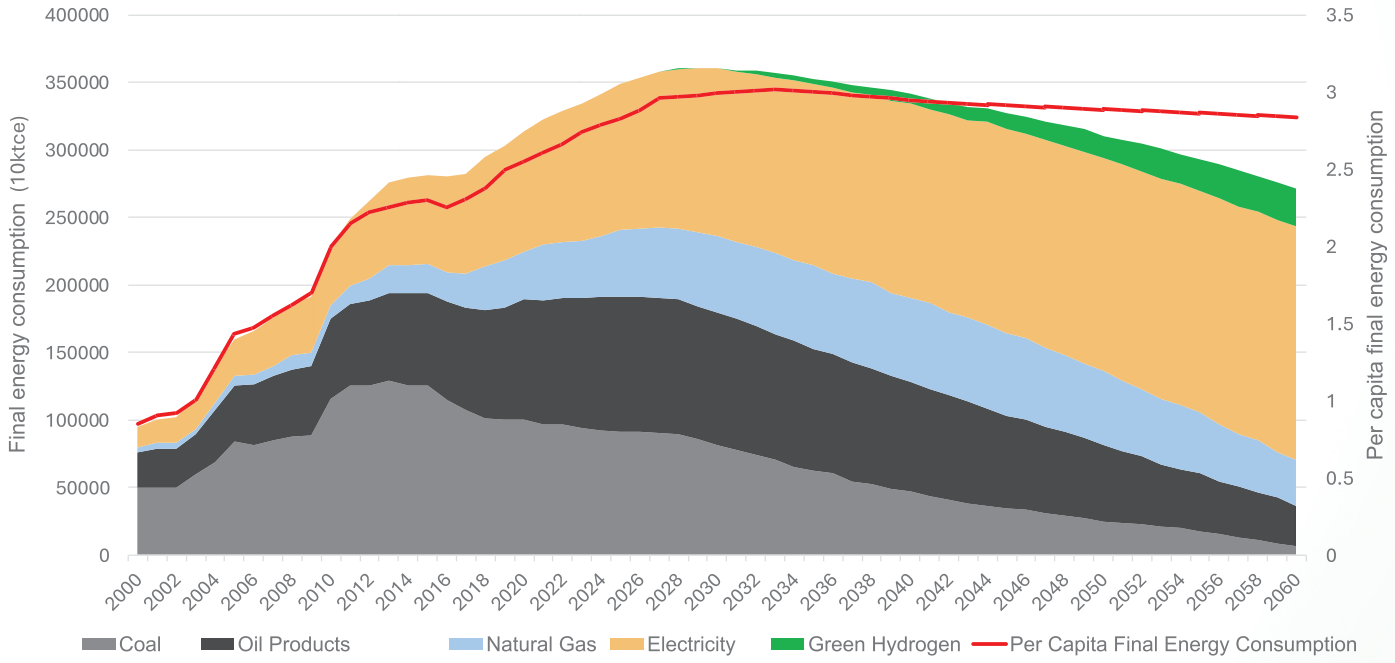


Figure 4. Projection of China's final energy consumption (2020–2060). Adapted from [10].

Beyond total volume, **Figure 4** highlights a structural shift in the final energy mix. The share of **coal, oil products, and natural gas** is expected to decline over time, while electricity and, increasingly, **green hydrogen** emerge as significant drivers of the transition in final energy consumption. The **per capita** final energy consumption curve also reinforces a trend of stabilization followed by a decline toward 2060, consistent with the carbon neutrality objective.

The Shift Toward Industrial Electrification

Electricity is projected to consolidate itself as the main industrial energy source in the coming decades, with a strong increase in its share of the energy mix:

- **2020:** 29.4% share
- **2060:** 65.8% share

This data highlights the irreversible electrification of production processes, positioning the power sector (and green hydrogen) at the center of the global industrial strategy.

Figure 5 summarizes the projected structural change in China's industrial energy consumption mix through 2060. Consistent with the scenario described above, coal shows a continuous decline in share, falling from 45.4% in 2020 to about 35% in 2030 and reaching 4.1% in 2060, reflecting the gradual substitution of fossil fuels by lower-carbon energy carriers.

Over the same horizon, electricity consolidates itself as the main industrial energy source, increasing its share from 29.4% in 2020 to 65.8% in 2060, highlighting the growing electrification of industrial processes.

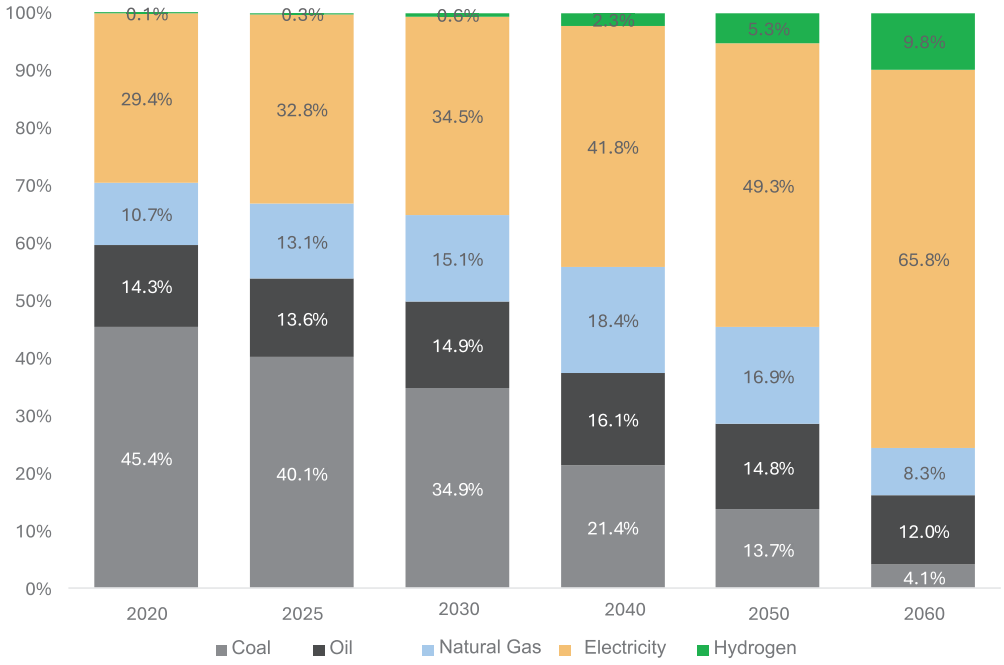


Figure 5. Changes in the Composition of Energy Consumption in China's Industrial Sector. Adapted from [10].



Natural gas increases its relevance in the medium term, reaching a peak share around 2040, driven by a "coal-to-gas" transition, but gradually loses space thereafter, falling to 8.3% in 2060 as it is replaced by electricity and hydrogen. Finally, hydrogen emerges as a relevant industrial energy vector, rising from a negligible share at the beginning of the period to 9.8% in 2060. This growth is associated with its use as a reducing agent and a fuel for high-temperature heat, contributing to the reduction of direct emissions in the sector after the peak observed before 2030.

Strategic Discrepancy: National Targets vs. Regional Ambition

A central feature of China's strategy is the gap between central government caution and provincial ambition. The number of Chinese companies operating in the hydrogen sector is already significant, revealing a rapidly consolidating industrial ecosystem.

Aggregated Provincial Targets

Surveys of provincial plans (CGEP/Columbia [5], RMI [3], Agora [6]) show that:

- Combined targets for renewable hydrogen by 2025 reach approximately 1.1–1.2 Mt/year, equivalent to around 5–12 times the national target (100–200 kt/year) [5].
- Inner Mongolia alone sets a target of 480,000 t/year of renewable hydrogen by 2025 and projects a potential capacity of up to 1.4 Mt/year when planned projects are included [5].

Based only on operational and under-construction projects, Inner Mongolia's annual capacity already exceeds the national target of 100–200 kt/year, illustrating how "one or two key provinces" can meet and surpass the central target [5].

Logic Behind the Discrepancy

This is not a coordination failure; it reflects a governance model:

Decentralized stress-testing – Beijing defines broad guidelines and a minimum threshold, while provinces "cross the river by feeling the stones," taking on the risk of overinvestment. What works is then replicated nationally.

Interprovincial competition for capital and subsidies – Provinces compete to attract state-owned enterprises (SOEs) and investors, leveraging wind and solar resources to offer low-cost hydrogen to industrial clusters [5].

Systemic risk containment – Project failures remain localized, while successful initiatives are scaled up as national models.

The Economic Geography of Hydrogen: The West–East Axis

The geography of hydrogen reflects China's structural energy pattern: resources concentrated in the West/North and demand centered in the East/South.

Supply bases in the North and Northwest

Regions such as Inner Mongolia, Xinjiang, Gansu, Ningxia, Qinghai, and Jilin form the core of hydrogen "megabases" [3]. To make this spatial logic more concrete, **Figure 6** illustrates examples of existing and potential green hydrogen megabases connected to industrial and logistics corridors.

In practice, these "megabases" operate as integrated green hydrogen hubs: production is not conceived as isolated projects, but as territorial systems that combine abundant renewable resources, industrial scale, and links to existing value chains, accelerating learning curves and reducing costs. **Figure 6** helps visualize this design by showing where supply bases are located and how they connect to industrial and logistics corridors.

Across the underlying documents, three recurring features define these hubs: (i) large-scale wind and solar complexes in semi-arid regions, (ii) integration of electrolysis with industrial clusters, especially in heavy chemical industries, and (iii) local regulatory conditions that encourage additional renewable generation, ensuring projects do not rely on the grid or "cannibalize" existing electricity supply.

In addition, the hub model depends on transport and other midstream infrastructure. The West–East axis therefore relies on dedicated corridors, including pipeline projects and network planning, to connect low-cost production bases with major coastal industrial centers. This reinforces the understanding that "megabases" are part of a broader infrastructure strategy rather than merely a portfolio of standalone projects.



Figure 6. Existing and potential green hydrogen megabases in China and their main integration corridors. Adapted from [3].

This figure helps visualize the logic of megabases or hubs in the North and Northwest, where the availability of wind and solar resources, land, and integration with existing industrial value chains allow for cost reduction and faster scaling. In practice, these bases share three recurring characteristics.

- Large wind and solar complexes in semi-arid areas (Gobi Desert and surrounding regions).
- Integration of electrolyzers with chemical complexes (e.g., Ningxia, "coal-to-chemicals" projects using green hydrogen to reduce carbon intensity) [3]. A flagship example of this strategy is Sinopec's green hydrogen project in Kuqa (Xinjiang), where a dedicated solar complex powers electrolyzers integrated into an existing chemical plant. The renewable hydrogen produced gradually replaces fossil-based hydrogen used in the same industrial site, reducing carbon intensity without requiring immediate structural changes to end-use equipment [1].

  Case Study: Sinopec Kuqa Project (Xinjiang)

  A real-world example of an efficient energy transition:
  - **Infrastructure:** Dedicated solar complex powering electrolyzers integrated into an existing chemical plant.
  - **Strategy:** Progressive replacement of fossil hydrogen with renewable hydrogen at the same site.
  - **Competitive Advantage:** Reduction of carbon intensity without requiring structural changes to end-use equipment.

  Implication for Brazil: The model demonstrates the feasibility of integrating green hydrogen into already established industrial and chemical hubs, such as Pecém (CE).

- Local policies, such as those in Inner Mongolia, require proof that hydrogen projects are not "cannibalizing" grid power (i.e., that they are actually using additional/dedicated renewable energy). [3]

Innovation and Consumption Hubs in the East and South

The Yangtze River Delta (Shanghai, Jiangsu, Zhejiang) and the Greater Bay Area (Guangdong) concentrate:

- Industrial demand (refining, petrochemicals, fine chemicals, steel), capital, and technological capacity [2].
- A focus on a high-value hydrogen economy, including fuel cell manufacturing, vehicles, components, refueling stations, and port applications [2].
- Regulatory innovation, such as in Guangdong, which relaxes land-use restrictions for hydrogen refueling stations (HRSs) on non-chemical land—an approach viewed as a potential reference for national-level reform.

The West–East connection depends on new hydrogen corridors, including the Ulanqab–Beijing pipeline (400 km, 0.1–0.5 Mt/year), the first long-distance pipeline integrated into national planning [5].

More broadly, hydrogen pipeline infrastructure is still at an early stage: in 2022, only just over 100 km were in operation. However, official scenarios project the construction of around 2,000 km of dedicated hydrogen pipelines by 2030 and approximately 30,000 km by 2060, equivalent to roughly one quarter of China's current natural gas pipeline network. These West–East and North–South hydrogen corridors are seen as key infrastructure linking low-cost renewable production bases to major coastal industrial hubs [1].



Priority Sector Applications

Although public visibility is often centered on vehicles, China's strategy is fundamentally industrial. The center of gravity of green hydrogen in China lies in the substitution of inputs and production routes within large existing value chains, such as refining, ammonia/fertilizers, methanol, and increasingly steelmaking, with a focus on scale, cost, and competitiveness.

This framing provides a useful reference for Brazil, where the narrative still tends to focus more on individual projects than on industrial transformation and the structuring of long-term anchor demand.

Chemicals and Refining – Anchor Demand

Most of the ~34–35 Mt/year of hydrogen consumed today is used in ammonia, methanol, and refining.

- The first wave of green hydrogen deployment consists of **replacing gray hydrogen without changing the end use**. This is a central lever of China's strategy, as it enables rapid scaling by switching the hydrogen source in existing industrial processes such as fertilizers, methanol-to-olefins routes, and refining desulfurization. This reduces adoption barriers because it does not require redesigning downstream industrial processes, only replacing the hydrogen supply, thereby accelerating volume growth and learning with lower operational risk.[6].

There is also a strong focus on **green methanol**, produced from green hydrogen and captured carbon dioxide or biogenic CO_2. This leverages China's leadership in the methanol value chain and its existing installed capacity. This pathway is treated as a pragmatic route to scale low-carbon maritime fuels and chemical feedstocks, combining high potential demand with already established industrial infrastructure and capabilities.

Green Steel – Technological Frontier

As the world's largest steel producer, China sees the hydrogen-based DRI (Direct Reduced Iron) route as strategic:

- Groups such as **Baowu** and **HBIS** are piloting hydrogen-based DRI to reduce exposure to carbon-related trade barriers such as the **European Union Carbon Border Adjustment Mechanism (CBAM)** [3].
- RMI and BCG analyses indicate that replacing gray hydrogen with green hydrogen in DRI-based steelmaking is one of the **"no-regret"** cases for the 2030s [2].

Heavy Transport – "Batteries for cars, hydrogen for trucks"

China does not prioritize hydrogen-powered passenger vehicles in its hydrogen mobility policies.. The strategy is:

- **Batteries for light-duty vehicles; hydrogen for heavy-duty transport.**
- A target of 50,000 FCEVs by 2025, focused on **heavy trucks, buses, urban logistics, and mining trucks**, where hydrogen's energy density is an advantage [2].
- Subsidies focused on "**city clusters**" that build complete value chains (production, refueling, and fleets), rather than subsidizing vehicles in isolation.

Energy Storage and the Power System

With record additions of solar and wind capacity, China faces significant curtailment. Hydrogen enters as:

- **Flexible load** – electrolyzers absorb renewable surpluses, converting them into hydrogen for industrial use or seasonal storage [2].
- A component of **microgrids and hydrogen–electricity–heat** cogeneration in industrial and distributed applications [3].

Demand Management and Flexibility in China's Hydrogen Strategy

In the Chinese context, hydrogen is not conceived only as an industrial feedstock or alternative fuel, but as a **strategic flexibility resource on the demand side** of the power system. Although Western terminology such as demand response (DR) appears only sporadically, Chinese policy and literature primarily frame the concept through its own approaches, such as the "**Source–Grid–Load–Storage**" integration model and mechanisms of "**peak shaving and valley filling**." In essence, these concepts describe a system in which demand is no longer passive, but dynamically responds to grid signals, with hydrogen playing a central role [3,7,11].

In this framework, electrolyzer plants are treated as **programmable flexible loads**. In renewable-rich bases in the North and Northwest (Inner Mongolia, Xinjiang, Gansu), hydrogen production is modulated according to wind and solar generation: it increases when there is renewable surplus and low prices (filling demand "valleys") and decreases during peak congestion periods, with stored hydrogen or energy redirected to other uses. The wind/solar-to-hydrogen (power-to-hydrogen) model is explicitly promoted as a way to reduce curtailment and stabilize grid operation, shifting part of the balancing role previously performed by thermal power plants [2].

From a technological perspective, China combines **alkaline electrolysis (ALK)**, which is lower-cost and suited for baseload production, with more responsive technologies such as **PEM** and hybrid battery systems to enable fast ramping and provision of ancillary services. This architecture turns hydrogen facilities into sophisticated controllable loads capable of participating in frequency

regulation, peak adjustment, and real-time price response schemes. In parallel, hydrogen storage (including salt cavern projects) is designed as a **long-duration storage** solution, complementing batteries in managing daily, weekly, and seasonal imbalances [2,12].

In China, the continued dominance of alkaline electrolysis as the leading pathway depends not only on industrial scale but also on improvements in efficiency and operational flexibility, which explains the prioritization of specific R&D fronts across the cell, stack, and system value chain.

This is illustrated in **Figure 7,** where, over the 2021–2022 period, alkaline electrolysis was the dominant technology in green hydrogen projects in China, both in terms of number of projects and installed or planned capacity. In the left panel, this is clearly visible: alkaline electrolysis accounts for the largest share of confirmed projects and, above all, the majority of total capacity, indicating that it is the preferred pathway for large-scale initiatives.

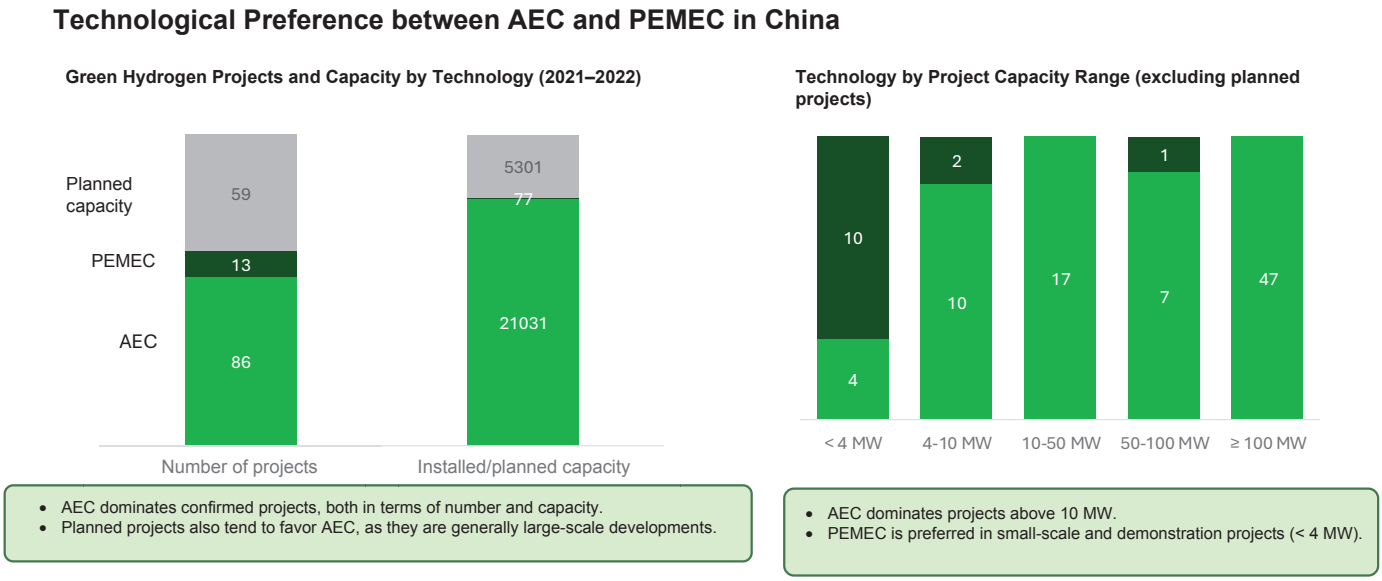


Figure 7. Technological preference between alkaline electrolysis cells/systems (AEC/ALK) and proton exchange membrane electrolysis cells (PEMEC/PEM) in China, 2021–2022. Adapted from [2].

Figure 8 summarizes how this competitiveness is pursued through two engineering and industrialization levers. The first is the degree of product standardization, which determines the potential for mass production and cost reduction through large-scale manufacturing. The second is the adoption of pressurized systems, which improves downstream efficiency by reducing the need for additional compression, thereby enhancing overall system economics in end-use applications.

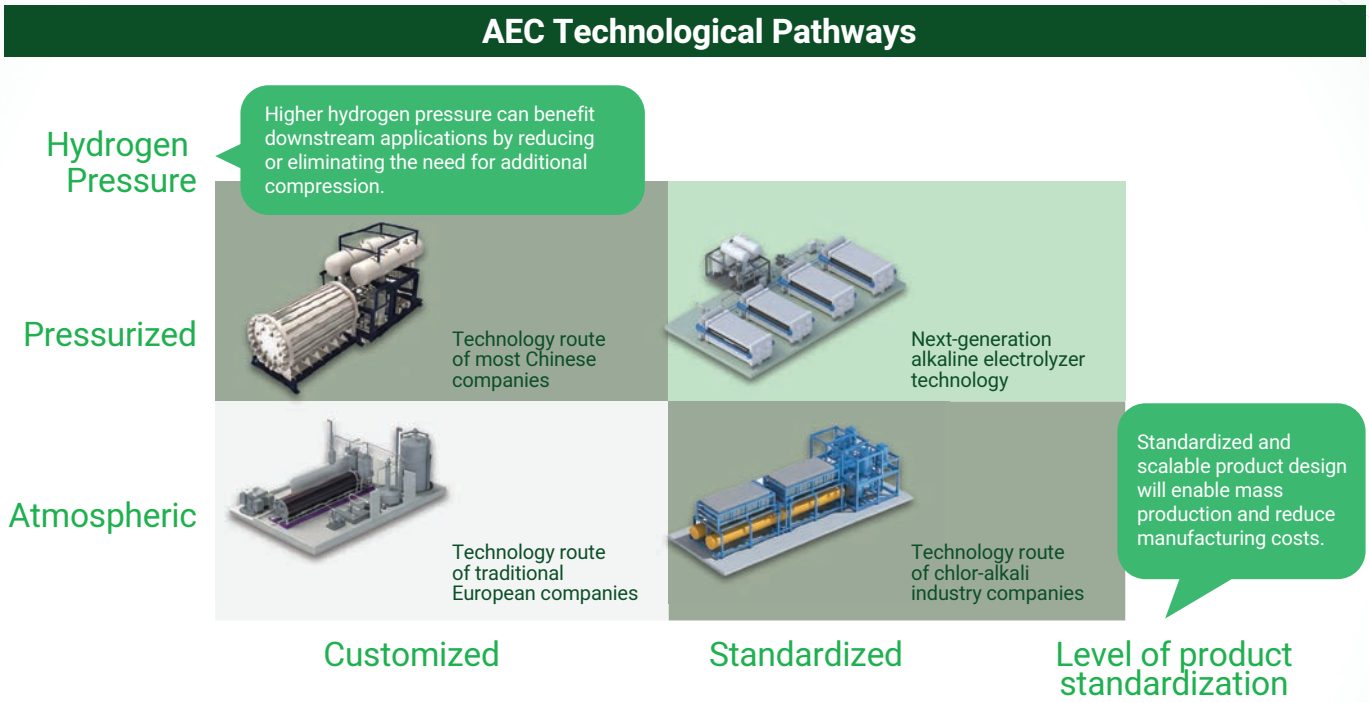


Figure 8. Technological pathways of alkaline electrolysis for green hydrogen production. Adapted from [2].



Alkaline electrolysis systems are advancing toward higher efficiency, driven by innovations in critical dimensions such as current density, energy consumption, operational flexibility, operating pressure, and maintenance convenience. In the case of China, where alkaline electrolysis remains the dominant pathway for enabling scale and cost reduction in green hydrogen production, this incremental improvement effort is treated as part of the broader industrialization strategy of the value chain, with gains distributed from the cell level to the full system.

Figure 9 organizes these improvement fronts and the future directions of research and development for alkaline electrolyzers and their peripheral systems, highlighting the trade-offs that must be balanced across different levels, cell, stack, and system, to make the technology more adaptable to large-scale production and integration with renewable energy sources.

Improvement Areas							Future R&D directions:
		Current density	Energy consumption	Flexibility	Operational pressure	Ease of maintenance	
Cell	Electrode / catalyst	✓	✓	✓			Reduce impedance and performance degradation through material optimization
	Membrane	✓	✓	✓	✓		Improve tightness and reduce losses with better membrane design and materials
	Flow field	✓	✓	✓			Redesign flow fields and channels for better electrolyte distribution and higher efficiency
Stack				✓	✓	✓	Optimize the stack with modular design and innovative structures
System			✓	✓			Adapt the system for different applications

Figure 9. Alkaline electrolyzers in China: improvement areas and future R&D directions. Adapted from [2].

Another important dimension of China's strategy is the development of virtual power plants (VPPs) integrating electricity and hydrogen assets. In this arrangement, green hydrogen ceases to be merely an industrial product and becomes a **flexibility resource for the power system**, since electrolysis can operate as an **elastic load**, with adjustable power demand and the ability to shift consumption over time.

In practice, the elasticity of electrolyzers means they can rapidly **reduce, pause, or increase** electricity demand according to grid signals, renewable energy availability, and hourly price dynamics, converting excess wind and solar generation into hydrogen when electricity is abundant and inexpensive, and scaling back when the system needs to relieve congestion or meet peak demand. In jurisdictions such as Shanghai and Guangdong, regulators have already established specific frameworks for VPPs that aggregate distributed renewable generation, flexible loads—including electrolyzers and hydrogen refueling stations — and, in some cases, fuel cells. In these arrangements, hydrogen assets can stack revenues: they sell hydrogen as an industrial commodity while also being compensated for flexibility services and load-balancing support to the grid, improving project economics and reducing the effective levelized cost of hydrogen [6].

The practical application of this demand-side management differs across regions. In the North/Northwest, the focus is on absorbing as much local renewable energy as possible through hydrogen megabases (off-grid projects or projects connected to weak grids, fully coupled to renewable

generation). In the industrialized East/South, hydrogen is integrated into urban microgrids, industrial parks, and hydrogen corridors (Yangtze River, Greater Bay Area), functioning as a distributed flexibility resource to relieve grid congestion and support local reliability [5,6].

Despite the clear political alignment, China recognizes significant challenges in scaling this demand-side management (DSM) model with hydrogen: the **cost of flexibility** (especially for technologies such as PEM), the still limited transport and storage infrastructure (pipelines and salt caverns), and the **need to advance regulatory and market frameworks** that allow hydrogen to fully participate in energy, ancillary services, and carbon markets.

Even so, the strategic direction is unequivocal: in the Chinese model, hydrogen is an integral part of the "new energy system," functioning simultaneously as a vector for industrial decarbonization and as a form of "system-scale battery" activated from the demand side [3,7,12].

Hydrogen as a Pillar of the "New Energy System"

China's strategy positions hydrogen with a clear dual and complementary role:

1. Decarbonization Vector: Direct decarbonization of heavy industrial processes.
2. "System-Scale Battery": Acting as a grid-balancing mechanism, activated from the demand side to absorb and store surplus energy.

Why this matters: This model transforms hydrogen into a key element of energy security, rather than merely an industrial feedstock.



Technological and Industrial Landscape

Electrolysis: Advantage in ALK, Race in PEM/SOEC

In the electrolysis segment, China starts with a clear advantage in alkaline technology. In the electrolysis segment, China starts with a clear advantage in alkaline technology, also referred to as AEC or ALK. The supply chain for alkaline electrolyzers is already largely dominated domestically and enables CAPEX levels significantly lower than those of Western suppliers, around one-third to one-half of comparable costs. This favors large-scale projects and accelerates the formation of the domestic market [2].

In PEM technology (proton exchange membrane electrolyzers), there is explicit recognition that operational performance tends to be better suited to systems with high shares of wind and solar power, due to its superior ability to respond to electricity variability. Even so, critical components such as membranes and platinum-group-metal-based catalysts remain more dependent on imports, which is why policy documents highlight targeted R&D efforts aimed at localization and reducing technological bottlenecks [2].

Finally, earlier-stage technologies such as solid oxide electrolysis (SOEC) also appear in the innovation agenda. They remain largely at the laboratory and demonstration stages but are considered medium- and long-term options, particularly if they deliver efficiency gains and new pathways for industrial integration [13,14].

Cost Curve and Parity

The cost of **green hydrogen** still remains substantially higher than hydrogen produced from coal. Consolidated estimates from the cited studies place green hydrogen in the range of approximately **RMB 33–40 per kg**, while coal-based hydrogen remains around **RMB 10 per kg** under current supply conditions [3].

Nevertheless, the documents highlight two clear levers to reduce this gap.

The first is access to very **low-cost renewable electricity**. Studies associated with the RMI and the China Hydrogen Alliance indicate that when renewable electricity costs fall below **RMB 0.15 per kWh**, green hydrogen can reach levels below RMB 15 per kg, approaching economic parity, especially when carbon-related costs are internalized [3].

The second lever is industrial scale. The sectoral scenario of 100 GW of electrolysis capacity by 2030, proposed by RMI in partnership with the China Hydrogen Alliance, serves as a benchmark for capturing manufacturing learning effects and reducing CAPEX over time, replicating dynamics already observed in the solar and battery value chains [3].

In addition to the decline in renewable electricity costs and the large-scale manufacturing of electrolyzers, carbon pricing policy plays an increasingly important role in hydrogen economics. The expected trajectory of China's carbon market projects prices around RMB 100/tCO_2eq by 2030, rising to several hundred RMB/tCO_2eq in the following decades [1].

This trend is expected to progressively increase the cost of gray hydrogen and fossil fuels, shortening the path toward cost parity for green and blue hydrogen in carbon-intensive industrial sectors [1].

Competitiveness Accelerator: Cost Parity

A market shift is emerging that is changing the financial viability of projects:

- Pressure on Fossil Fuels: The progressive increase in the cost of gray hydrogen and conventional fuels.
- Shorter Timeline: Cost parity between green/blue hydrogen and gray hydrogen may be reached sooner than previously expected in carbon-intensive sectors.

Impact: This reduces financial barriers to industrial adoption and accelerates the transition in hard-to-abate sectors.



Legal and Institutional Update (2024–2025)

Beyond the Energy Law, the *China Legal Briefing* (January 2025) points to significant changes in the legal ecosystem affecting the structuring and governance of hydrogen-related companies and projects, with direct impacts on capitalization, corporate credibility, and investor appetite [4].

Corporate Registration and Capitalization

The Implementation Measures for Company Registration Management (2025) expand the possibility of capital contributions through **intangible assets**, including intellectual property and certain usage rights. This is particularly relevant for technology-intensive startups and joint ventures, which often possess strong knowledge assets but limited cash availability in early stages [4].

At the same time, the same regulatory package increases scrutiny over **inflated registered capital** structures and excessively long capital contribution deadlines, encouraging greater discipline and transparency. In the context of the hydrogen sector, this is understood as a mechanism to reduce information asymmetries and improve the quality of corporate vehicles, potentially supporting the attraction of institutional capital to hydrogen-related projects, including green hydrogen value chains [4].

Dispute Resolution and Contractual Security

Recent guidance from the Chinese judicial system, cited in the *China Legal Briefing*, indicates a trend toward greater predictability in the treatment of complex business disputes. Among the practical signals are incentives for consolidating interconnected litigation into a single judicial analysis, especially when disputes involve long contractual chains such as EPC agreements, pipeline access rules, and controversies related to network and infrastructure use [4].

The same material also points to efforts to reduce arbitrary procedural dismissals and strengthen more efficient solutions for technically complex disputes, with preference for mediation and negotiation when conflicts involve infrastructure access, coordination among stakeholders, and interpretation of technical obligations [4].

For industrial-scale hydrogen projects, this is directly relevant: these ventures involve multiple parties and simultaneous contracts, integrating renewable generation, electrolysis, logistics and distribution, pipelines, and off-takers, in addition to interfaces with local governments. A judicial environment that favors consolidation, predictability, and consensual mechanisms tends to reduce execution risk and transaction costs during both implementation and operation phases [4].

Structural Challenges and Risks

Despite recent momentum, the documents indicate that China's hydrogen strategy faces structural challenges that may limit the pace, efficiency, and national integration of the sector.

From an infrastructure perspective, logistics remain a bottleneck: the network of dedicated hydrogen pipelines is still incipient, and expansion depends on flagship projects. In this context, the Ulanqab–Beijing pipeline is treated as a milestone, as it is one of the first long-distance corridors incorporated into national planning, signaling a transition from a road-transport-based model to a trunk network logic [5].

In parallel, there is a regulatory dimension directly linked to international competitiveness. China is still consolidating standards and criteria to reliably differentiate "green hydrogen" from "low-carbon hydrogen." This gap in taxonomy and certification may create friction for exports in value chains subject to traceability requirements and carbon adjustment mechanisms such as the CBAM, especially when destination markets already operate under more mature and standardized criteria [5].

Finally, competition among provinces, while accelerating project development, may also generate distortions. The literature highlights the risk of local protectionism through local-content requirements as a condition for access to subsidies and incentives. If intensified, this behavior could fragment the domestic market, reduce economies of scale, and hinder the efficient consolidation of the national supply chain [5].



Conclusion: Adaptive State Capitalism and the "Chinese Hydrogen Era"

China's green hydrogen strategy is an emblematic case of adaptive state capitalism. There is a clearly defined central strategic direction, anchored in the Dual Carbon goals, the 2021–2035 Plan, and the institutional reinforcement brought by the Energy Law. At the same time, execution is deliberately decentralized, with provinces and state-owned enterprises conducting large-scale experiments, testing technological arrangements and business models that, when successful, tend to be normalized and replicated nationwide in an iterative learning cycle [1].

Within this framework, performance through 2025 should not be assessed solely against the minimum targets, but also by the ability to unlock infrastructure and governance bottlenecks. Two points stand out: enabling corridors and transport solutions that allow continuous scale expansion and, in parallel, harmonizing standards to reduce regulatory friction and consolidate a more integrated national market, with more predictable rules for investment and certification [1].

Looking toward 2030–2035, the decisive test becomes sectoral integration. The critical factor will be the extent to which green hydrogen is materially incorporated into heavy industry and into flexibility mechanisms of the power system, expanding China's ability to convert inland renewable resources into transportable energy and industrial inputs. More than project announcements, it is this integration that will indicate whether the country can transition from an economic model heavily anchored in coal and energy-intensive production to one sustained by renewables and low-carbon technologies [1].

From the perspective of 2060, Chinese scenarios indicate that success will be measured less by the number of projects and more by the structural transformation of the energy mix. The implicit objective is for renewable hydrogen to become a stable component of final energy consumption, with a double-digit share, and for dedicated hydrogen production to be predominantly based on non-fossil sources. In this scenario, China is likely to move beyond being merely the world's largest hydrogen consumer and consolidate leadership as a supplier of technology, equipment, and integrated solutions within the international green hydrogen economy [1].

What China is doing with green hydrogen is not merely a domestic policy: it is an industrial-scale strategy that is likely to reprice equipment, inputs, and project models in the international market. When a country organizes demand, standardizes technological pathways, and accelerates productive capacity, the practical effect is lower unit costs, shorter timelines, and the establishment of certain technological architectures as the "new normal" for global investors and buyers—even outside China [6, 7].

The parallel with solar and wind energy is direct. Historical trajectories show that when China decides to industrialize a value chain, the learning curve accelerates and the world begins operating under a new level of cost and availability. This effect does not depend on geopolitical consensus: the effect is driven by economies of scale, speed of execution, and the diffusion of suppliers and

integrated technology packages [6, 7].

This does not mean that all markets will follow China's regulatory lead. The United States and the European Union may continue to pursue their own requirements, local-content rules, and distinct sustainability criteria. Even in these scenarios, however, the cost benchmark and delivery capacity associated with Chinese scale are likely to pressure competitors and influence global purchasing and investment decisions—from the design of industrial hubs to the selection of technologies and supply contracts [6, 7].



For the global market, the central implication is that green hydrogen is likely to move beyond "pilot project" narratives toward competition based on productivity, standardization, and scale. In other words, the discussion becomes less about intention and more about who can achieve economic viability, build infrastructure, and integrate production, logistics, and industrial use with controlled risk.

It is in this environment that China's strategy functions as a directional signal: it does not force adoption, but it redefines the benchmark for competitiveness and the pace of sector maturation.

Dimension	Reference situation (2023/24 – estimated)	2025 Target (national floor)	Industry projection (2030)	Vision 2035/2060
Green hydrogen production	< 50 kt/year	100–200 kt/year	Sectoral scenario of 100 GW of electrolysis capacity, corresponding to approximately 7.7 Mt/year	Renewable hydrogen gains an increasing share of hydrogen production and final energy consumption
FCEVs	~15–20k vehicles	~50,000 vehicles	Expansion concentrated in heavy-duty transport, logistics, buses, and mining	Broader adoption in transport segments that are difficult to electrify directly.
Regional focus	Fragmented projects	Pilot clusters in 5 regions	West–East integration via pipelines and logistical chains (ammonia/methanol)	A relatively unified national network for green hydrogen production, transport, and consumption.
Key technologies	Mature ALK; emerging PEM; SOEC in R&D	Consolidation of the domestic ALK chain	Green/gray hydrogen cost parity in regions with better resources; start of scale in PEM	Global leadership in ALK and strong position in PEM/SOEC, with a mostly domestic supply chain.
Main applications	Chemical (gray hydrogen) and transport pilots	Heavy transport (demonstration) and specific replacement of gray hydrogen	Strong penetration in chemicals, steel, and heavy transport; start in energy storage	Systemic use in industry, transport, seasonal storage, and distributed generation (CHP).
Total hydrogen demand (t/year)	~33–34 Mt/year (predominantly gray hydrogen used in chemicals and refining)	There is no specific numerical target for total demand; focus on qualifying and decarbonizing part of the existing volume	~35 Mt/year, with the start of relevant substitution by low-carbon hydrogen in chemicals, refining, steelmaking, and heavy transport	Path to ~60 Mt/year in 2050 and ~86 Mt/year in 2060, with an increasing share of renewable hydrogen and an increasingly relevant role in China's final energy consumption

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