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THE FUTURE OF ENERGY STORAGE IN THE INDO-PACIFIC

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By Nofri Yenita Dahlan and Nguyen Duc Tuyen

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NBR SPECIAL REPORT #119 | SEPTEMBER 2025

POWERING TRANSITIONS

The Future of Energy Storage in the Indo-Pacific

TABLE OF CONTENTS

THE NATIONAL BUREAU *of* ASIAN RESEARCH

NBR SPECIAL REPORT #119 | SEPTEMBER 2025

Advancing Battery Energy Storage Systems (BESS) in the Asia-Pacific: Opportunities, Challenges, and Strategic Pathways

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EXECUTIVE SUMMARY

This essay offers a comprehensive overview of battery energy storage systems (BESS) deployment and the investment landscape in the Asia-Pacific, identifies key challenges and opportunities, and proposes strategic actions to accelerate BESS adoption.

MAIN ARGUMENT

The global shift toward clean energy is accelerating, with the Asia-Pacific region emerging as a key player in the energy transition. In recent years, countries across the region have rapidly expanded their deployment of renewable energy, particularly solar. This trend is driven by falling technology costs, supportive policies, and growing access to international climate finance. However, the variable nature of solar and wind energy has underscored the critical need for energy storage solutions to ensure grid stability and reliability. BESS are now central to enabling a flexible, resilient, and low-carbon power system. The Asia-Pacific is projected to lead the global BESS market by 2026, with China, Japan, India, and Australia at the forefront. BESS deployment is thus a critical enabler of the Asia-Pacific's clean energy transition, and strategic policy action is essential to scale the adoption of such systems in a way that enhances energy security, grid resilience, and low-carbon development.

POLICY IMPLICATIONS

- To best utilize BESS in achieving the clean energy transition, governments should establish clear and stable regulatory frameworks to de-risk BESS investments.
- Expanded public-private financing mechanisms to lower capital costs and scale deployment can and should play a key role in facilitating BESS development and adoption.
- As BESS gains greater usage, regional cooperation for BESS supply chains, standards, and cross-border technology transfer will be essential.

The global shift toward clean energy has been gaining significant momentum, and the Asia-Pacific region is emerging as one of the most dynamic arenas for this transition. Characterized by rapid economic growth, urbanization, and rising energy demand, the region includes both major energy producers and consumers. Home to approximately 60% of the world's population,[1] the Asia-Pacific contributes two-thirds of global economic growth.[2] The region is projected to consume nearly half of global energy by 2050, calling for bold action to meet demand while accelerating decarbonization.[3]

This essay argues that countries in the Asia-Pacific must urgently scale up their deployment of battery energy storage systems (BESS) to position themselves as global leaders in the energy transition. Those countries that strategically support this shift stand to gain economically and geopolitically. The increasing risks of climate vulnerability, coupled with rapid economic growth in the region and increasing demand for renewable energy (RE), make BESS not only a technical imperative but a strategic asset.

Countries across Southeast Asia, the Pacific Islands, and South Asia are increasingly pursuing decarbonization of their energy systems in response to domestic priorities, including growing energy demand, economic development goals, and national climate commitments. This effort must be balanced with the need to ensure reliable energy access and maintain economic resilience. The dual challenges of environmental risk and energy security are further intensified by the region's vulnerability to climate change such as extreme weather events, rising sea levels, and natural resource dependency, as well as by exposure to global geopolitical tensions and the complex task of financing the energy transition.[4] While recent years have seen strong momentum in the deployment of RE—particularly solar photovoltaics (PV) driven by plummeting costs, supportive policies, and international climate finance—its variable nature has exposed systemic vulnerabilities. As a result, energy storage has become a central pillar of future energy systems and a key enabler of a stable and resilient low-carbon energy future.

The Asia-Pacific is expected to lead the global BESS market by 2026, with China, Japan, India, and Australia leading the way.[5] The U.S. and Asia-Pacific BESS market was valued at $15.45 billion in 2023 and is expected to reach $98.23 billion by 2031, with a projected compound annual growth rate of 26% from 2023 to 2031.[6] Lithium-ion batteries dominate due to their low cost and versatility for large and small-scale use, with a projected market value of $109 billion by 2035.[7]

BESS has become a cornerstone in the modern energy transition strategy, offering a flexible solution to the variability of RE generation. Such systems enable the storage of excess electricity during periods of high generation (e.g., peak solar hours) and its release during periods of high demand or low generation, thereby flattening the supply-demand curve. This capability significantly enhances the reliability, grid stability, and resilience of power systems with a high share of RE. From a decarbonization perspective, BESS supports the phase-out of peaking

1 Economic and Social Commission for Asia and the Pacific, *Asia-Pacific Population and Development Report 2023* (Bangkok: UN Publication, 2023).

2 U.S. Department of State, *The Indo-Pacific Strategy* (Washington, D.C., February 2022).

3 James Bowen, "Re-energising Indo-Pacific Relations: Australia's Clean Energy Opportunity," Climate Council and Perth US-Asia Centre, July 2022.

4 Tulika Gupta et al., "Accelerating the Indo-Pacific Energy Transition," CEEW, May 2023.

5 "Asia-Pacific to Lead the Global Battery Energy Storage Market by 2026," Global Data, https://www.globaldata.com/data-insights/automotive/asia-pacific-to-lead-the-global-battery-energy-storage-market-by-2026.

6 "U.S. and Asia Pacific Battery Energy Storage System Market 2031," Insight Partners, 2025, https://www.theinsightpartners.com/reports/us-and-asia-pacific-battery-energy-storage-system-market.

7 Conrad Nichols, "Countries with Soon-to-Boom Li-ion BESS Markets," IDTechEx, December 4, 2024.

fossil fuel plants, often powered by gas, which are traditionally used to maintain grid stability during demand surges. In addition, BESS facilitates grid deferral by delaying the need for costly infrastructure upgrades, while promoting decentralized energy solutions that can be community-led and tailored to local needs. In the context of energy security, BESS reduces dependence on energy imports by making better use of locally generated RE. This is especially relevant for island nations and remote communities in the Asia-Pacific that face high fuel logistic costs and frequent power outages. By enhancing self-sufficiency and providing backup power during grid failures, BESS plays a strategic role in strengthening national energy resilience against climate and geopolitical disruptions.

This essay provides a comprehensive analysis of the deployment and investment landscape for BESS across the Asia-Pacific region. It explores the current state of BESS technologies, examines the policy and regulatory frameworks shaping their adoption, and identifies key opportunities and challenges influencing market growth. The essay also charts strategic directions and outlines policy options to support the scaling and integration of BESS within regional energy systems, contributing to the broader goals of energy security, grid resilience, and the clean energy transition.

BESS Deployment and the Investment Landscape in the Asia-Pacific

The Deployment of BESS Technology

The Asia-Pacific is projected to lead the global BESS market by 2026, driven by surging electricity demand, rapid energy transitions, and the need to strengthen power grids. Countries across the region are scaling up storage to support RE integration and ensure grid stability. China plays a pivotal role in accelerating global BESS deployment. In 2023, it added 22 gigawatts (GW) of new storage capacity—accounting for 36% of global additions—propelled by falling costs of lithium iron phosphate (LFP) batteries and strong national targets. The rollout of projects like the 100-megawatt (MW)/200-megawatt-hour (MWh) semi-solid BESS in Zhejiang in 2024 exemplifies China's shift toward advanced storage technologies and grid flexibility solutions.[8] This momentum positions the country as a benchmark for regional BESS strategies, influencing technology costs and adoption across the Asia-Pacific.

India's cumulative BESS capacity stood at 219.1 MWh as of March 2024, with major growth occurring in states like Chhattisgarh and Rajasthan, driven by state-level renewable and storage policies.[9] Australia, facing urgent grid reliability challenges from coal plant retirements, is investing heavily in large-scale BESS. Its projects include the 300 MW Victorian Big Battery and the 275-MW/2,200-MWh Richmond Valley project, under a scheme targeting 500-MW/2-GWh to stabilize the grid. Meanwhile, Japan requires solar panels on new homes to boost battery use and launched its first grid-scale BESS (2-MW/8-MWh) in 2023, encouraging energy trading through regulatory reforms.[10]

In Southeast Asia, Thailand, Vietnam, Indonesia, Malaysia, and Singapore are in the early stages of BESS adoption but show strong potential. Together, they account for over 80% of electricity use by members of the Association of Southeast Asian Nations (ASEAN), making their

8 "U.S. and Asia Pacific Battery Energy Storage System Market 2031."

9 Arjun Joshi, "India's Installed Battery Storage Capacity Hits 219 MWh," Mercom India, July 9, 2024.

10 Andy Colthorpe, "First BESS in Japan to Commercially Trade Energy Commissioned by Country's Biggest Solar Developer," Energy-Storage.News, June 27, 2023.

progress critical to the region's clean energy goals.[11] Growing electricity consumption and the need to integrate intermittent renewables are pushing these countries to explore BESS as part of their broader grid development strategies. Indonesia has joined the BESS Consortium and is developing a 50 MW solar plant with a 14 MWh BESS project in Nusantara through a partnership between Sembcorp Industries and PT PLN Nusantara Renewables. Vietnam is moving forward with hybrid solar-storage projects. Singapore recently completed the region's largest BESS project (285 MWh) in just six months, reaching its national target three years early.[12] In Malaysia, the Ministry of Energy Transition and Water Transformation launched a competitive bid in November 2024 for a 400-MW/1,600-MWh grid-scale BESS project in Peninsular Malaysia.[13] While behind China in scale, Southeast Asia benefits from declining technology costs and regional collaboration, setting the stage for rapid growth in storage deployment.

Future BESS Investment Scenarios

The "Asia Pacific's Energy Transition Outlook" presents projections of installed battery storage capacity in selected Asia-Pacific markets under both the Economic Transition Scenario (ETS) and the Net Zero Scenario (NZS).[14] The ETS and the NZS represent two distinct pathways for the global energy system. The ETS is an exploratory, cost-based scenario that projects how the power, industrial, transportation, and construction sectors might evolve with no additional policy support beyond what already exists. The scenario primarily sees decarbonization as occurring in the power and transportation sectors and is aligned with a global temperature rise of approximately 2.6°C. In contrast, the NZS is a normative, climate-aligned scenario that outlines a challenging but feasible path to achieve net-zero emissions by 2050, without relying on carbon removal after that date. The scenario fully decarbonizes all major sectors—power, transportation, industrial, and construction—and is consistent with efforts to limit global warming to around 1.75°C.

Table 1 compares battery storage projections under the ETS and the NZS for key Asian countries and highlights the key differences. China sees storage reaching up to 1,289 GW by 2040 under the NZS, with growth plateauing and dominated by utility-scale systems (82%–83%).[15] India experiences steady growth, with storage rising from 183 GW (ETS) to 636 GW (NZS) by 2050, mostly utility-scale (80%–88%). Japan relies largely on small-scale batteries due to rooftop solar adoption, peaking at 57 GW in 2040 (NZS) before a decline as older battery systems reach the end of their useful life and are taken out of service. South Korea shows modest growth to 22 GW by 2050 under the NZS, shifting from small-scale dominance in the ETS to more utility-scale deployment. Indonesia is projected to grow rapidly, especially under the NZS, reaching 226 GW by 2050 with over 85% from utility-scale systems. Vietnam also scales up significantly in the NZS, from 17 GW in 2030 to 124 GW by 2050, driven by the need for flexibility as renewable energy expands.

Under both the ETS and NZS, all Asia-Pacific markets are expected to significantly scale up BESS assets to enhance power system flexibility in response to increasing RE penetration. In countries with wholesale electricity markets such as Australia, the growing price volatility

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11 International Energy Agency (IEA), "Southeast Asia Energy Outlook 2024," October 2024.

12 Tim Daiss, "Battery Energy Storage Systems Development—ASEAN Members Fall Behind," Energy Tracker Asia, June 12, 2024.

13 Intan Farhana Zainul, "BESS Programme: A Game Changer for the Malaysian Energy Landscape?" Edge Malaysia, December 24, 2024.

14 BloombergNEF, "Asia Pacific's Energy Transition Outlook," commissioned by GenZero, October 16, 2024.

15 A utility-scale battery system refers to a large-capacity energy storage system that is connected to the electric power grid, typically operated by a utility company or independent power producer.

TABLE 1 Battery energy storage capacity outlook by selected country (2040–50)

Country	ETS (GW)	NZS (GW)	Key differences / Notes
China	923 GW (2040); 900 GW (2050)	1,289 GW (2040); 860 GW (2050)	Growth plateaus post-2040; 82%–83% from utility-scale systems
India	183 GW (2040); 375 GW (2050)	322 GW (2040); 636 GW (2050)	Continuous growth to 2050; high share of utility-scale (80%–88%)
Japan	32 GW (2050)	57 GW (2040); 48 GW (2050)	Mostly small-scale batteries (52%–79%) due to rooftop solar; peak in 2040 followed by declines due to retirements
South Korea	17 GW (2050)	22 GW (2050)	Slower growth due to nuclear; the ETS dominated by small-scale (58%); the NZS shifts to utility-scale (56%)
Indonesia	29 GW (2040); 110 GW (2050)	78 GW (2040); 226 GW (2050)	Rapid utility-scale growth (85%–93%) to support RE
Vietnam	12 GW (2030); 32 GW (2040); 64 GW (2050)	17 GW (2030); 64 GW (2040); 124 GW (2050)	Faster growth in the NZS; battery demand driven by the need for flexibility as RE expands

caused by high volumes of solar generation during daylight hours is expanding opportunities for energy arbitrage. This trend is strengthening the economic case for battery storage investments.

Focusing specifically on the outlook for Southeast Asia, a study published in 2024 evaluated the BESS market potential in five key Southeast Asian countries—Indonesia, Malaysia, the Philippines, Thailand, and Vietnam—using frameworks based on market potential and industry competitiveness.[16] The findings suggested that the BESS market in these countries currently has low attractiveness, characterized by limited market size, early-stage development, and a lack of specific regulations and supportive policies. Nevertheless, as the RE sector and power demand continue to grow in response to economic development, significant opportunities for BESS expansion are expected to emerge across the region.

The BESS Technology Landscape

Overview of Energy Storage Technologies

Energy storage technologies can be grouped into five main types: mechanical, electrochemical, thermal, electrical, and chemical.[17] Each stores energy differently and serves various needs, from powering homes and industries to stabilizing national grids. One of the earliest and most established forms is pumped hydro storage (PHS), which stores energy by moving water between two reservoirs at different elevations. While effective for balancing electricity in hydropower systems, PHS is expensive, requires specific geographic features, and can have environmental impacts due to large infrastructure and long-distance transmission lines.

[16] Yeojin Yoo and Yoonhee Ha, "Market Attractiveness Analysis of Battery Energy Storage Systems in Indonesia, Malaysia, the Philippines, Thailand, and Vietnam," *Renewable and Sustainable Energy Reviews* 191 (2024).

[17] Asian Development Bank, *Handbook On Battery Energy Storage System* (Manila: ADB, 2018).

Newer storage technologies are becoming more common as energy systems evolve. BESS, especially lithium-ion batteries, is widely used with RE, electric vehicles, and power grids due to flexibility, reliability, and falling costs. Other types like electrical storage (e.g., capacitors) deliver quick energy bursts, while both thermal and chemical storage (e.g., hydrogen fuel cells or heat storage) support long-term needs in industry. BESS and PHS are expected to remain key for large-scale storage through 2050.[18] Between 2030 and 2050, battery storage is projected to grow nearly twelvefold, driven by technology advances and cost reductions (see **Figure 1**). With more solar and wind power coming online by 2030, battery storage will play a vital role in balancing electricity supply and improving grid reliability.

BESS Applications: Utility-Scale, Behind-the-Meter, and Off-Grid

BESS can be used in both grid-connected and off-grid settings to support different levels of the electricity network. **Figure 2** provides an overview of these applications, ranging from large utility-scale systems to smaller end-user solutions. At the grid level, BESS supports two main functions: bulk storage and balancing storage.[19] Bulk storage is often used with large RE projects like solar and wind farms to store excess power during high production and release it during low generation, ensuring a steady energy supply. Balancing storage helps maintain grid stability by quickly adjusting to fluctuations in supply and demand to keep voltage and frequency stable. Distributed BESS, installed at various smaller locations, adds resilience and flexibility to the grid. At the end-user level, behind-the-meter BESS serves homes, industries, and commercial buildings. In homes, BESS stores surplus solar energy for later use, cutting electricity bills and improving energy independence. Industrial and commercial BESS helps reduce peak demand charges and provides backup power.

For most power systems, the 20%–30% penetration level for RE represents a critical tipping point where BESS begins to deliver significant grid services. At this stage, it can provide essential functions such as frequency regulation, ramping reserves, peak shaving, and energy arbitrage. As RE shares increase further—particularly beyond 50% and approaching 80%—the need for storage expands considerably, in both capacity and duration, to address challenges such as renewable curtailment, system resilience, and deferral of grid infrastructure upgrades.[20] This threshold helps explain the varying timelines and scales of BESS deployment across regions.

In off-grid applications, BESS is essential for delivering reliable electricity in remote or isolated areas not connected to a national grid. These systems store energy from local sources like solar panels, supplying power at night or during cloudy weather. This improves energy reliability and reduces reliance on diesel generators, lowering both fuel costs and emissions. For example, the Asian Development Bank (ADB) highlights hybrid solar PV-BESS systems deployed in island nations such as Tonga and the Cook Islands.[21] In Malaysia, the Sarawak Alternative Rural Electrification Scheme has implemented similar off-grid systems to provide stable electricity to rural communities.

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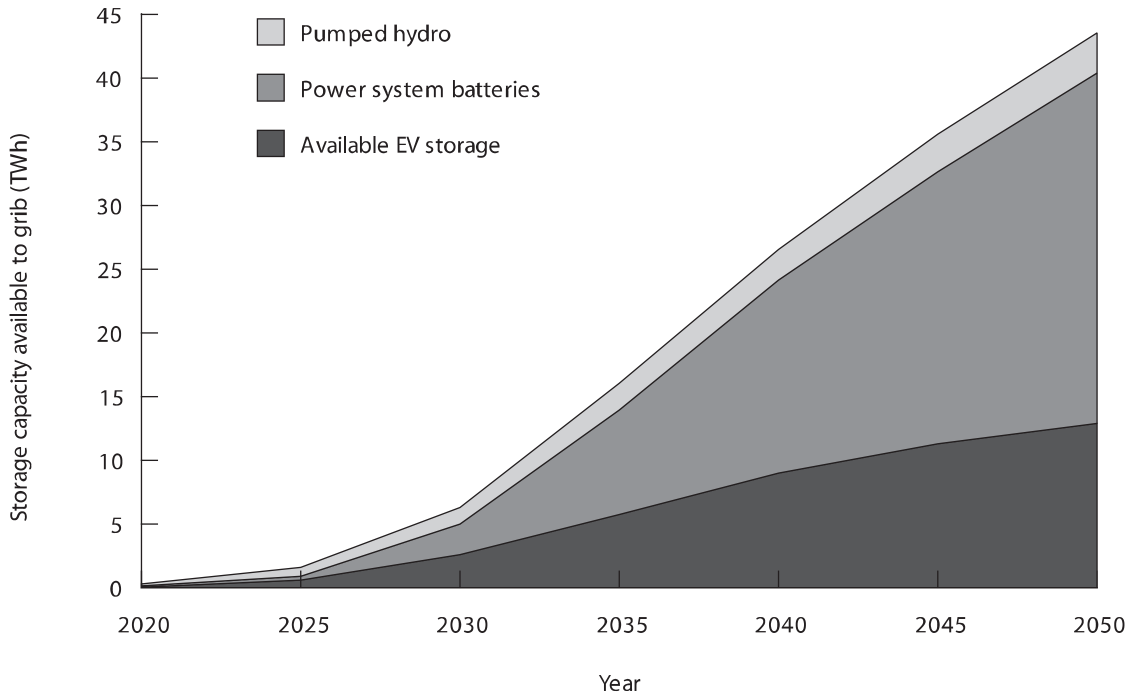
[18] DNV, "Energy Storage Systems in the APAC Region: The Opportunities, Challenges and the Business Cases," 2021.

[19] ADB, *Hybrid and Battery Energy Storage Systems Review and Recommendations for Pacific Island Projects* (Manila: ADB, 2022).

[20] Oliver Schmidt and Iain Staffell, *Monetizing Energy Storage: A Toolkit to Assess Future Cost and Value* (Oxford: Oxford University Press, 2023).

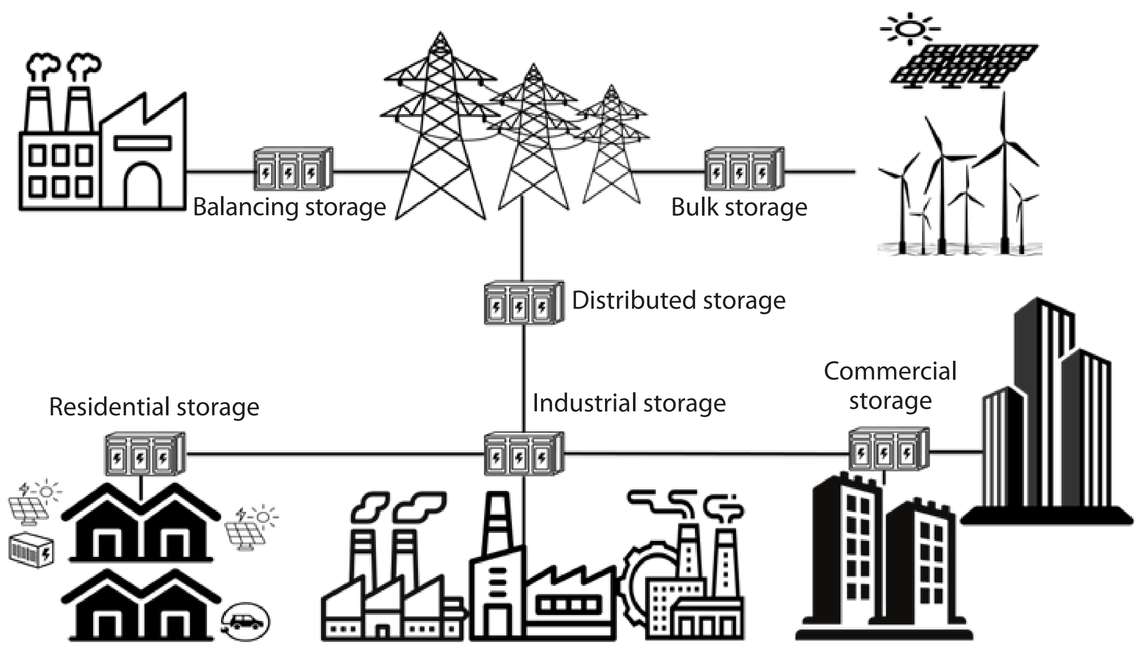
[21] ADB, *Hybrid and Battery Energy Storage Systems Review*.

FIGURE 1 Forecasted energy storage capacity available to power grids globally



SOURCE: "Energy Storage Systems in the APAC Region," DNV, 2021.

FIGURE 2 Applications of BESS in the electricity network



BESS Policy and the Regulatory Landscape

National BESS-Related Policies in Advanced Economies

BESS policies are being adopted globally for a variety of strategic reasons, with one of the primary drivers being their significant potential to reduce greenhouse gas emissions. However, each country's policy approach reflects its unique energy challenges and priorities.[22] For example, the United States and Australia have introduced BESS policies primarily to enhance power system stability and manage the variability of RE. In Japan, BESS policies are geared toward ensuring emergency power supply due to the country's high exposure to natural disasters. Germany has prioritized BESS deployment to facilitate the integration of RE into the grid, while South Korea's policies aim to reduce peak demand for residential and commercial users.[23] Yet, even though policies are shaped by different national priorities, most countries are expanding the scope of BESS applications to maximize their benefits, ranging from grid reliability and backup power to support for clean energy integration and energy market flexibility. **Table 2** provides an overview of key BESS policies in selected countries.

National BESS-Related Policies in ASEAN Countries

ASEAN is progressively incorporating BESS into national and regional energy strategies to support RE integration, grid stability, and energy transition goals. While a unified regional BESS policy is still absent, ASEAN-wide initiatives such as the ASEAN Plan of Action for Energy Cooperation and the ASEAN Battery Safety Network promote standard harmonization and knowledge sharing. Member states are at different stages of development: Malaysia leads with clear targets under its National Energy Transition Roadmap and supportive schemes like Self-Consumption (SELCO) and the Corporate Renewable Energy Supply Scheme (CRESS); the Philippines is integrating BESS into market and regulatory frameworks;[24] Thailand and Indonesia are incorporating BESS into their energy master plan;[25] Vietnam is developing national standards with international support;[26] and Singapore is piloting advanced energy storage solutions.[27] According to the ASEAN Centre for Energy,[28] the most widespread application of BESS in the region is in off-grid renewable energy projects. The Philippines is the leading country in deploying BESS for off-grid solar—which aligns with the geographic reality of many ASEAN member states—being archipelagic with numerous small islands and remote communities that have limited or no access to the central electricity grid.

Grid Codes and Safety Standards

To ensure safe and efficient BESS operation, various international and national standards have been developed for the integration of BESS into power grids. In the United States, IEEE 1547.9-2022

22 Suleiman B. Sani et al., "Energy Storage System Policies: Way Forward and Opportunities for Emerging Economies," *Journal of Energy Storage* 32 (2020).

23 Sung-In Lee, "Plans for Energy Storage Systems Market Creation," Korea Energy Economics Institute, 2015.

24 Nel Consulting Limited, "Final Report: Upgrading Design and Implementation of Energy Battery Storage Market Mechanism of the Philippines Electricity Market Mechanism," 2022.

25 "National Electricity Plan (RUKN) 2024–2060 Indonesia," Climate Policy Database.

26 Energy Transition Partnership, "Development of the National Standards for Battery Energy Storage System," July 2024.

27 Andy Colthorpe, "Singapore Could Expand SE Asia's Biggest BESS and Flow Battery, Launches VPP Push," Energy-Storage.News, October 23, 2024.

28 ASEAN Centre for Energy, "Enabling Policies for Promoting Battery Energy Storage in ASEAN," Policy Brief, no. 1, January 2021.

TABLE 2 Overview of key BESS policies in advanced countries

Country	BESS policies
United States	• Federal level ∘ Inflation Reduction Act and Bipartisan Infrastructure Law provide major tax credits and grants for BESS. ∘ The Department of Energy's GRIP Program supports grid resilience and utility-scale storage. ∘ Funding is provided for U.S.-based battery manufacturing and recycling. ∘ Reforms by the Federal Energy Regulatory Commission enable better market access and compensation for BESS.
	• State level ∘ States like California, New York, Massachusetts, and New Jersey lead BESS deployment. ∘ California targets up to 50 GW battery storage by 2035. ∘ State incentives include procurement mandates, rebates, and grid integration programs.
United Kingdom	• No direct subsidies are provided for BESS; the focus is on creating a self-sustaining market.
	• The government supports research, development, and demonstration projects.
	• Regulatory reforms aim to remove barriers, including proposed exemptions from certain consumer levies.
	• Programs like Enhanced Frequency Response engage BESS providers to deliver fast grid-stabilizing services.
Germany	• No direct subsidies exist for BESS, but adoption is supported through regulations and innovation funding.
	• BESS is integrated to stabilize the grid, store excess RE, and provide balancing services.
	• Residential BESS is promoted with rooftop solar via incentives like KfW loan programs.
	• BESS policies are part of a broader strategy to enhance grid flexibility during Germany's transition from fossil fuels and nuclear power.
Japan	• BESS support began in the 1970s with government programs like the Moonlight Project to reduce oil dependence.
	• Continuous investment in R&D through METI and NEDO to advance batteries, smart grids, and RE integration.
	• After the Fukushima disaster, BESS became key for energy security and managing renewable variability.
	• Subsidies are available for BESS, especially for disaster preparedness; regulations differentiate small- and large-scale systems.
	• National targets are set to boost Japan's role in the global battery market.
China	• BESS development has been supported since 2005 through policies on market growth, grid integration, environmental goals, and financial incentives.
	• There is strong government investment in R&D and demonstration projects, supported by policies that encourage innovation through pilot programs and drive progress toward commercial deployment.
	• The focus is on integrating BESS with energy internet systems for better control and data management.

Table 2 continued

Country	BESS policies
South Korea	• The K-ESS 2020 strategy was launched in 2011 to promote BESS development and commercialization.
	• The government has supported BESS in smart grids and energy management, including large-scale utility projects.
	• Incentives have been introduced to encourage BESS adoption by small and medium-sized enterprises.
	• The Electricity Charge Discount Program was launched in 2015 and enhanced in 2017 to lower charging costs during off-peak hours and reward peak load reduction.
Australia	• South Australia's low-carbon investment plan includes financial incentives for solar-plus-battery systems.
	• The Adelaide City Council pioneered direct battery subsidies, which were later matched by the state.
	• The 2018 Home Battery Scheme supported over 30,000 household battery installations.
	• South Australia hosts the Hornsdale Power Reserve, which is the world's largest lithium-ion battery.
	• The Australian Capital Territory (ACT) aims for 100% renewable electricity and promotes BESS through the Next Generation Renewables program.
	• ACT's REIDS supports BESS and RE R&D through testbeds and partnerships.
	• In 2023–24, new funding rounds and tenders were announced to support grid-scale BESS and long-duration energy storage as part of Australia's transition strategy.

SOURCE: For the United States, see U.S. Environment Protection Agency, "Summary of Inflation Reduction Act Provisions Related to Renewable Energy," updated January 28, 2025; U.S. Department of Energy, Office of Clean Energy Demonstrations, "Grid Resilience and Innovation Partnerships (GRIP)"; U.S. Department of Energy, "Biden-Harris Administration Announces over $3 Billion to Support America's Battery Manufacturing Sector, Create over 12,000 Jobs, and Enhance National Security," 2024; Quintessa Davis and Dixon Wallace, "FERC Accepts NYISO's 2025–2029 Demand Curve Reset," Troutman Pepper Locke, February 4, 2025; and California Energy Commission, "Battery Storage Goals and Planning." For the UK, see X. Potau, S. Leistner, and G. Morrison, "Battery Promoting Policies in Selected Member States," Batstorm Work Package 5, June 2018; Ofgem, "Clarifying the Regulatory Framework for Electricity Storage: Statutory Consultation on Electricity Generation Licence Changes and Next Steps," June 26, 2019, 1–12; and National Grid UK, "Enhanced Frequency Response," March 2016. For Germany, see IEA, "Subsidy for Solar PV with Storage Installations (Programm zur Förderung von PV-Batteriespeichern)," March 18, 2016. For Japan, see Max Berre, "The Energy Storage Landscape in Japan," EU-Japan Centre for Industrial Cooperation, September 2016; and Ministry of Economy, Trade and Industry (Japan), *4th Strategic Energy Plan* (Tokyo, 2014). For China, see Fei-fei Yang and Xin-gang Zhao, "Policies and Economic Efficiency of China's Distributed Photovoltaic and Energy Storage Industry," *Energy* 154 (2018): 221–30; and Yanwei Xiao et al., "Comparative Analysis on Energy Storage Policies at Home and Abroad and Its Enlightenment," *IOP Conference Series: Earth and Environmental Science* 267 (2019). For South Korea, see Sung-In Lee, "Plans for Energy Storage Systems Market Creation (Korea)," 2015; and Byuk-Keun Jo, Seungmin Jung, and Gilsoo Jang, "Feasibility Analysis of Behind-the-Meter Energy Storage System According to Public Policy on an Electricity Charge Discount Program," *Sustainability* 22, no. 1 (2019). For Australia, see Clean Energy Council, "Clean Energy Australia Report 2020," 2020; "How the South Australian Government Is Supporting Renewables and Energy Storage," Solar Choice, March 30, 2016; Hornsdale Power Reserve, "South Australia's Biggest Battery"; ACT Environment and Sustainable Development Directorate, "Sustainable Energy Policy: Energy for a Sustainable City, 2011–2020," 2011; ACT Environment Planning and Sustainable Development Directorate, "Next Generation Energy Storage (Next Gen) Program"; and ACT Environment Planning and Sustainable Development Directorate, "Growth in the Clean Economy."

and UL 1741 focus on the interconnection and equipment safety of distributed energy resources, covering grid stability and electrical protection.[29] Globally, IEC standards such as IEC TS 62786-3:2023, IEC 62933-3-2:2023, and IEC 62933-5-1:2024 address BESS connection to distribution networks, RE integration, frequency regulation, and safety protocols.[30] DNV-RP-0043 provides comprehensive guidelines on BESS performance, safety, and lifecycle management.[31] China's GB/T 44112-2024 outlines operational controls and grid compliance for electrochemical storage.[32] In Malaysia, the Malaysian Grid Code governs grid integration and stability, while Bomba's Fire Safety Guidelines ensure the safe installation and emergency handling of BESS in facilities like data centers.

ASEAN is stepping up regional efforts to improve BESS safety and standards through several key initiatives. In 2024 the ASEAN Centre for Energy and Huawei Digital Power released a policy brief identifying gaps in electrical safety regulations and recommending the adoption of international standards like IEC 62619, IEC 63056, and IEC 62933-5-2.[33] To further support this objective, the ASEAN Battery Safety Network was launched under the ASEAN Committee on Science, Technology, and Innovation to promote safe battery use in the energy and mobility sectors. The network brings together regulators, industry, and academia to harmonize safety protocols, improve incident response, and build regional capacity. At the national level, countries like Vietnam—supported by the Southeast Asia Energy Transition Partnership—are developing BESS-specific regulations and safety standards, offering useful models for broader regional adoption.

BESS Opportunities and Challenges

The Asia-Pacific presents a multifaceted landscape for the implementation of BESS technology shaped by both significant opportunities and persistent challenges. As countries across the region accelerate their transition toward RE, battery energy storage has emerged as a crucial enabler for grid flexibility, energy reliability, and efficient integration of variable renewable energy (VRE) sources such as solar and wind. According to the International Energy Agency, VRE sources are projected to account for two-thirds of global renewable electricity generation by 2030, up from less than 45% today. Over the forecast period, the contribution of solar PV to meeting global power demand is expected to triple, while wind power nearly doubles. As VREs are set to contribute around 90% of the global increase in renewable electricity generation by 2030, the need for additional power system flexibility becomes critical.[34]

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29 IEEE SA, "IEEE Guide for Using IEEE Std 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems," IEEE 1547.9-202; and UL Standards and Engagement, "Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources," UL 1741.

30 EC, "Distributed Energy Resources Connection with the Grid—Part 3: Additional Requirements for Stationary Battery Energy Storage System," IEC TS 62786-3:2023; IEC, "Electrical Energy Storage (EES) Systems—Part 3-2: Planning and Performance Assessment of Electrical Energy Storage Systems—Additional Requirements for Power Intensive and Renewable Energy Sources Integration Related Applications," IEC TS 62933-3-2:2023; and IEC, "Electrical Energy Storage (EES) Systems—Part 5-1: Safety Considerations for Grid-Integrated EES systems—General Specification," IEC 62933-5-1:2024.

31 DNV, "Safety, Operation and Performance of Grid-Connected Energy Storage Systems," DNV-RP-0043.

32 GB, "Operation Control Specifications for Electrochemical Energy Storage Power Stations Connected to the Grid."

33 Zahrah Zafira, Marcel Nicky Arianto, and Beni Suryadi, "Mapping the Current State of Electrical Safety Regulations in ASEAN: Preliminary Assessment of Electrical Safety Standards and Practices for Solar Photovoltaics (PV) and Battery Energy Storage Systems (BESS)," ASEAN Centre for Energy, Policy Brief, no 7, September 2024.

34 IEA, "Renewables 2024: Analysis and forecast to 2030," October 2024.

However, the pace and scale of deployment vary widely due to disparities in infrastructure readiness, technical capabilities, and the support level of regulatory and policy frameworks. While some nations have introduced targeted incentives and roadmaps to support storage technologies, others are still in the early stages of integrating BESS into their energy planning. This section examines the key opportunities driving the deployment of BESS, including rapid market expansion, increasing demand for grid stability, supportive policies and incentives, technological advancements with cost reductions, and strategic partnerships. It also highlights major challenges such as regulatory gaps, financial barriers, workforce capability shortages, supply chain concentration and raw material scarcity, geopolitical tensions, and cybersecurity risks.

BESS Opportunities

Rapid market growth due to rising renewable energy adoption. A major opportunity lies in the Asia-Pacific's emerging dominance in the global BESS market. The region is projected to account for nearly 70% of global demand by 2026, fueled by ambitious RE targets, declining technology costs, and strong policy support.[35] According to the NZS, installed BESS capacity in the region is forecast to reach 2.2 terawatts by 2050, which is over 60 times the 2023 level, representing 56% of global capacity.[36] Under both the NZS and the ETS, large-scale BESS deployment across the region will be critical to delivering the grid flexibility required for high penetration of VRE. In markets with liberalized electricity systems, such as Australia, the growing share of daytime solar generation has led to increased price volatility, creating enhanced opportunities for energy arbitrage. These evolving market conditions significantly strengthen the economic case for BESS investment and support long-term market viability.

Growing demand for grid stability and energy resilience. A major driver for the adoption of BESS is the need to strengthen grid stability and energy resilience, especially with the growing share of VRE like solar power. Solar energy, while clean and abundant, is intermittent and can cause power fluctuations that challenge grid reliability. BESS helps address this by storing excess energy during low-demand periods and releasing it when demand is high, improving frequency control, voltage stability, and peak load management. In Malaysia a study by DNV-GL for the Single Buyer found that the peninsular grid can technically handle up to 30% solar penetration during peak demand.[37] Under the New Capacity Target scenario, solar penetration is expected to remain below this threshold in 2025. However, concerns arise when solar reaches over 24% of peak demand, especially on low-demand days such as national holidays with clear weather. In such situations, energy storage becomes critical to prevent system instability. While only minimal storage was needed before 2025, planning must begin now as solar penetration is expected to hit 30% by 2035. More broadly in Southeast Asia, countries like the Philippines and Indonesia are using BESS to improve energy security in remote or disaster-prone areas. As extreme weather and climate risks grow, BESS is becoming an essential tool for building more resilient and reliable power systems across the region. For example, in the Philippines, BESS installations have helped stabilize microgrids in typhoon-affected islands, ensuring power supply during grid outages. Similarly, Indonesia has deployed BESS in remote islands to maintain electricity access where

35 "BESS the Linchpin for Asia's Renewable Energy Targets," Asian Insiders, February 11, 2025.

36 BloombergNEF, "Asia Pacific's Energy Transition Outlook."

37 DNV, "Consultation Services On Renewable Energy Penetration Study for Peninsular Malaysia and Sabah, Final Report for Peninsular Malaysia System for the Single Buyer," November 2018.

diesel supply chains are vulnerable during natural disasters. In Japan, after the 2011 Fukushima disaster, the government recognized the value of distributed storage in enhancing energy resilience and preventing large-scale blackouts.

Supportive policies and incentives. Recent policy developments across the Asia-Pacific have driven substantial investments in BESS, as countries work to strengthen grid reliability and accelerate RE integration. Governments in the region are increasingly implementing targeted policies, incentives, and regulatory frameworks to catalyze BESS deployment. For instance, India's 2023 National Electricity Plan sets an ambitious target of approximately 47,244 MW (236 GWh) of BESS capacity by 2031–32, signaling a decisive move toward a power system not based on fossil fuels.[38] Japan, meanwhile, has launched multiple subsidy schemes to enhance domestic battery manufacturing and support utility-scale storage as part of its broader decarbonization and energy security strategy.[39] In Singapore the government has initiated consultations with industry stakeholders to explore investment opportunities and shape enabling regulations for energy storage. To facilitate large-scale deployment, several Asia-Pacific markets have adopted mechanisms such as energy storage capacity auctions and policy frameworks that shift the responsibility for firming variable renewable generation onto power producers. India is leading with increasingly sophisticated RE auctions that integrate storage. Likewise, countries such as Australia and the Philippines have introduced power market reforms to enable BESS participation in energy, ancillary services, and capacity markets. However, most countries still lack an adequate regulatory framework for battery storage, which is a key barrier to the development of viable business models.[40]

Technological innovation and cost reduction. Recent innovations in BESS are playing a key role in reducing both capital and operational costs, thereby supporting wider adoption. Advances in battery chemistries such as LFP and emerging sodium-ion batteries are lowering material costs and enhancing safety and durability. Modular and scalable system designs are also becoming more common, enabling easier deployment and reducing installation and engineering costs.[41] In addition, digitalization and artificial intelligence (AI) have introduced cost-saving opportunities across system maintenance and operation. AI-based predictive maintenance tools reduce downtime and extend battery life through real-time diagnostics and condition monitoring.[42] Similarly, smart energy management systems powered by AI optimize charge and discharge cycles for better integration with intermittent renewable sources.[43] Manufacturing costs are also reduced through technological innovation.[44] Furthermore, second-life EV batteries are being repurposed for stationary applications, significantly reducing upfront investment while promoting circular economy goals.[45] In distributed settings, blockchain is being explored to facilitate peer-to-peer energy trading and lower transaction costs, supporting decentralized

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38 "Central Electricity Authority Notifies the National Electricity Plan for the Period of 2022–32," Ministry of Power (India), May 31, 2023.

39 "Battery Storage Subsidies in Japan," Atsumi and Sakai, February 17, 2023.

40 IEA, "Batteries and Secure Energy Transitions," World Energy Outlook Special Report, April 2024.

41 Wood Mackenzie, "Global Battery Energy Storage Supply Chain 2022," Market Report, August 2022.

42 Ya Zhang et al., "State of Health Estimation of Lithium-Ion Batteries Based on the Regional Triangle," *Journal of Energy Storage* 69 (2023).

43 Mohammed Amine Hoummadi et al., "AI-Enhanced Energy Management Systems for Efficient Flow Control in Microgrids," *IET Renewable Power Generation* (2025).

44 "Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh," BloombergNEF, November 26, 2023.

45 Linda Colarullo and Jagruti Thakur, "Second-Life EV Batteries for Stationary Storage Applications in Local Energy Communities," *Renewable and Sustainable Energy Reviews* 169 (2022).

BESS deployment.[46] Collectively, these innovations are shaping a more cost-effective and flexible energy storage ecosystem.

The cost of utility-scale battery storage projects can vary widely depending on the location, the technology used, and local regulations. Some recent projects have cost over $500/kWh, while others have been delivered for less than $200/kWh. According to the IEA, in the Stated Policies Scenario (STEPS), the average global upfront cost for a four-hour battery storage system is expected to drop from $290/kWh in 2022 to around $175/kWh by 2030, contributing to a 40% reduction. By 2050, costs are projected to fall by 55% compared with 2022 levels. Currently, regional costs range from $200/kWh to over $300/kWh, but this gap is expected to narrow as countries gain experience and adopt new technologies. China has the lowest battery storage costs today and is likely to maintain this position through 2030. Costs in the United States and Europe are currently higher, but they are expected to decrease as deployment expands. In India, rapid market growth is helping to significantly lower costs. These cost reductions are mainly driven by advances in battery technology, more efficient manufacturing, and cheaper system integration. Standardization could further accelerate this trend. In addition, as more batteries are used in both storage and electric vehicles, shared learning will further lower prices.

Collaborative partnerships. Collaborative partnerships between governments, industry players, international organizations, and research institutions present a significant opportunity to accelerate the adoption of BESS in the Asia-Pacific. These partnerships could help address financing, technology transfer, and capacity-building challenges by pooling resources, sharing knowledge, and reducing investment risks. For example, in India the Global Energy Alliance for People and Planet is working with local utilities and the private sector to develop grid-scale battery storage projects that support renewable integration in underserved regions.[47] Similarly, in Vietnam the ADB has partnered with the government and private developers to launch pilot BESS projects aimed at supporting solar energy deployment and improving grid reliability.[48] In Australia, public-private initiatives like the Hornsdale Power Reserve developed by Neoen and supported by the South Australian government demonstrate how collaboration can facilitate world-leading BESS installations that enhance energy resilience.[49] These examples highlight how cross-sector and cross-border partnerships can unlock investment, build technical capabilities, and scale up the deployment of BESS to support clean energy transitions.

BESS Challenges

Lack of a comprehensive regulatory framework. Despite growing interest in BESS, many countries still lack proper policies and regulations to support the development of battery energy storage, particularly within ASEAN, where awareness of energy storage solutions remains low. In many places, regulations have not kept up with new technology, making it difficult to support BESS deployment. For example, policies may not clearly define how BESS can be integrated in the power system or participate in energy markets. This creates uncertainty for investors and project developers.

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46 Merlinda Andoni et al., "Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities," *Renewable and Sustainable Energy Reviews* 100 (2019).

47 Global Energy Alliance for People and Planet, "People-Powered Energy Transition in India," 2023.

48 Thuy Tuong, "New ADB Partnership Prioritizes Vietnam Energy Storage Efforts, Indonesia Coal Phase-Out," *Investor*, April 18, 2023.

49 "Neoen to Build 300 MW Victorian Big Battery in Australia, One of the World's Largest Batteries," Neoen, November 5, 2025.

Delays in getting grid connections are also a major challenge. In the United States, for example, many BESS projects are stuck in long queues waiting for approval. In 2023, more than 1,000 GW of storage projects were waiting to be connected to the grid. The average wait time can be up to five years, which discourages new investment.[50]

In many countries, market rules were designed for traditional energy sources, not for modern storage systems. As a result, BESS may not receive the right price signals to operate efficiently or generate fair revenue. In China, for example, storage systems connected to solar and wind often operate at very low capacity (around 6%) because they lack clear access to the energy market. This limits their value and discourages investment. In Malaysia the government's BESS bidding program is similar to the traditional power purchase agreements used by power utilities and independent power producers. Under a typical power purchase agreement, developers recover their investment by selling a known amount of electricity to the grid at fixed tariffs. For BESS projects, however, revenue is much less clear. Since batteries do not generate electricity but store and discharge it based on grid needs, their actual utilization—how often and how much they are used—is uncertain. This includes questions about usage frequency, volume, and capacity at different sites. As a result, it is difficult for developers to predict how much income they will generate, making it challenging to design a viable pricing or tariff model.

Finally, for behind-the-meter applications, inadequate net-metering schemes or missing time-of-use pricing further reduces the financial attractiveness of BESS for consumers and small businesses. For example, when excess electricity is credited at a flat rate regardless of the time it was generated, there is little motivation to store solar energy for use during peak hours.

Financial barriers. One of the most significant challenges facing widespread BESS deployment is the high upfront capital cost associated with energy storage technologies. Despite falling battery prices globally, large-scale BESS projects still require substantial investment in infrastructure, inverters, safety systems, and integration with existing grid assets. This financial burden can be particularly prohibitive in developing ASEAN countries, where budget constraints and competing infrastructure priorities exist.

Access to financing remains a major hurdle due to perceived technology risks, lack of historical performance data, and uncertain revenue streams. For instance, revenue models based on grid services like frequency regulation or demand charge reduction are still evolving in many countries, making it difficult for investors and banks to assess long-term returns. Moreover, many BESS projects rely on hybrid or pilot-scale deployments, which are less attractive to traditional lenders.

In Malaysia, while supportive policies like SELCO and CRESS exist, many commercial and industrial players still struggle to secure favorable financing terms for BESS integration without bundled incentives. In Indonesia and the Philippines, the challenge is further complicated by currency risks and less mature capital markets for clean energy projects.

Currently, financing for BESS in the region comes from a mix of government budgets, private investors, donor-backed pilots, and concessional loans. Multilateral development banks such as the ADB and World Bank are increasingly stepping in to provide technical assistance, concessional financing, clean energy funds, guarantees to de-risk early-stage projects, and support for larger national rollouts. Innovative financing mechanisms such as blended finance, green bonds, public-

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50 Energy Technologies Area, Berkeley Lab, "Grid Connection Backlog Grows by 30% in 2023, Dominated by Requests for Solar, Wind, and Energy Storage," April 10, 2024.

private partnerships, and results-based financing are increasingly necessary to de-risk BESS investments and attract private capital.

Technical expertise and workforce capability shortage. One of the key challenges to BESS adoption in the Asia-Pacific is the lack of technical expertise and skilled workers across the battery value chain. Designing, installing, and maintaining BESS—especially at grid-scale—requires specialized knowledge in areas such as power electronics, battery chemistry, energy management systems, and safety protocols. Many countries in the region are still building local capabilities in these areas. For instance, in India the limited pool of engineers trained in BESS-specific technologies has slowed project execution timelines and increased reliance on foreign expertise as the country strives to meet the government's ambitious targets for battery storage.[51] Similarly, in Indonesia and the Philippines the deployment of BESS in off-grid areas is often hindered by a shortage of trained local technicians to manage and service the systems, resulting in longer downtimes and higher maintenance costs.[52] Even in more developed markets like Malaysia, training programs focused on battery storage remain in their early stages, with limited integration of storage technologies in university curricula and technical training institutes.[53] Moreover, safety and standards compliance require certified professionals, but certification schemes are either nascent or absent in many Asia-Pacific nations. This shortage of qualified personnel poses a barrier to scaling BESS projects efficiently and safely.

To address this challenge, more partnerships between private companies and universities are being encouraged to create specialized training programs and industry certifications. Some companies involved in BESS are working with local universities to offer internships, training labs, and courses. Governments can also expand vocational training to teach battery storage skills, especially in rural areas. Setting up national training centers focused on energy storage could help build long-term local expertise across the region. Regional collaboration on training, knowledge sharing, and public-private capacity-building partnerships is essential to accelerate workforce readiness and reduce dependency on international experts.

Supply chain concentration and raw material scarcity. The global battery supply chain is highly complex and spans multiple interconnected stages—from the mining of critical mineral ores, such as lithium, cobalt, nickel, and graphite, to refining, cell manufacturing, system integration, and finally recycling or reuse at the end of the battery's life.[54] These materials are transformed into components like cathodes, anodes, and electrolytes, which are then used to produce battery cells and packs for deployment in RE systems, electric vehicles, and energy storage applications.

Critical risks stem from geographic and ownership concentration of both extraction and processing. Indonesia, for instance, leads global nickel mining, the Democratic Republic of the Congo dominates cobalt, and China is the top producer of graphite. However, refining is even more centralized: China controls over 60% of global lithium processing and over 90% of graphite refining. Indonesia holds the largest nickel refining capacity, yet a substantial portion—approximately 75%—is owned or controlled by Chinese companies through joint ventures and

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[51] Randheer Singh et al., "Need for Advanced Chemistry Cell Energy Storage in India (Part III of III)," NITI Aayog, 2022.

[52] International Renewable Energy Agency (IRENA), *Renewable Energy Market Analysis: Southeast Asia* (Abu Dhabi: IRENA, 2018).

[53] IRENA, *Malaysia Energy Transition Outlook* (Abu Dhabi: IRENA, 2023).

[54] "Developing a Global Trade Union Battery Supply Chain Strategy," Industrial, November 20, 2020.

strategic investments.[55] This dynamic means that ASEAN countries may have mineral reserves but still rely heavily on Chinese capital, technology, and export arrangements for processing.

Between 2019 and 2023, supply chains grew more concentrated, heightening the risk of geopolitical disruptions. For example, lithium prices spiked nearly ninefold from early 2021 to late 2022, then collapsed by almost 80%, curbing investment appetite and creating uncertainty.[56] While lower prices help reduce battery costs, they can discourage further investment in mining and refining, worsening long-term supply risks.

Geopolitical risks. The global battery supply chain is facing rising geopolitical risks as well, especially for BESS, due to highly concentrated production of critical minerals and intensifying trade tensions. China holds a dominant position in the battery value chain, refining roughly 70% of the world's lithium and producing the vast majority of graphite and other key battery inputs. This concentration has raised concerns among Western nations over economic dependencies and supply chain vulnerabilities. For example, the U.S. Department of Homeland Security flagged the overreliance on Chinese utility-scale batteries as a national risk, prompting the United States to introduce policies like the Inflation Reduction Act (IRA) to build up domestic battery manufacturing capacity and reduce foreign dependence.[57]

In response to China's dominance, the Quad nations (Australia, India, Japan, and the United States) have sought to diversify their sources of critical minerals,[58] while some resource-rich countries like Indonesia have enforced export bans (e.g., nickel) to strengthen local industry, leading to trade disputes. Notably, the European Union filed a case against Indonesia at the World Trade Organization (WTO). Although the WTO ruled in favor of the EU, Indonesia has maintained its export restrictions as it appeals the ruling.[59] Even small supply-side shocks can ripple across tight markets. Myanmar is not a major global supplier, but its rare earth export disruptions in 2021—caused by border closures during the Covid-19 pandemic and political instability—triggered price spikes across the value chain.[60]

The situation escalated further in 2025, when the United States imposed tariffs of up to 145% on Chinese imports, including lithium-ion batteries, while China retaliated with tariffs of up to 125% on U.S. goods and imposed new export controls on materials such as rare earth elements and battery-grade graphite.[61] This new wave of the U.S.-China trade war disrupted battery material flows, particularly affecting American utilities and manufacturers who rely heavily on Chinese LFP batteries.[62]

Within ASEAN, countries have generally taken a more neutral and pragmatic approach. While there has been no bloc-wide legislation mimicking the IRA, concerns about overdependence on Chinese supply chains are growing. Malaysia's National Energy Transition Roadmap and Indonesia's downstream policies reflect a strategic intent to localize more of the battery value

55 "Chinese Firms Control around 75% of Indonesian Nickel Refining Capacity, Report Finds," Reuters, February 5, 2025.

56 IEA, "Batteries and Secure Energy Transitions."

57 Zeyi Yang, "U.S. Government Says Relying on Chinese Lithium Batteries Is Too Risky," *Wired*, October 21, 2021; and Ahmed Mehdi and Tom Moerenhout, "The IRA and the US Battery Supply Chain: Background and Key Drivers," June 2023.

58 "Critical Minerals in Global Trade," ASIA House, March 26, 2024.

59 Fadhil Haidar Sulaeman, "Indonesia Admits Defeat in WTO Nickel-Export Dispute," *Jakarta Post*, November 22, 2022.

60 Yu-Hsuan Wu and Phung Quoc Huy, "Geopolitics of Critical Minerals," in "Critical Minerals: Global Supply Chains and Indo-Pacific Geopolitics," National Bureau of Asian Research, NBR Special Report, no. 102, December 2022.

61 Noah Gordon, "How the U.S.-China Trade War Could Derail the Energy Transition," Carnegie Endowment for International Peace, April 17, 2025.

62 "Economic Consequences of US Tariffs on Chinese Lithium-Ion Batteries," LARGE, April 16, 2025.

chain, though such moves are often more economically driven than politically framed. Unlike their Western counterparts, ASEAN nations tend to prioritize resilience and economic opportunity over decoupling, focusing on supply chain diversification, industrial investment incentives, and regional cooperation to hedge against future shocks. These and other geopolitical developments underscore the urgent need for Asia-Pacific countries to diversify their supply sources and invest in resilient, regionally integrated battery supply chains that can withstand global market and political volatility.[63]

Cybersecurity risks. Cybersecurity poses a significant challenge to the safe and reliable deployment of BESS, especially as these systems become increasingly connected through digital platforms and integrated into national grids. BESS projects rely heavily on digital controls, data communication systems, and cloud-based platforms for monitoring, dispatching, and performance optimization. This connectivity makes them vulnerable to cyberattacks that could disrupt energy supply, damage infrastructure, or lead to data breaches. For example, in the United States the Department of Energy has emphasized the importance of securing energy storage technologies, including BESS, as part of a broader strategy to protect clean energy infrastructure from cyberattacks. The focus is on implementing robust cybersecurity measures to safeguard these critical components of the energy system.[64] In Australia the 2021 cyber incident involving the power company CS Energy highlighted vulnerabilities in the energy sector's information technology systems, prompting calls for stronger cybersecurity protocols, including for storage systems.[65] Similarly, Japan has developed specific guidelines for energy storage system operators to implement cybersecurity best practices in line with the growing use of AI and the Internet of Things in grid operations.[66] U.S. energy officials have begun reassessing the potential security risks of Chinese-made equipment used in renewable energy infrastructure after the discovery of unexplained communication components embedded in some devices.[67] As BESS systems become more widespread in countries like India, Malaysia, and Indonesia, ensuring robust cybersecurity frameworks, including real-time threat detection, data encryption, and secure communication protocols, is essential to avoid operational risks and maintain grid stability.

Conclusion: Strategic Pathways

This concluding section provides a structured pathway for BESS development in the Asia-Pacific region, addressing both challenges and opportunities. **Table 3** outlines key strategies for policy, finance, research, workforce development, and international cooperation.

BESS is becoming essential for the Asia-Pacific region to meet its clean energy and energy security goals. With rising energy demand, climate risks, and the need to move away from fossil fuels, BESS offers a flexible and reliable solution. It helps store RE, balance the grid, and reduce dependence on imported fuels, especially in remote and island communities. This essays shows that China, India, Japan, and Australia are leading the way in BESS development, while countries

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63 Ilaria Mazzocco, "Analyzing the Impact of the U.S.-China Trade War on China's Energy Transition," Center for Strategic and International Studies, April 22, 2025.

64 Justine Calma, "Cyberattacks on Clean Energy Are Coming—the White House Has a Plan," Verge, August 9, 2024.

65 "CS Energy Responds to Cyber Security Incident," CS Energy, November 30, 2021.

66 Tadashi Okabe, "Customized Approach to Cybersecurity: Japanese Electric Power Utilities Establish Unique Strategies on Cybersecurity," *T&D World*, April 2020.

67 Sarah Mcfarlane, "Rogue Communication Devices Found in Chinese Solar Power Inverters," Reuters, May 2025.

TABLE 3 Key strategies for BESS development

Strategic pillars	Key actions
Strengthening the policy and regulatory framework	• *Establish clear BESS-specific regulations*. Governments should define the role of BESS in national energy plans and implement supportive regulations that enable market access, grid participation, and fair treatment in tariff structures.
	• *Standardization and grid codes.* Uniform technical standards should be introduced for interconnection, safety, and performance. Grid codes should recognize BESS as both load and generation, enabling participation in ancillary services and energy markets.
	• *Incentive mechanisms.* Targeted incentives such as tax breaks, subsidies, and performance-based remuneration (e.g., for frequency regulation or peak shaving) should be implemented.
Scaling up finance for the energy transition	• *De-risking investments.* Governments and multilateral banks could provide loan guarantees, concessional financing, or insurance against policy or market risk to attract private investment in BESS.
	• *Green bonds and carbon markets.* The issuance of green bonds and the integration of BESS into carbon credit schemes to channel climate finance should be promoted.
	• *Blended finance models.* Public and private capital should be combined to scale projects, particularly in developing markets with less mature financing ecosystems.
Boosting research and development	• *Innovation in materials and design*. Governments fund and guide research by universities and public labs to develop new battery types; private companies help by co-developing and testing new ideas.
	• *Digitalization and AI integration.* Private tech companies lead the way in using AI for smart battery operations, like predicting breakdowns or managing energy better. Governments provide funding and facilities, while state-owned enterprises test and use these tools in real projects.
	• *Pilot and demonstration projects.* Governments and state-owned enterprises set up living labs to test BESS systems in real conditions in collaboration with private companies and universities.
Building capacity and technical expertise	• *Training programs.* Collaboration is needed with universities and vocational institutions to train engineers and technicians in battery safety, operations, and maintenance.
	• *Knowledge transfer.* Secondments, internships, and technical exchanges should be facilitated with leading institutions and private companies globally.
	• *Certification and accreditation.* Accredited BESS training and certification programs should be developed for installation and commissioning of professionals.
Enhancing international collaboration	• *Regional cooperation platforms.* Regional bodies (e.g., ASEAN Power Grid forums or APEC energy working groups) should be established to harmonize standards and share best practices.
	• *Cross-border projects*. Regional interconnection projects that incorporate BESS for cross-border energy trade and balancing are needed.
	• *Global technology partnerships.* Partnerships are needed with countries leading in BESS technology (e.g., South Korea, Japan, Australia, and the United States) for joint development and technology transfer.

in Southeast Asia are starting to grow their markets. However, challenges like unclear policies, high costs, limited skilled workers, and lack of financing are slowing progress.

To move forward, the Asia-Pacific must focus on several key areas. First, governments could strengthen policy and regulatory frameworks by establishing clear rules that define the role of BESS in national energy plans. This includes creating technical standards and fair pricing structures that allow BESS to fully participate in energy markets and grid operations. Second, more financing options are needed to support BESS deployment. Blended finance models that combine public and private funding—along with tools like green bonds, carbon credits, and risk guarantees—could help reduce investment barriers, especially in developing markets. Third, innovation must be supported through investment in research and development. This includes advancing new battery technologies, integrating digital tools such as AI for energy management, and setting up pilot projects to test BESS in real-world conditions. Fourth, capacity building is critical. The region needs more skilled professionals who are trained in BESS installation, operation, and safety. Collaborations with universities, vocational institutions, and international experts can help develop accredited training and certification programs. Finally, stronger regional and international cooperation will accelerate progress. Sharing knowledge, harmonizing standards, and working together on cross-border projects will create a more integrated and resilient energy future. Partnerships with global leaders in BESS technology can also support technology transfer and local innovation.

In short, BESS could play a major role in helping the Asia-Pacific lead the global clean energy transition. But this will require smart policies, strong partnerships, and targeted investments to unlock its full potential.

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Scaling Up Hydrogen Energy in the Indo-Pacific

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EXECUTIVE SUMMARY

This essay analyzes the current state of hydrogen technologies across the Indo-Pacific, highlighting national strategies, production capacities, and infrastructure development, and considers Vietnam as a case study of hydrogen development within the region.

MAIN ARGUMENT

Hydrogen is becoming a key driver of decarbonization in major sectors like transportation, chemicals, and steel. As the Indo-Pacific accelerates its clean energy transition, hydrogen offers strong long-term potential. Yet most hydrogen today is still "gray" (produced from fossil fuels without carbon capture). In 2023, green hydrogen made up just 0.1% of global production. Scaling up the production of hydrogen energy across the Indo-Pacific is thus an urgent priority. Global players like the U.S. and China are already shaping hydrogen development through bold investments and policy support. The U.S. Inflation Reduction Act incentivized green hydrogen and fostered international cooperation, while China leads in infrastructure and capacity-building across Southeast Asia. Regional platforms such as the ASEAN Centre for Energy and the Asia Zero Emission Community are also aligning policies and facilitating knowledge transfer. Within this context, Vietnam offers a valuable case study for hydrogen development. The country has set an ambitious target of producing 10–20 million tonnes of hydrogen annually by 2050—equivalent to 10%–20% of current global output. While Vietnam currently lacks a fully developed hydrogen infrastructure, it has begun laying the groundwork to become a serious player in the regional hydrogen economy, particularly by leveraging offshore wind resources and emerging partnerships. With joint investment and coordinated strategies, the Indo-Pacific has a real opportunity to lead in building a sustainable hydrogen economy. Vietnam is poised to become a key regional player within this economy in the years ahead.

POLICY IMPLICATIONS

- As countries across the Indo-Pacific face mounting pressure to reduce emissions and strengthen energy security, green hydrogen offers a viable pathway to transition to clean energy—especially in hard-to-abate sectors such as steel, chemicals, and heavy transportation.
- To effectively develop hydrogen energy in the ASEAN region, member states could enhance regional cooperation by developing an integrated hydrogen roadmap and establishing a hydro training center, among other strategies and initiatives.
- Given Vietnam's proactive policy direction, renewable energy potential, and international engagement, the country is well-positioned to become a leading force in the Indo-Pacific hydrogen economy and serve as a model for other developing countries.

Hydrogen is playing an increasingly vital role in decarbonizing major industrial sectors such as transportation, aerospace, chemicals, and steel production. As the Indo-Pacific accelerates its clean energy transition, hydrogen is emerging as a key energy source with significant long-term potential. Thus, a deep understanding of hydrogen systems is essential for policymakers to shape effective energy strategies.

This report explores the evolving hydrogen landscape across the Indo-Pacific, with a particular focus on Vietnam's approach to scaling up production, infrastructure, and partnerships. As home to some of the world's largest energy consumers, the region faces mounting pressure to adopt sustainable energy solutions to support long-term development. In response, fourteen representative countries have set cost-reduction targets for low-carbon hydrogen—aiming to reduce prices from $3.7–$11.7 per kilogram to $1.1–$2.4 per kilogram by 2050.[1] Looking ahead, green hydrogen is expected to become the dominant clean energy source in this region.[2] Vietnam has also set an ambitious target of producing 10–20 million tonnes of hydrogen annually by 2050, primarily through renewable energy (RE) and carbon capture technologies—equivalent to 10%–20% of today's global output.

Leading countries such as the United States and China continue to drive progress in hydrogen infrastructure and innovation. In the United States the Inflation Reduction Act (IRA)—reinforced by finalized Section 45V tax credit rules in early 2025—continues to support clean hydrogen development and encourage international cooperation through knowledge-sharing and private-sector engagement. However, recently passed legislation such as the One Big Beautiful Bill Act shortens the eligibility window for tax incentives and reduces funding, placing the U.S. hydrogen sector at risk. China, meanwhile, leads in hydrogen production and infrastructure development, with projects under the Belt and Road Initiative supporting technology transfer and local capacity-building across Southeast Asia.

Regional organizations are also helping bridge the gap between emerging and advanced economies. Platforms such as the Association of Southeast Asian Nations (ASEAN) Centre for Energy, the Asia Zero Emission Community (AZEC), and various bilateral initiatives are aligning policy frameworks, coordinating research, and delivering capacity-building programs. These programs provide critical support for countries just beginning their hydrogen journey.

Yet despite its promise, most hydrogen today is still "gray"—produced from fossil fuels without carbon capture, utilization, and storage (CCUS).[3] In 2023, gray hydrogen accounted for approximately 83% of global output. By contrast, blue hydrogen produced with CCUS contributed only around 1%, and green hydrogen represented just 0.1% of the total production.

Europe has emerged as a global frontrunner in low-emission hydrogen deployment, leading with a wave of projects already under construction or operation. In parallel, countries such as the United States, China, Japan, and South Korea have made substantial progress in establishing hydrogen infrastructure—ranging from advanced storage technologies and extensive pipeline

1 Nandakumar Janardhanan et al., "Sub-national Drivers of India's Green Hydrogen Development," *Asia-Pacific Tech Monitor,* April–June 2024, https://apctt.org/sites/default/files/2024-10/Green%20Hydrogen%20technologies%20April-June%202024%20for%20Web_0.pdf; and Hussain Almajed, Omar Jose Guerra Fernandez, and Daniella Rough, "Analysis of Hydrogen Supply Chain Readiness in Selected Indo-Pacific Countries," National Renewable Energy Laboratory, January 2025, https://docs.nrel.gov/docs/fy25osti/92575.pdf.

2 Yanfei Li et al., "A Strategic Roadmap for ASEAN to Develop Hydrogen Energy: Economic Prospects and Carbon Emission Reduction," *International Journal of Hydrogen Energy* 48, no. 30 (2023): 11113–30. Green hydrogen is produced via electrolysis powered by renewable energy, whereas gray hydrogen comes from fossil fuels without carbon capture, and blue hydrogen uses similar sources but with carbon capture and storage.

3 International Energy Agency, "World Energy Outlook 2024," October 2024.

systems to the rollout of fuel cell vehicles (FCVs). Backed by bold national strategies, these nations are actively positioning themselves at the forefront of the hydrogen economy.

In contrast, India, Australia, and members of ASEAN such as Vietnam, among other countries, are still in the early stages of hydrogen development. Despite facing infrastructural challenges, these nations have recognized hydrogen's potential in supporting decarbonization and energy security. Vietnam, in particular, stands out for its ambitious green hydrogen goals, leveraging its vast RE resources, notably offshore wind power, to achieve a production target of up to 20 million tonnes of hydrogen by 2050.

As the Indo-Pacific region moves toward cleaner energy solutions, hydrogen technology will play an increasingly crucial role. This essay provides in-depth analysis of the current state of hydrogen technologies across Indo-Pacific countries, highlighting national strategies, production capacities, and infrastructure development. It also explores Vietnam's strategic vision and emerging role in regional cooperation as a case study of hydrogen development, emphasizing the country's potential to become a leading green hydrogen producer and exporter in Southeast Asia.

The Current State of Hydrogen Technologies in Indo-Pacific Countries

Gray hydrogen remains the dominant production method, with high-pressure gaseous storage as the most widely used solution (see **Table 1**). The United States, China, and Japan have advanced hydrogen infrastructure, including pipelines, large-scale storage, and hydrogen vehicle networks. In contrast, India, ASEAN countries, and Australia are still in the early stages, with limited storage and distribution systems. Vietnam, despite lacking advanced infrastructure, has set ambitious goals for green hydrogen development, particularly through leveraging offshore wind power for hydrogen production.

Hydrogen Technologies

Global hydrogen trends and progress in the Indo-Pacific. Globally, hydrogen technology is shifting toward cleaner pathways. The United States initially led with net-zero targets and generous incentives, but recent policy reversals have cast doubt on its long-term leadership in green technology. In contrast, China is rapidly advancing and aims to build a national hydrogen vehicle fleet and refueling network by 2030. Nevertheless, the United States continues to pursue one of the world's most ambitious green hydrogen production goals, at around 10 million tons per year by 2030, roughly double the targets set by China and India, each at about 5 million tons.[4]

Japan and South Korea have concrete strategies for hydrogen technology. Japan is targeting widespread FCV adoption by 2030, while South Korea is planning a scaled rollout by 2040. Australia, for its part, is investing in green hydrogen R&D and industrial hubs, and India is positioning itself as a global green hydrogen exporter.

In Southeast Asia, Vietnam, Malaysia, and Indonesia are building foundational infrastructure. As noted earlier, Vietnam targets 20 million tonnes of hydrogen by 2050, mainly from offshore wind power. Malaysia seeks to become a regional export hub, while Indonesia is leveraging its renewable resources for large-scale production.

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[4] U.S. Department of Energy, "U.S. National Clean Hydrogen Strategy and Roadmap," June 2023.

TABLE 1 Review of hydrogen technologies

Country	Hydrogen infrastructure	Development trends
United States	• Production: Mainly steam-methane reforming • Storage: Cryogenic tanks and underground storage (salt caverns, aquifers) • Distribution: Tanker trucks and pipelines	Shift from leadership to uncertainty due to policy reversals, despite IRA investment
China	• Production: Mainly from coal, 3% from electrolysis • Storage: High-pressure gas and liquid hydrogen; solid-state under research • Distribution: Long pipe trailers and pipelines	Aims to lead globally; targets 1 million hydrogen vehicles, 1,000 hydrogen refueling stations by 2030
India	• Production: Primarily gray hydrogen • Storage/distribution: Underdeveloped	Wants to be global hub; National Hydrogen Mission and Green Hydrogen Policy launched to support this aspiration
Australia	• Production: Fossil-based; green hydrogen under research • Storage/distribution: Limited; underground storage under research	Transitioning to green hydrogen for industrial and power use
Japan	• Production: Limited domestic, mostly imports • Storage: Chemical-based, hydrides, liquid organic hydrogen carriers, cartridges • Distribution: 157 fueling stations, early stage of pipeline development	Wants global hydrogen supply chain; targets 800,000 FCVs and 900 hydrogen refueling stations by 2030
South Korea	• Production: Mostly gray hydrogen; green limited due to geography • Storage/distribution: Underground storage under research, limited pipeline network	Transitioning to blue and green hydrogen via 2019 roadmap; targets 3 million fuel cell electric vehicles and 1,200 hydrogen refueling stations by 2040
ASEAN countries	• Production: Mostly fossil-based; green hydrogen at an early stage • Storage/distribution: Generally lacking	National hydrogen strategies established in Singapore, Indonesia, Malaysia, and Vietnam
Vietnam	• Production: Mostly gray hydrogen; some blue hydrogen • Storage/distribution: No robust transport, storage, or liquefaction	Targets 100,000–500,000 tonnes/year by 2030 and 10–20 million tonnes/year by 2050; focus on offshore wind

SOURCE: The information in this table has been compiled by the author. Sources are available upon request.

Building on these ambitions, several Indo-Pacific nations have launched major hydrogen pilot projects, showcasing a variety of approaches to production, storage, and use. **Table 2** surveys some of these projects.

Hydrogen project timelines and investment gaps. Japan led early, commissioning the Fukushima Hydrogen Energy Research Field in 2020, just three years after its proposal. Australia followed with the Hydrogen Energy Supply Chain (HESC) project, moving from the proposal stage in 2018 to operation by 2021. While the United States and China have stronger resources, their large-scale

TABLE 2 Government hydrogen pilot projects

Country/ region	Project name	Proposed year	Construction year	Operation year	Investment (million $)	Output
United States	Intermountain Power Green Hydrogen Project	2020	2021	2025	1,900	30,000 tons/ year
	NextEra's Hydrogen Pilot Projects	2021	2023	2025	65 (mainly for RE sources)	Small-scale (20 MW ELY)
	Gulf Coast Hydrogen Hub (HyVelocity Hub)	2022	2024	NA	1,200	Not disclosed
China	Xinjiang Green Hydrogen Project (Sinopec)	2021	2022	2023	NA	20,000 tons/ year
	Inner Mongolia Green Hydrogen Project	2023	2023	NA	NA	10,000 tons/ year
India	National Green Hydrogen Mission	2023	2023	2030 (estimated)	2,000	5,000,000 tons/year
Australia	Hydrogen Energy Supply Chain	2018	2018	2022	1,400	Exported to Japan
	Hydrogen Park South Australia (HyP SA)	2019	2020	2021	14.5	Supplies 4,000 households
	Green Hydrogen and Battery Storage System	2022	2023	2025	32.5	Pilot-scale
Japan	Fukushima Hydrogen Energy Research Field	2017	2018	2020	NA	1,200 Nm^3/ hour
	Kawasaki Hydrogen Pilot Plant (Asahi Kasei)	2022	2022	2024	NA	(4 x 0.8) MW ELY modules
South Korea	Next Level Hydrogen City Initiative	2022	2023	2026 (estimated)	NA	Infrastructure expansion
	PV GAS Pilot Project (Vietnam)	2022	2023	2025	NA	Small-scale

Table 2 continued

Country/ region	Project Name	Proposed year	Construction year	Operation year	Investment (million $)	Output
ASEAN	Singapore's Hydrogen Testbed	2022	2023	2025	NA	Pilot-scale
	Hydrogen Fuel Cell Electric Bus Project (Thailand)	2021	2022	2024	NA	Pilot-scale
	Pioneer Hydrogen Project (Malaysia)	2022	2023	2025	NA	Under development
Vietnam	Tra Vinh Green Hydrogen Project (Vietnam)	2022	2023	2025	327.7	24,000 tons/ year

SOURCE: The information in this table has been compiled by the author. Sources are available upon request.

pilot projects began later. India and ASEAN countries (namely, Vietnam, Thailand, and Malaysia) are trailing slightly. Their projects are expected from 2025 onward and are typically smaller in scale.

In terms of investment, developed countries like the United States and Australia have committed substantial public funding (e.g., the Intermountain Power and HESC projects, respectively). However, U.S. commitments now face uncertainty due to policy shifts and proposed budget rollbacks during the second Trump administration. Although China is scaling up production rapidly, it has not disclosed a clear breakdown of public and private investment. India's Green Hydrogen Mission operates on a modest budget and depends on private and foreign capital. ASEAN countries mostly focus on pilot projects with limited or undisclosed funding.

This disparity between investment in hydrogen projects across countries highlights the crucial role of the private sector, especially in developing economies where public funding is scarce. While governments in wealthy nations can de-risk early-stage projects, emerging markets must rely more on private capital, exposing them to greater financial and institutional challenges. The result is a growing divide in hydrogen infrastructure, investment strategies, and execution capacity.

Hydrogen in Power Systems

Hydrogen is emerging as a flexible tool in power decarbonization. In the Indo-Pacific, co-firing hydrogen with fossil fuels in existing thermal plants enables emission cuts without major infrastructure changes, supporting a gradual clean energy transition. **Table 3** summarizes major hydrogen and ammonia co-firing projects in the Indo-Pacific, focusing on those already demonstrated, operational, or set to begin by 2027. It highlights diverse strategies, such as hydrogen-LNG (liquefied natural gas) and ammonia-coal co-firing, in countries like South Korea, Japan, China, Indonesia, Singapore, and Australia.

TABLE 3 Hydrogen co-firing projects in the Indo-Pacific

Country	Companies	Fuel	Year of operation (or expected)	Name of project
United States	Long Ridge Energy Terminal	Natural gas and hydrogen	2022 (operational)	Long Ridge Hydrogen Blending Project
China	GE Vernova and Shenzhen Energy	Natural gas and hydrogen	Early 2025 (operational)	Guangming Hydrogen-Ready CCGT Project
Australia	CS Energy and IHI	Hydrogen and ammonia co-firing	2024–25	Kogan Creek Hydrogen/ Ammonia Pilot Project
Japan	JERA and IHI	Ammonia and coal co-firing	2024	Hekinan Ammonia Co-firing Project
South Korea	Hanwha Impact and Korea Western Power	Hydrogen and LNG co-firing	2023 (demonstrated)	Daesan Hydrogen Co-firing Project
Indonesia	Mitsubishi Heavy Industries (MHI) and PT PLN	Natural gas and hydrogen	Feasibility ongoing	Tanjung Priok Hydrogen Co-firing Study
Singapore	Keppel and Mitsubishi Power	Natural gas and hydrogen	Expected in 2026	Keppel Sakra Hydrogen-Ready Plant

SOURCE: The information in this table has been compiled by the author. Sources are available upon request.

Hydrogen production can help reduce RE curtailment—where excess solar or wind power goes unused—by redirecting surplus electricity to power electrolyzers. These devices produce green hydrogen, which supports grid flexibility and decarbonization goals. The hydrogen can then be stored or used in fuel cells for power generation or as fuel for vehicles. Countries like Australia and Vietnam are integrating electrolyzers with renewables to scale up hydrogen production.

Fostering Hydrogen-Tech Advancements: Actions of Leading Nations

Enhancing cross-border collaboration. Leading countries are enhancing cross-border collaboration by developing frameworks for global hydrogen trade—focusing on standardized infrastructure, certification systems, and aligned regulations. While Indo-Pacific initiatives like Japan's Asia Energy Transition Initiative and Australia's HESC project show promise, they remain fragmented without regional integration.

In contrast, the EU's Hydrogen Strategy, supported by the European Clean Hydrogen Alliance, offers a coordinated roadmap toward a unified hydrogen market by 2030. Global initiatives like the Mission Innovation Hydrogen Challenge also help drive joint R&D, reducing costs and accelerating the deployment of competitive green hydrogen technologies.

Accelerating equipment manufacturing. Early investment in equipment manufacturing, especially electrolyzers, is vital to building a low-carbon hydrogen supply chain in the Indo-Pacific. Leading nations such as the United States, China, Japan, South Korea, and Australia will need to scale up domestic production of key technologies to reduce costs and prevent supply bottlenecks. Despite widespread recognition of electrolysis's potential, few countries in the region have concrete plans for local electrolyzer manufacturing, with only a handful—such as Japan, South Korea, China, India, and Australia—having announced specific strategies, funding programs, or local projects. In contrast, most Southeast Asian and Central Asian countries remain in early-stage studies or memoranda of understanding, lacking concrete investments or domestic manufacturing plans for electrolyzers.[5] To address this gap, governments will need to implement comprehensive strategies that support the full equipment supply chain, including targeted incentives and technology transfer partnerships. These actions would help stabilize costs and accelerate the region's hydrogen transition.

Building infrastructure and scaling hydrogen applications. To advance hydrogen adoption, leading Asia-Pacific nations—such as Japan, South Korea, and Australia—could focus on developing core infrastructure, including pipelines, liquid hydrogen terminals, and high-pressure storage. Inspired by the EU's Hydrogen Backbone initiative, these countries could establish a regional hydrogen network and expand underground storage in salt caverns or depleted gas fields to improve system flexibility.

At the same time, scaling up hydrogen use in hard-to-abate industries—like steel, cement, and chemicals—is essential. Programs such as Japan's Green Innovation Fund and South Korea's Hydrogen Economy Roadmap show how hydrogen can decarbonize industrial sectors. In the transportation sector, initiatives like Singapore's maritime energy transition and Australia's deployment of Hyundai hydrogen trucks demonstrate the region's leadership in hydrogen-powered mobility. Together, these efforts can set a regional benchmark for infrastructure and application development, encouraging smaller countries to follow suit and accelerating the transition to a low-carbon economy.

Advancing policy and financial incentives. To accelerate hydrogen deployment, Indo-Pacific leaders such as the United States, Japan, South Korea, and Australia, along with India and Singapore, must commit to long-term subsidies and tax incentives for green hydrogen production and infrastructure. With costs for green hydrogen still high at $3–$8 per kilogram (kg), compared with $1–$2/kg for gray hydrogen, such support is vital to close the economic gap. Carbon pricing—through taxes or emissions trading—can further level the playing field. Notable examples include the U.S. IRA, which offers up to $3/kg in tax credits, and India's National Green Hydrogen Mission, backed by public investment. These policies not only boost production and demand but also attract private capital, positioning hydrogen as a competitive solution for long-duration storage and industrial decarbonization.

Leading Countries and Their Key Partners in Implementing Hydrogen Technologies

Developed countries such as the United States, Japan, Australia, South Korea, and China, as well as the EU, have established a robust model of diverse collaboration to advance hydrogen technology, combining private-sector innovation with government support. Major corporations like Toyota and Hyundai are leading in FCV technology, while energy giants such as Shell and Sinopec are investing heavily in hydrogen production and infrastructure. For instance, Shell is

[5] Almajed et al., "Analysis of Hydrogen Supply Chain Readiness."

developing a 200 megawatt (MW) electrolyzer in the Netherlands, and Sinopec is constructing the world's largest green hydrogen facility in China with a capacity of 260 MW.[6]

Regarding the United States, this commitment has been supported by Department of Energy initiatives such as the H2@Scale program and the 2024 Hydrogen Program Plan, which targets reducing clean hydrogen costs to $1/kg by 2031. These efforts are reinforced by funding from agencies like the Office of Energy Efficiency and Renewable Energy and the Office of Clean Energy Demonstration. However, recent policy shifts under the Trump administration have introduced uncertainty about the future of these programs.

These nations also engage in strong international partnerships. Japan and Australia are collaborating on the HESC project, the EU and South Korea are jointly advancing fuel cell and storage technologies, China and Germany are developing green hydrogen production and applications like hydrogen-powered steelmaking, and the United States and India are working under the Strategic Clean Energy Partnership to lower hydrogen costs.

Key Questions for the Integration of Hydrogen with RE Systems in the Indo-Pacific

As the Indo-Pacific region progresses toward deep decarbonization, integrating hydrogen with RE systems emerges not only as a technological opportunity but as a strategic imperative. Hydrogen—particularly green hydrogen produced via electrolysis powered by solar and wind—can serve as a long-duration energy storage medium, a flexible load to absorb excess renewable generation, and a decarbonization agent for hard-to-abate sectors. However, unlocking this potential requires addressing multiple, interrelated questions across infrastructure, economics, regulation, and grid operation.

What Infrastructure Is Required for Hydrogen Production, Storage, and Distribution?

A robust and integrated infrastructure backbone is essential to scale a green hydrogen economy. The Indo-Pacific region shows wide disparity in this regard:

- *Electrolysis plants*. Many countries (e.g., Vietnam, Indonesia, and the Philippines) lack large-scale electrolyzers. The capacity to scale and localize production is essential to reduce costs and increase energy security.
- *RE generation co-location*. Electrolyzers need proximity to cheap and stable renewable power, raising land-use questions, especially in densely populated nations.
- *Storage technologies*. High-pressure tanks, cryogenic liquid hydrogen, and underground caverns each have unique cost and safety implications. Countries like Australia and the United States are experimenting with salt cavern storage, which ASEAN nations currently lack.

[6] "Shell to Start Building Europe's Largest Renewable Hydrogen Plant: Holland Hydrogen I," Green Car Congress, July 7, 2022, https://www.greencarcongress.com/2022/07/20220707-shell.html; and Leigh Collins and Xu Yihe, "World's Largest Green Hydrogen Project—China's 260MW Kuqa Facility—to Be Commissioned at the End of May," Hydrogen Insight, May 26, 2023, https://www.hydrogeninsight.com/production/world-s-largest-green-hydrogen-project-chinas-260mw-kuqa-facility-to-be-commissioned-at-the-end-of-may/2-1-1457242.

- *Pipeline networks*. Most pipelines are built for natural gas and may not be hydrogen-compatible due to embrittlement.[7] Retrofitting or building new hydrogen-ready pipelines is capital-intensive and requires regulatory clarity.
- *Maritime transport infrastructure*. Exporting countries must invest in liquefaction, conversion, and port terminals for maritime shipping.

What Are the Economic and Financial Implications?

Green hydrogen in the Indo-Pacific currently costs \$4–\$8/kg—well above the competitive threshold (around \$2/kg). Key cost drivers include the following:

- *Electricity price*. Since electricity makes up 60%–70% of the cost of green hydrogen, low-cost RE is a prerequisite.
- *Electrolyzer capital and efficiency*. Asian countries often rely on imported electrolyzers from Europe or China, raising the amount of capital expenditure.
- *Utilization rate*. Fluctuating RE input leads to underused electrolyzers, lowering economic viability.
- *Transport and storage costs*. Especially for export scenarios, liquefaction or conversion to carriers like ammonia adds substantial cost.
- *Carbon pricing mechanisms*. Emissions trading schemes, carbon taxes, and other carbon pricing mechanisms can shift the cost-competitiveness in favor of green hydrogen.
- *Water supply and treatment*. Producing 1 kg of green hydrogen requires around 9 liters of high-purity water.[8] In water-stressed regions, the cost of securing, purifying, and transporting water can significantly affect project economics.

What Policy and Regulatory Frameworks Are Needed?

Without coherent policies and regulatory support, green hydrogen will remain a niche technology. Governments should focus on the following measures:

- *Subsidies and incentives*. Feed-in tariffs, tax breaks, and hydrogen purchase guarantees (as seen in the U.S. IRA and Japan's Strategic Energy Plan) should be prioritized.
- *Standardization and certification*. Governments will need to define what qualifies as green hydrogen (e.g., by setting a standard for carbon intensity) to ensure cross-border compatibility for hydrogen trade.
- *Safety regulations*. Governments will also need to develop norms for pipeline pressure limits, blending thresholds, and refueling stations to ensure public and environmental safety.
- *Regulatory support for innovation*. Further research is needed to investigate how governments can best foster innovation through regulatory frameworks that allow for testing and scaling of hydrogen technologies, such as through hydrogen valleys or testbeds.
- *Long-term targets*. Governments need to develop clear national roadmaps that integrate hydrogen into their power planning, industrial policy, and climate targets.

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7 Hydrogen embrittlement occurs when hydrogen atoms diffuse into metals—especially under high pressure—causing them to become brittle and prone to cracking or sudden failure. This poses a significant challenge for hydrogen storage tanks, pipelines, and other infrastructure components.

8 "Hydrogen Production and Water Consumption," Hydrogen Europe, December 2020, https://hydrogeneurope.eu/wp-content/uploads/2022/02/Hydrogen-production-water-consumption_fin.pdf.

Vietnam's Strategic Developments in Hydrogen Production and Infrastructure

While many nations are exploring hydrogen as a pathway to decarbonize their energy systems, Vietnam deserves attention because it has the fastest-growing RE capacity in Southeast Asia.[9] With RE integration of around 26.4% as of April 2024, hydrogen is poised to support RE growth and become an important energy carrier in Vietnam's future energy mix.[10]

Vietnam's Strategic Developments in Hydrogen Production

The amount and demand of hydrogen in Vietnam. Currently, annual hydrogen production for the domestic market is approximately 500 kilotons. However it is primarily produced from fossil fuels like coal or natural gas.[11] Oil refineries and fertilizer plants consume a large portion of hydrogen produced. Small amounts of hydrogen are used for the steel, glass, electronics, and food industries, accounting for around 0.5% of Vietnam's current total hydrogen demand.[12] Hydrogen-related industries include oil refining, fertilizer production, power generation, transportation, steel, and cement.

Goals and directions for hydrogen technology. According to Decision 165 signed by Prime Minister Phạm Minh Chính in 2024, Vietnam will aim to increase green and blue hydrogen production to 100,000–500,000 tonnes/year in 2030 and 10–20 million tonnes/year in 2050.[13] In the document, Vietnam set its strategic energy transition goals in two phases. By 2030, it mainly aims to implement advanced green hydrogen production and apply CCUS technologies for the other types of hydrogen. By 2050, Vietnam aims to master green hydrogen production technologies and advance expertise in CCUS for hydrogen production from diverse energy sources.

Policies supporting green hydrogen. Vietnam is promoting hydrogen to replace fossil fuels over time. The coal industry will also produce hydrogen with the CCUS method instead of the traditional process.[14] Since 2020, Vietnam has demonstrated a strong commitment to hydrogen energy through key policies. Resolution 55-NQ/TW of the Politburo set the foundation for clean energy development. At the 26th UN Conference of the Parties (COP26), Vietnam pledged to achieve net-zero emissions by 2050, reinforcing the importance of hydrogen in decarbonizing industries like steel, cement, and transportation.[15] The Power Development Plan VIII (2023) further emphasized hydrogen's role in replacing fossil fuels and integrating with RE. This commitment culminated in the Hydrogen Energy Development Strategy (2024), which aims to develop Vietnam's hydrogen energy ecosystem based on RE and set specific goals for each field of hydrogen, from production and use to storage and export.

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9 International Energy Agency (IEA), "Southeast Asia Energy Outlook 2022," 2022.

10 "Some Issues on Renewable Energy Development in Vietnam Today; Current Status, Potential and Suggested Solutions," https://sct.binhdinh.gov.vn/vi/news/tin-bien-tap/mot-so-van-de-ve-phat-trien-nang-luong-tai-tao-o-viet-nam-hien-nay-thuc-trang-tiem-nang-va-goi-y-giai-phap-2455.html.

11 Van Phong, "Green Hydrogen Production and Export: What Opportunities for Vietnam?" Doanh Nhan Saigon Online, February 10, 2024, https://doanhnhansaigon.vn/san-xuat-va-xuat-khau-hydrogen-xanh-co-hoi-nao-cho-viet-nam-313705.html.

12 Nguyen Duc Tuyen, "Lessons from Hydrogen Strategy in Vietnam and the United States," National Bureau of Asian Research, NBR Commentary, May 29, 2024; and Anh Tuan Hoang et al., "Green Hydrogen Economy: Prospects and Policies in Vietnam," *International Journal of Hydrogen Energy* 48, no. 80 (2023): 31049–62.

13 Hoang et al., "Green Hydrogen Economy: Prospects and Policies in Vietnam."

14 Nguyen, "Lessons from Hydrogen Strategy in Vietnam and the United States."

15 "Efforts to implement Vietnam's commitments at the COP26 Conference," Ministry of Industry and Trade (Vietnam), July 15, 2022, https://moit.gov.vn/bao-ve-moi-truong/no-luc-thuc-hien-cac-cam-ket-cua-viet-nam-tai-hoi-nghi-cop26.html.

Vietnam's Development Strategies in Hydrogen Infrastructure

Southern Vietnam is poised to be the center for hydrogen production due to its great potential in RE (821,000 MW in total for offshore and onshore wind and 963,000 MW for solar) and its concentration of big harbors.[16] Tra Vinh Province is considered the most important location for increasing clean energy production in Vietnam.

There are several steps the government and private sector could take to increase hydrogen production and capacity:

- Prioritize the development of the capacity of RE sources for export and the production of new energy (e.g., hydrogen and green ammonia) while ensuring energy security and achieving high economic efficiency.
- Increase offshore wind development to produce hydrogen.
- Develop small modular reactor (SMR) capabilities and conduct research on pilot SMRs, which have the potential to become a clean energy source for hydrogen production in the future.
- Develop LNG-based projects and LNG import infrastructure in a synchronized manner with an appropriate scale, utilizing modern technology.
- Implement a roadmap for fuel transition to hydrogen once the technology becomes commercially viable and cost-effective.

The Vietnamese government has proposed several hydrogen factory projects. Examples include Ben Tre's green hydrogen factory, which is the first green hydrogen factory in Vietnam, and the construction of a green hydrogen center in Quang Tri. Aside from investing in hydrogen facilities, the government is also focused on promoting the development of hydrogen technology through cooperation with initiatives such as COP, the Just Energy Transition Partnership (JETP), and AZEC.

Another key dimension of Vietnam's hydrogen strategy is storage and transport. By 2050, the country aims to develop and complete a hydrogen energy infrastructure for storage, transport, distribution, and use on a scale of approximately 10–20 million tonnes per year. It also is working to expand and refine hydrogen energy distribution systems for the transportation sector nationwide, aligning with global trends.[17] The existing gas pipelines Bach Ho, Nam Con Son, and PM3 can help transport hydrogen to supplement the depleted gas supply and provide fuel for power plants. Finally, Vietnam is working to develop pumped storage hydropower plants with a total capacity of approximately 2,400 MW by 2030 to regulate load, provide capacity reserves, and support the integration of large-scale RE sources. In the future, when both hydrogen storage systems and pumped storage hydropower become available, there will be challenges regarding optimal energy storage strategies, including determining which storage system should be prioritized and how to coordinate the operation of these storage resources.

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16 Vietnamese Government, "Decision 500/QD-TTg 2023 National Power Development Master Plan for the 2021–2030 Period, with a Vision to 2050," 2023, https://thuvienphapluat. vn/van-ban/Thuong-mai/Quyet-dinh-500-QD-TTg-2023-Quy-hoach-phat-trien dien-luc-quoc-gia-2021-2030-tam-nhin-20," 2023; and Dang-Chuong Ta et al., "An Assessment Potential of Large-Scale Hydrogen Export from Vietnam to Asian Countries: Techno-Economic Analysis, Transport Options, and Energy Carriers' Comparison," *International Journal of Hydrogen Energy* 65 (2024): 687–703.

17 Ministry of Industry and Trade (Vietnam), "Vietnam's Hydrogen Energy Development Strategy and LNG Power Development Plan in Line with the National Energy Master Plan," https://vepg.vn/wp-content/uploads/2024/05/1_EN_MOIT-Presentation-on-LNG-and-Hydrogen_23-May_KE2.pdf.

Vietnam's Hydrogen Production and Infrastructure Readiness

Although Vietnam has demonstrated a strong political commitment to hydrogen energy, it faces significant technical and structural challenges across the value chain (see **Table 4**). Despite rapid RE growth, limited grid flexibility and weak control over RE output have led to curtailments, undermining green hydrogen reliability. The absence of hydrogen-ready infrastructure and limited domestic capacity in electrolyzer manufacturing and CCUS further highlight the need for strategic interventions. To address these gaps, Vietnam could consider several policy actions.

Further development of a national hydrogen roadmap. In ASEAN, most countries do not yet have clear hydrogen regulations. Vietnam's hydrogen strategy remains conceptual, lacking a concrete roadmap covering pipelines, storage, and refueling. This is not due to uncertainties around technology or political will, but the time needed for regulatory processes and institutional coordination to support deployment. Clear infrastructure development targets, tax incentives, and technical standards are essential to move from vision to action.

Establishment of incentives for local electrolyzer manufacturing and technology transfer. Vietnam relies largely on imported electrolyzer technology (key partners could include Japan, South Korea,

TABLE 4 The readiness of Vietnam's hydrogen technologies

Category	Current status (2025)	Target vision (2050)	Gap/challenges
Hydrogen production	Around 500 kilotons/year, mostly gray hydrogen from fossil fuels	10–20 million tonnes/year, primarily green hydrogen from renewables	Rapid RE growth but poor control; no large-scale electrolysis; high green hydrogen cost
Electrolysis capacity	Only pilot projects; no commercial-scale systems	Widespread deployment for green hydrogen	No domestic manufacturing; import dependence; limited technical expertise
CCUS integration	In early-stage feasibility studies	Mature CCUS use for blue hydrogen in coal/gas sectors	No infrastructure; high retrofit cost; regulatory uncertainty
Hydrogen storage	No liquid or underground storage	National-scale storage (e.g., tanks, salt caverns)	No safety standards; no R&D centers
Transportation infrastructure	Existing gas pipelines not hydrogen-compatible	Retrofitted pipelines and terminals for H_2/ammonia	High retrofitting costs; lack of blending rules and material testing
Hydrogen refueling stations	None currently	Nationwide network for mobility and industry	No investment incentives; no technical guidelines or skilled workforce
Policy and regulation	General roadmap exists; no legal framework	Full regulatory system (safety, pricing, tracking, certification)	Fragmented authority; needs alignment with global standards
Industrial applications	Mainly in refineries and fertilizer	Expanded to steel, power, transport, chemicals	Needs process upgrades, large capital expenditure, and stable hydrogen supply

SOURCE: The information in this table has been compiled by the author. Sources are available upon request.

and Germany due to their influence in the field). Policies such as R&D tax incentives, subsidies, and joint ventures can promote domestic manufacturing.

Enhanced grid and RE forecasting capabilities. Hydrogen production needs stable, predictable electricity. Vietnam will need to improve RE forecasting and grid management to minimize curtailments and ensure consistent hydrogen output.

Acceleration of pilot projects. The lack of real-world pilot projects deters investment and perpetuates the "chicken and egg" dilemma. Vietnam should launch pilot projects across multiple sectors, such as transportation, ammonia, and steel, to build practical use cases and investor confidence.

Introduction of hydrogen-specific regulations. Vietnam lacks clear regulations on hydrogen safety, transport, and certification. While this is common in emerging markets, global standards (e.g., the EU's Hydrogen Strategy and the International Organization for Standardization's ISO/TC 197) offer a reference point. Clear domestic rules are needed to support infrastructure and market development.

LNG Development Strategies for a Transition Phase

LNG is expected to play a key interim role in Vietnam. Given current infrastructure and economic conditions, LNG offers a reliable short- and medium-term solution while green hydrogen capacity is being developed. Under the Power Development Plan VIII, Vietnam targets 23 gigawatts (GW) of LNG-to-power capacity by 2030, driven by projects like the Thi Vai LNG Terminal, which has been operational since 2023 and produces 1 million tons/year, and the upcoming Son My LNG Terminal, which will produce 3.6 million tons/year by 2026.[18]

LNG helps countries meet rising power demand and stabilizes the grid, especially during renewable intermittency. In early hydrogen deployment, it can serve as a backup fuel. Global experience (e.g., in Europe and Japan) shows that LNG infrastructure can later be retrofitted for hydrogen or ammonia, extending its value. In addition, many new LNG power plants are technically capable of co-firing natural gas with hydrogen or ammonia blends, allowing gradual decarbonization of thermal generation without full infrastructure replacement. By aligning LNG investments with future hydrogen goals, Vietnam can optimize current assets while building a scalable, flexible hydrogen economy.

Geographic Areas for Hydrogen Development in Vietnam: An Analysis

Northern Vietnam: Emerging areas for hydrogen infrastructure. Northern Vietnam's proximity to China gives it strategic access to advanced hydrogen technologies and supply chains. Border provinces like Lang Son and Quang Ninh, along with major ports such as Cai Lan and Hai Phong, enable both cross-border and maritime trade, supporting industrial hydrogen adoption, renewable production, and future export opportunities. Industrial hubs such as Hanoi, Bac Ninh, and Hai Phong are important cities for integrating hydrogen into key industries like steel, cement, and transportation.

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[18] Ivy Yin, "Two Green Hydrogen Projects Totaling 30,000 mt/Year of Capacity Start Up in China," S&P Global, June 30, 2023, https://www.spglobal.com/commodity-insights/en/news-research/latest-news/energy-transition/063023-two-green-hydrogen-projects-totaling-30000-mtyear-of-capacity-start-up-in-china; and "PV GAS and AES Signs 'Joint-Venture Agreement to Establish and Operate Son My LNG Terminal Co., Ltd,'" Petrovietnam, September 24, 2021, https://www.pvn.vn/sites/en/Pages/detail.aspx?NewsID=54fe4267-05df-49f2-bfe9-622a774f670a.

Central Vietnam: The main hydrogen power supply area. The central region of Vietnam holds strong potential for green hydrogen development, driven by abundant solar and wind resources. Provinces such as Binh Thuan and Ninh Thuan receive high solar irradiation—up to 2,500 sunshine hours per year.[19] Offshore wind potential is also significant, with central coastal areas contributing a large share of Vietnam's estimated 160 GW total offshore wind capacity. Quang Ngai and Phu Yen are particularly well-positioned to host electrolyzer-powered hydrogen production, while Quang Tri and Thua Thien-Hue are emerging as key sites for green hydrogen and ammonia projects. Together, these provinces form a strategic corridor advancing Vietnam's national hydrogen strategy.

Southern Vietnam: A strategic hub for the hydrogen supply chain. The southern region's port infrastructure, particularly in Ho Chi Minh City, Vung Tau, and the Mekong Delta, offers a strategic advantage for hydrogen export.[20] These major ports not only are essential for domestic energy distribution but also serve as gateways for international hydrogen export, whether in liquefied form or as green ammonia. This enhances Vietnam's potential to become a global leader in hydrogen trade.

Summary. The central coast leads in hydrogen production thanks to superior renewable resources, while the south supports export logistics, and the north connects to industrial demand and international technology. Together, these regions form a geographically diversified hydrogen ecosystem in Vietnam.

The Technical Capabilities of Domestic Companies

Developing a hydrogen economy in Vietnam requires both strong RE investment and robust technological infrastructure. A successful transition depends on domestic companies owning and developing core technologies—such as electrolyzers, advanced storage, and hydrogen transport systems. Strengthening local capabilities will reduce reliance on foreign technology, cut costs, and enable better integration with existing energy systems. Key Vietnamese corporations with expertise in energy, industrial processes, and renewables are essential to driving innovation and building a competitive, self-sustaining hydrogen market. Several firms already possess the necessary technological foundation to advance hydrogen development, particularly in energy infrastructure and renewable generation.

Regional Cooperation in Hydrogen Development: Vietnam's Emerging Role

This section analyzes global and regional trends in hydrogen cooperation, beginning with international frameworks, followed by Indo-Pacific and ASEAN initiatives. Observations on Vietnam's role are interwoven throughout this discussion to reflect the country's participation at each level. The section concludes with a survey of Vietnam's other strategic partnerships to highlight the country's broader engagement beyond multilateral platforms.

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19 "Two Provinces See Wind and Solar Power Projects Boom, Expected to Attract Hundreds of Trillions in Investment," SCI Group, December 15, 2021, https://scigroup.vn/hai-tinh-bung-no-du-an-dien-gio-dien-mat-troi-tang-truong-but-pha-du-kien-hut-tram-nghin-ty-von-dau-tu.

20 "Ba Ria—Vung Tau: Potential and Development Path to Become a Major Logistics Hub in the Southeastern Region," Everich, December 6, 2024, https://everichvietnam.com/ba-ria-vung-tau-potential-and-development-path-to-become-a-major-logistics-hub-in-the-southeastern-region.

Global Clean Energy Cooperation

The Conference of the Parties. COP is the main decision-making body of the UN Framework Convention on Climate Change, first held in March 1995. It brings together nearly every country to negotiate climate action. Since the Paris Agreement at COP21 in 2015, countries are expected to submit increasingly ambitious national climate commitments. For Vietnam, COP26 in Glasgow was pivotal, marking its pledge for net-zero emissions by 2050—a shift that underpins energy reforms, including hydrogen development. Recent COP meetings, such as COP28 in 2023, have highlighted the role of hydrogen energy in decarbonizing hard-to-abate sectors and encouraged its inclusion in long-term strategies for reducing carbon emissions.

Just Energy Transition Partnership. JETP was launched at COP26 in 2021 to support developing countries in shifting from coal to cleaner energy in an equitable way. Vietnam became the third country to join JETP, signing a $15.5 billion deal in 2022 with backing from the G-7 and other partners. The package blends public and private financing to help Vietnam reduce its reliance on coal, upgrade its grid, and boost renewables. While hydrogen is not yet central to JETP, its role in Vietnam's decarbonization roadmap opens the door for future funding toward hydrogen infrastructure, technology transfer, and integration with offshore wind.

Indo-Pacific Hydrogen Partnerships

The Hydrogen Council: A global industry-led initiative. The Hydrogen Council, founded at the 2017 World Economic Forum in Davos, is the world's largest hydrogen initiative, uniting over 140 major companies—including Shell, Toyota, Sinopec, and Hyundai—to advance hydrogen-based clean energy. Member countries include the United States, EU nations, China, Japan, and South Korea, with rising involvement from Indo-Pacific countries. The Hydrogen Council promotes policy, innovation, and large-scale investment to make hydrogen more cost-competitive across industries, transportation, and power. While Vietnam has no companies in the council, it may still benefit through technology spillovers, investment, and integration into global supply chains led by member firms.

The impact of U.S. energy policy. The Indo-Pacific Economic Framework for Prosperity (IPEF), launched during the Biden administration, included a clean economy pillar, which emphasized deepened regional cooperation in clean energy and decarbonization. Through the IPEF, the United States fosters multilateral engagement on clean technology, supply chains, and digital trade across fourteen member countries. The United States also passed the IRA in 2022, offering tax credits worth up to $3/kg for green hydrogen and expanding support in 2024 with up to $2.2 billion in funding for clean hydrogen hubs.[21]

However, under the second Trump administration, energy policy is shifting. The One Big Beautiful Bill Act terminates hydrogen tax credits by 2026 (instead of 2033), and the Department of Energy is considering cutting funding to four of seven hydrogen hubs.[22] These moves threaten to reduce U.S. engagement in multilateral initiatives like the IPEF, dampen private investment, and undermine partner confidence. Without sustained U.S. leadership, regional energy cooperation

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21 Chengling Yang et al., "Sustainability and Challenges of Renewable Energy in ASEAN Countries: Insights from the Indo-Pacific Economic Framework," *Environmental Development* 54 (2025): 101145.

22 Neil Ford, "Trump Tax Bill Risks Exodus of Clean Hydrogen Investment," June 22, 2025, https://www.reuters.com/business/energy/trump-tax-bill-risks-exodus-clean-hydrogen-investment-2025-06-17.

might pivot to Japan, Australia, or the EU, while protectionist trade measures could destabilize clean energy supply chains in Asia.

Quad initiatives for clean hydrogen. The current version of the Quad, which brings together the United States, Japan, India, and Australia, was launched in 2017. Among its many goals, the Quad aims to lead global efforts in clean hydrogen development.[23] Through coordinated R&D, supply chain collaboration, and regulatory harmonization, it seeks to reduce costs and accelerate deployment. A key focus is capacity building and knowledge sharing with developing Indo-Pacific countries, including Vietnam, to support their integration of hydrogen into national energy transitions. The Quad offers both technical resources and policy guidance that can help these countries bridge capability gaps and align with regional hydrogen standards.

Hydrogen Partnerships in the ASEAN Region

Southeast Asia's perspective on the benefits and value of the IPEF. Although the future of the IPEF is less clear today, many of its energy-related policies were welcomed by ASEAN member states and continue to see strong support. Southeast Asian countries such Vietnam, Indonesia, and Thailand see the IPEF as a platform to accelerate their transition to clean energy. In particular, the framework's focus on clean energy and decarbonization aligns with the region's goals of reducing carbon emissions and integrating RE into their energy systems. For example, Vietnam's ambitious green hydrogen targets and Indonesia's RE plans could benefit from the IPEF's collaborative initiatives and technological sharing.

The IPEF also offers opportunities for Southeast Asian nations to access advanced hydrogen and RE technologies, as well as financial resources from developed economies like the United States, Japan, and Australia. This is particularly valuable for countries with limited technical expertise and funding, such as Vietnam and the Philippines, which are in the early stages of hydrogen development.

Moreover, the framework's emphasis on supply chain resilience is critical for Southeast Asia, which is heavily reliant on global supply chains for energy technologies, including solar panels, batteries, and hydrogen equipment. The IPEF could help diversify supply chains and reduce dependence on a single country, such as China, for critical energy components.

Finally, the IPEF strengthens regional coordination mechanisms on energy and climate policy. This is crucial for supporting initiatives such as the ASEAN Plan of Action for Energy Cooperation (APAEC), which aims to enhance regional interconnection, harmonize standards, and promote clean energy trade across borders. By integrating the IPEF's collaborative model, Southeast Asian countries can align their policy frameworks, co-develop large-scale hydrogen infrastructure, and share best practices in grid modernization, emissions tracking, and carbon markets. Such synergies will help ensure that Southeast Asia's clean energy transition is both inclusive and regionally cohesive. Most countries in Southeast Asia strongly support the IPEF and hope to see it continue to play a significant role in the region.

U.S engagement in Southeast Asia. As Southeast Asia accelerates its hydrogen ambitions, international collaboration has become essential. Countries like Japan, Germany, and South Korea have engaged early through training programs, technical support, and pilot projects, shaping regional standards and technology pathways—particularly in Vietnam, Thailand, and Indonesia.

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[23] Abhimanyu Pal et al., "Powering Squarely into the Future: A Strategic Analysis of Hydrogen Energy in QUAD Nations," *International Journal of Hydrogen Energy* 49, Part D (2024): 16–41.

To stay competitive, the United States must deepen its engagement. While the IPEF remains Washington's primary platform for hydrogen cooperation in the region, it is not the only channel. In the context of the USAID stop-work order and the Trump administration's broader suspension of foreign aid, there are growing concerns that reduced U.S. development assistance could weaken U.S. influence and capacity to drive regional initiatives. Without strong U.S. leadership, the IPEF's clean economy pillar risks losing momentum—potentially allowing other actors to dominate regional standard-setting and infrastructure development. To strengthen its role in the region, the United States should consider the following measures:

- *Expansion of financial and technical support*. The United States could leverage IRA momentum by channeling grants and blended finance to key ASEAN countries (e.g., Vietnam, Indonesia, and the Philippines). It could also promote technology transfer through training programs, joint R&D centers, and hydrogen deployment support.
- *Improvement of market signals and de-risking of investment*. The United States could offer preferential trade measures for clean technology, even without formal free trade agreements. It could also use loan guarantees, tax credits, and risk insurance to mobilize the investment of U.S. private capital into ASEAN's hydrogen value chain.
- *Alignment with ASEAN-led frameworks*. The United States could coordinate with existing platforms like the APAEC and the ASEAN Centre for Energy to strengthen their legitimacy and regional ownership. It could also co-finance regional hydrogen hubs or cross-border infrastructure to enhance energy security.
- *Mitigation of geopolitical sensitivities*. The IPEF could be framed as inclusive and cooperative rather than exclusive. To this end, participants should consider selective clean energy cooperation with China to stabilize regional supply chains.
- *Long-term policy stability*. The United States could work to anchor hydrogen cooperation in bipartisan legislation or trade-linked commitments. In particular, it could develop joint ASEAN-U.S. hydrogen roadmaps with measurable milestones to maintain momentum.

In sum, early engagement on hydrogen energy in Southeast Asia would position the United States to shape regional standards, secure long-term market access, and strengthen clean energy supply chains that benefit both ASEAN partners and U.S. industries.[24]

The geopolitical influence of China on ASEAN. China shares borders with ASEAN countries like Vietnam, Laos, and Myanmar and its geographic proximity—especially near key South China Sea trade routes—gives it natural strategic leverage in the region. As discussed earlier, China has emerged as a global leader in hydrogen, aligning with its "dual carbon" goals of achieving peak emissions by 2030 and carbon neutrality by 2060.[25] It leads in electrolyzer manufacturing and hydrogen patents and has built large-scale fuel cell and hydrogen infrastructure through both state-owned enterprises (e.g., Sinopec) and private firms. Projects like the Hydrogen Energy Corridor in the Yangtze River Delta and deployment of FCVs reflect this domestic momentum.[26] China's dominance in solar and wind also supports its ambitions to scale low-cost green hydrogen—though fossil-based hydrogen still dominates.

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[24] Sonja Butzengeiger et al., "The Structures of the Emerging International Hydrogen Trade and Their Geopolitical Implications," GIZ, May 2023.

[25] "China's Progress toward 'Dual Carbon' Goals in 3 Years," *Global Times*, September 22, 2023, https://www.globaltimes.cn/page/202309/1298711.shtml.

[26] Dou Shicong, "China to Build 4 Hydrogen Highways in Yangtze River Delta Region in 3 Years," Yicai Global, https://www.yicaiglobal.com/news/china-to-build-4-hydrogen-highways-in-yangtze-river-delta-region-in-3-years.

Through the Belt and Road Initiative, China exports this capability by financing hydrogen infrastructure across the ASEAN region—such as through the construction of energy parks and refueling stations. For example, it has launched pilot hydrogen projects with Thailand and Indonesia, offering technology transfers and financing.[27] While Chinese assistance strengthens energy ties, it also raises concerns over dependence on Chinese standards and supply chains.

In Vietnam, China plays a dual role in the clean energy transition both as a key technology partner and a strategic competitor. Chinese firms like LONGi and SPIC participate in Vietnam's RE projects that could underpin future hydrogen production.[28] However, Vietnam is actively working to diversify its hydrogen partnerships—particularly through cooperation with the United States, Japan, and the EU—to avoid overreliance on China and preserve its strategic autonomy.

Cooperation within the region. The ASEAN Centre for Energy is a crucial institution established to facilitate energy cooperation among ASEAN member states. Founded in 1999 and headquartered in Jakarta, it plays a vital role in promoting energy development, security, and sustainability across the region. The APAEC 2016–2025 prepared by the ASEAN Centre for Energy is a key strategic document aimed at enhancing collaboration and sustainable development in the energy sector among ASEAN member states. The second phase of the plan (2021–25) aims to deepen cooperation and further develop strategies for sustainable energy development, including through the integration of hydrogen, and creates a foundation for hydrogen development in the region. Although there is no specific long-term plan for hydrogen (to 2030 and 2050), the ASEAN region has identified hydrogen as important for minimizing environmental impacts.

Bilateral partnerships and early movers in ASEAN's hydrogen development. Several ASEAN countries are actively pursuing bilateral hydrogen cooperation, focusing on technology transfer and infrastructure development. Notable examples include the partnership between Singapore and Indonesia, Thailand and Malaysia's collaboration with Japan on hydrogen transport applications, and ongoing efforts between Vietnam and Japan to develop joint projects.[29] Countries like Singapore, Thailand, and Vietnam have also hosted basic green hydrogen training programs with support from Japan's Ministry of Economy, Trade and Industry and Germany's GIZ, while companies such as Kawasaki Heavy Industries and Siemens Energy have contributed technical expertise and supported early standard-setting efforts. Such early engagement strengthens local capacity, shapes future regulatory frameworks, and offers first-mover advantages. For example, Japan's leadership in ASEAN hydrogen policy dialogues via the Economic Research Institute for ASEAN and East Asia (ERIA) has positioned it as a preferred partner, while Vietnam's Ben Tre green hydrogen project, which sources core technology from Germany, highlights the tangible commercial benefits of early cooperation.[30]

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27 "Thailand to Build Its 1st Commercial Green Hydrogen Project with China," CGTN, January 28, 2024, https://news.cgtn.com/news/2024-01-28/Thailand-to-build-its-1st-commercial-green-hydrogen-project-with-China-1qIZQyfhjFu/p.html; and "China Shipbuilding Power Research Hydrogen Energy Technology Successfully Signed the Hydrogen Production and Refueling Integrated Station Project in Indonesia, Marking Another Significant Step in Overseas Expansion," SMM, February 24, 2025, https://news.metal.com/newscontent/103193795/China-Shipbuilding-Power-Research-Hydrogen-Energy-Technology-Successfully-Signed-the-Hydrogen-Production-and-Refueling-Integrated-Station-Project-in-Indonesia,-Marking-Another-Significant-Step-in-Overseas-Expansion.

28 "LONGi and SEV Drive Green Energy Transition in Vietnam's Electronics Industry," LONGi, December 3, 2024, https://www.longi.com/vn/news/longi-solar-sev-vietnam-electronic-industry.

29 Aida Čučuk, "New Alliance Looking into Hydrogen Pipeline Connecting Indonesia and Singapore," Offshore Energy, November 14, 2024, https://www.offshore-energy.biz/new-alliance-looking-into-hydrogen-pipeline-connecting-indonesia-and-singapore; "Election Commission 'Fully Prepared for Early Vote,'" *Nation* (Thailand) February 9, 2023, https://www.nationthailand.com/business/40024769; and "Japan and Vietnam Seeking for Hydrogen Cooperation," TuoiTre Online, September 17, 2024, https://tuoitre.vn/nhat-ban-va-viet-nam-tim-co-hoi-hop-tac-phat-trien-nang-luong-hydrogen-20240917154249597.htm.

30 "Green Hydrogen Production Plant to Start Construction in Ben Tre," Government Electronic Newspaper (Vietnam), May 25, 2022, https://baochinhphu.vn/sap-khoi-cong-nha-may-san-xuat-hydro-xanh-tai-ben-tre-102220524231206264.htm.

To effectively develop hydrogen energy in the ASEAN region, member states should consider the following strategies to enhance regional cooperation:

- *Geopolitical bargaining power*. A unified ASEAN voice would strengthen negotiations on technology transfer and climate finance, improving access to funding from initiatives like the G-7's JETP to support hydrogen infrastructure.
- *An integrated hydrogen roadmap*. A common regional framework would prevent market fragmentation, reinforce ASEAN's unified stance, and help attract large-scale investors.
- *International partnerships*. Engaging with institutions such as the World Bank, Asian Development Bank, and UN agencies is essential. Without such alliances, ASEAN risks being a rule-taker in the $300 billion global hydrogen market; with them, it can help shape the future hydrogen economy.
- *An ASEAN hydro training center*. Countries like Laos, Cambodia, and Myanmar lack access to hydrogen education and labs. A regional hub would ensure equitable training and help build technical capacity for deployment across the region.

The following initiatives led by ASEAN and the East Asia Summit should be prioritized as well to strengthen regional energy cooperation on clean energy and hydrogen development:

- *ASEAN Plan of Action for Energy Cooperation 2016–2025*. Prioritizing APAEC in discussions would ensure alignment with existing regional frameworks and maximize synergy with IPEF initiatives.
- *ASEAN hydrogen roadmap*. Although ASEAN has yet to establish a long-term hydrogen strategy, a dedicated ASEAN hydrogen roadmap could be developed to provide clear targets for 2030 and 2050. This roadmap would define policies, investment needs, and technology-sharing mechanisms for hydrogen development.
- *East Asia Summit Energy Cooperation Task Force*. The East Asia Summit provides a broader platform for ASEAN to discuss energy transition strategies with China, Japan, South Korea, and other regional partners. Prioritizing energy discussions through the summit would ensure greater policy coordination and financing for hydrogen projects.

The Asia Zero Emission Community's role in regional energy cooperation. First, AZEC could play a role in facilitating regional clean energy integration. It could support ASEAN's clean energy transition by promoting policies for zero-emission technologies, including hydrogen, CCUS, and RE expansion. It could also enhance cooperation between developed economies (e.g., Japan, South Korea, and Australia) and developing ASEAN nations on energy policy harmonization.

Second, AZEC could boost hydrogen and ammonia market development. In particular, it could serve as a platform to create a regional hydrogen and ammonia trading market by setting standards and ensuring supply chain stability. Countries like Japan and South Korea, which have high hydrogen demand, could collaborate with ASEAN nations that have production potential (e.g., Vietnam, Indonesia, and Malaysia).

Finally, AZEC could support investment and technology transfer. Member countries could establish joint funding mechanisms (e.g., public-private partnerships and green bonds) to accelerate hydrogen infrastructure development. AZEC could also promote technology-sharing agreements for hydrogen production, transport, and storage.

Conclusion

Hydrogen energy represents not just a technological option but a strategic lever for the Indo-Pacific's long-term decarbonization agenda. As countries across the region face mounting pressure to reduce emissions and strengthen energy security, green hydrogen offers a viable pathway—especially in hard-to-abate sectors such as steel, chemicals, and heavy transportation.

This essay has illustrated the uneven but dynamic progress of hydrogen technologies across the Indo-Pacific. Advanced economies such as the United States, Japan, China, and Australia are moving quickly, supported by large-scale investments, mature industrial ecosystems, and comprehensive policy frameworks. In contrast, emerging economies—including Vietnam—are still building the foundational infrastructure and regulatory environments necessary to support a hydrogen economy.

Despite these gaps, Vietnam stands out as a country with enormous green hydrogen potential. Its abundant renewable energy resources—particularly offshore wind and solar—can support large-scale electrolytic hydrogen production. The country's strategic targets, such as producing 10–20 million tonnes of hydrogen annually by 2050, are ambitious but feasible, provided that it addresses key barriers in electrolyzer manufacturing, hydrogen storage, and regulatory clarity. More broadly, Vietnam's hydrogen strategy is well aligned with regional and global trends. Through bilateral and multilateral platforms like AZEC, the IPEF, COP, and the JETP, it is deepening cooperation with key partners such as the United States, Japan, Germany, and Australia. These collaborations will be essential to unlock funding, facilitate technology transfer, and build institutional capacity. Regionally, Vietnam can play a pivotal role as a hydrogen bridge in Southeast Asia—serving both as a production hub and export gateway, especially via southern ports like Vung Tau and Tra Vinh. By strategically developing hydrogen infrastructure across its central, southern, and northern regions, Vietnam can simultaneously meet domestic decarbonization needs and contribute to regional hydrogen trade.

In summary, while significant challenges remain, Vietnam's proactive policy direction, renewable energy potential, and international engagement position it well to become a leading force in the Indo-Pacific hydrogen economy and serve as a model for other developing countries. With timely investment, institutional reform, and regional alignment, hydrogen could fuel not only Vietnam's energy transition but the energy transition across Southeast Asia and the entire Indo-Pacific.

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