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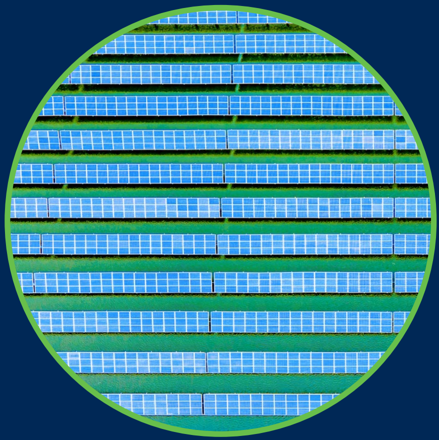
REPORT



Green Hydrogen for Decarbonizing Asia's Industrial Giants

Analyzing H_2 Electrolyzer Market Opportunity in Key Industrial Applications

GETTING ASIA TO NET ZERO

A High-level Policy Commission Convened by the Asia Society Policy Institute

Green Hydrogen for Decarbonizing Asia's Industrial Giants

Analyzing H_2 Electrolyzer Market Opportunity in Key Industrial Applications

A REPORT ON BEHALF OF THE HIGH-LEVEL POLICY COMMISSION ON GETTING ASIA TO NET ZERO

CONVENED BY THE ASIA SOCIETY POLICY INSTITUTE AS SECRETARIAT

ANALYSIS & REPORT PREPARED BY GLOBAL EFFICIENCY INTELLIGENCE

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ASIA SOCIETY POLICY INSTITUTE

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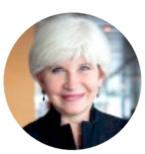

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FOREWORD

In recent decades, Asia has undergone an unprecedented transformation into the workshop of the world. Asian economies accounted for only 36% of industrial value added globally in 2000; by 2019, that share rose to more than 50%. During that period, the region's industrial value added grew more than threefold, from $2.7 trillion to $9.4 trillion.

Asia's incredible rise into a manufacturing powerhouse has reshaped the region's economy and brought hundreds of millions of people out of poverty. However, it has also massively expanded the region's emissions footprint and created significant difficulties for the region's net zero pathway.

Industry is notoriously difficult to decarbonize compared to other sectors—a large portion of the emissions from manufacturing comes from chemical reactions or other processes that require high heat or fossil fuels as inputs. Technologies now exist to abate such emissions, but it will take concerted efforts to bring them to cost and scale. Yet doing so will be critical for getting Asia to net zero emissions, given that such a comparatively large segment of the region's emissions comes from industry.

Moreover, as Asia's wealth rises, so too has its consumption, further complicating the climate-related challenges at hand. While Asia remains a net exporter of emissions, its growth in consumption-based emissions reflects that its own population is contributing to more global emissions as the region develops.

However, there is a silver lining: Asian manufacturers have an opportunity to serve as agents of change in the net zero transition—both regionally and globally.

They can do this in two key ways. First, Asia's manufacturing prowess positions the region to benefit from producing the technologies required for industrial decarbonization in Asia and beyond. The region's comparative advantage in production can be leveraged as a business opportunity as the world looks to procure the technologies that will be needed for achieving net zero emissions. Indeed, for industrial decarbonization, the biggest market will likely be Asia itself.

Second, if Asia can ensure that these clean technologies and other industrial products are manufactured using green and low-carbon processes, the region can win markets while accelerating decarbonization progress. Policies and regulations that advantage products made using less emissions are increasingly gaining steam around the world. Limiting emissions from production can help Asian exporters gain access to more markets globally and position themselves to benefit in a world that increasingly prioritizes life-cycle sustainability.

To enhance Asia's role in accelerating industry's net zero transformation, the High-level Policy Commission on Getting Asia to Net Zero commissioned efforts to explore the market opportunities underlying Asia's clean industrial transformation. This scope of inquiry included the state of emerging technologies that will be needed, the required scale of their deployment, and supporting policies that could enhance both supply and implementation.

Technologies to abate industrial emissions run the gamut and cover the range of industrial processes—from industrial heat pumps and electric boilers to green hydrogen for replacing fossil fuels as a clean feedstock, to thermal energy storage for renewable power, to targeted carbon capture and storage for those emissions that are exceedingly difficult to address through other means.

This paper narrows in on one of the most salient of these technologies, namely, the electrolyzers that will be required for producing green hydrogen in Asia's four largest economies: China, Japan, India, and South Korea. It explores the role of green hydrogen in decarbonizing three major industries—steel, ammonia, and methanol—where it can limit emissions by replacing carbon-intensive processes with renewable-powered electrolysis.

The opportunity created by net zero targets is monumental. Should the four countries stay on track to achieve their declared targets, the collective market potential for electrolyzers is expected to skyrocket to $180 billion by 2050, with a compound annual growth rate as high as 12% between 2030 and 2040 before the technology adjusts to more stable growth as it becomes widespread. This is nearly five times as large as the market under a business-as-usual scenario, and it could be even greater should countries fully align their net zero targets with a 1.5°C pathway and achieve net zero CO_2 emissions by 2050.

These findings underscore how ambitious and prominent net zero targets can shape demand for a new and critical technology, such as electrolyzers, that will be essential to decarbonizing the region and the world. Nations could therefore see net zero pathways as vehicles for driving development, rather than limiting it.

In fact, previous analysis from the High-level Policy Commission on Getting Asia to Net Zero found that achieving net zero emissions by 2050—in line with the Dubai Consensus from COP28 in December 2023—could boost the Asia-Pacific's GDP by as much as 6.3% above predicted levels and create up to 36.5 million jobs by the 2030s. Additional analysis showed that these benefits could be even greater for significant emitters such as India and Indonesia if they bring forward their net zero targets.

To reap such rewards, however, policies will need to be strengthened across the board to address loopholes. For instance, unless green hydrogen standards are properly structured and enforced, fossil-powered electricity may end up filling the gaps to spur hydrogen production via electrolysis, which risks contributing even more emissions. To this end, this report presents a suite of recommendations for key stakeholder groups to collectively support a robust ecosystem for green hydrogen production and use in these countries toward a net zero industry.

It will also be essential for countries to integrate strong 1.5°C-aligned targets and other signals into their Nationally Determined Contributions (NDCs under the UN climate change process. Doing so provides a strong, high-level political signal that reassures potential investors and incentivizes them to provide resources. China, Japan, India, and South Korea have all set targets and crafted various policy incentives for the hydrogen sector, such as financial incentives to localize electrolyzer production and the establishment of cooperative platforms to share best practices internationally. They could go even further by integrating sectoral targets, including for industry, into their updated NDCs due by early 2025 that will cover the period up until 2035.

While the market for some clean technologies is already dominated by certain players, the playing field for electrolyzer manufacturing remains wide open, with approximately 25% of global electrolyzer manufacturing projected to be up for grabs between now and 2030. Spreading the manufacture and deployment of these technologies around the Asian region will be critical for mitigating risks and ensuring a just, equitable, and orderly transition.

Climate targets need not just be guardrails—they can also double as investment plans and opportunities to spur growth. More ambitious targets can enlarge markets and attract resources, make development sustainable, and get Asia to net zero even faster.

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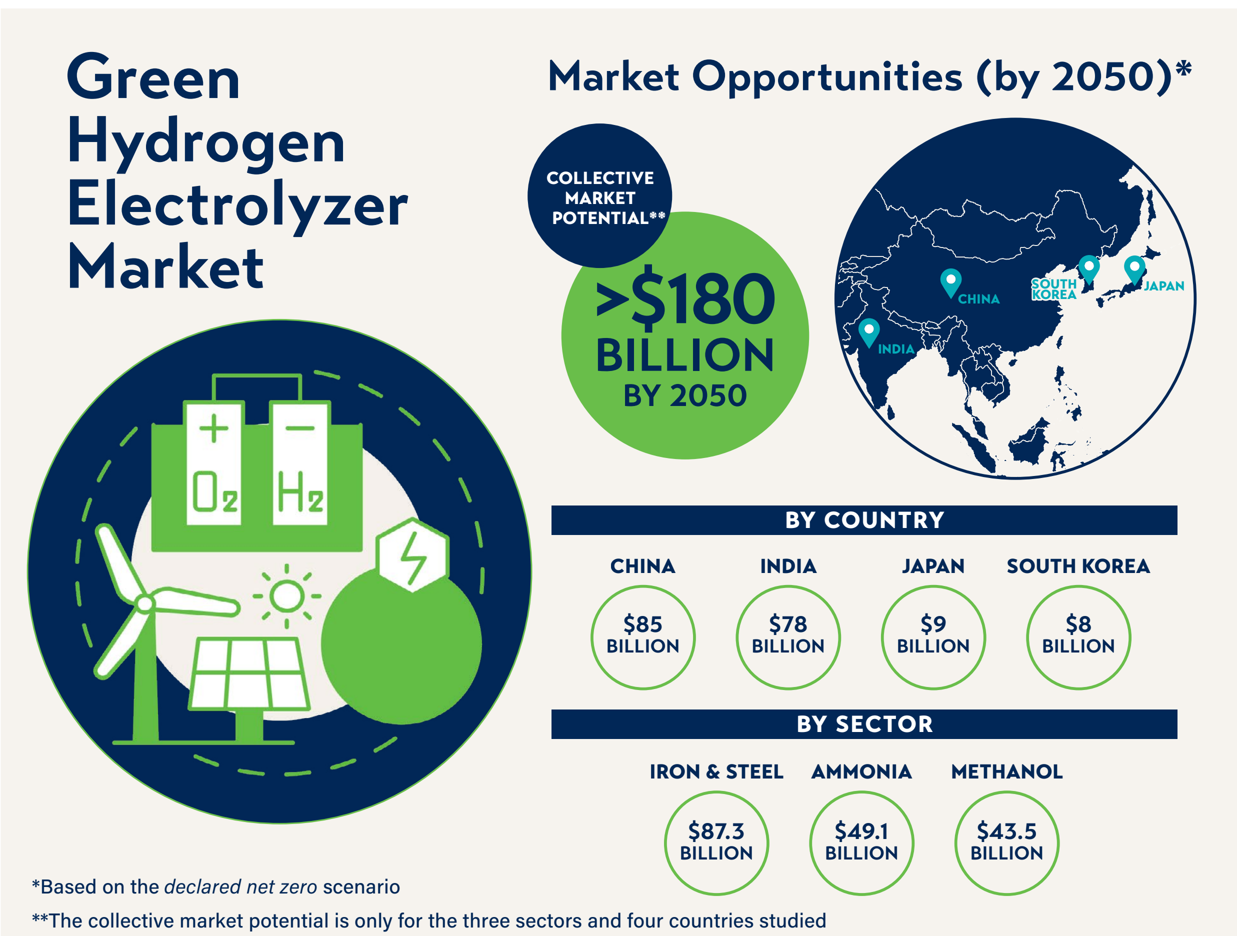
ACRONYMS

BAU	Business-as-usual
BF-BOF	Blast furnace–basic oxygen furnace
BOP	Balance of plant
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
CO_2	Carbon dioxide
DRI	Direct reduced iron
EAF	Electric arc furnace
EPC	Engineering, procurement, and construction
FH_2R	Fukushima H_2 Energy Research Field
GHG	Greenhouse gas
H_2	Green hydrogen
IoT	Internet of Things
PEM	Proton exchange membrane
PLI	Production Linked Incentive
R&D	Research and development
SIGHT	Strategic Interventions for Green Hydrogen Transition
SOE	Solid oxide electrolyzers
SOEC	Solid oxide electrolyzer cells

EXECUTIVE SUMMARY

This report evaluates the potential and trajectory of the green hydrogen (H_2) electrolyzers market within the context of various decarbonization scenarios, including declared net zero targets, across Asia's four largest economies: China, India, South Korea, and Japan. It explores the role of green H_2 in decarbonizing three major industries—steel, ammonia, and methanol—where it can replace carbon-intensive processes with renewable energy–powered electrolysis, offering a path to significantly reduce CO_2 emissions. The analysis provides a detailed look into the demand for green H_2, the necessary scale-up of electrolyzers, and the potential market growth up to 2050. By focusing on the current and future industrial landscapes, technological advancements, and supportive policy environments, the report aims to be a vital resource for stakeholders, highlighting the urgent need for wider adoption of these commercial technologies to achieve global net zero targets.

In the scenario based on declared net zero targets (hereinafter referred to as the *declared net zero* scenario), the electrolyzer market opportunity in China, India, Japan, and South Korea is projected to experience significant growth to meet the demand for green H_2 for direct reduced iron and steelmaking (H_2-DRI), green ammonia, and green methanol production. China's market potential is expected to soar from $22 billion in 2030 to $85 billion by 2050, while India's market is projected to reach $78 billion from $4 billion in 2030, showing

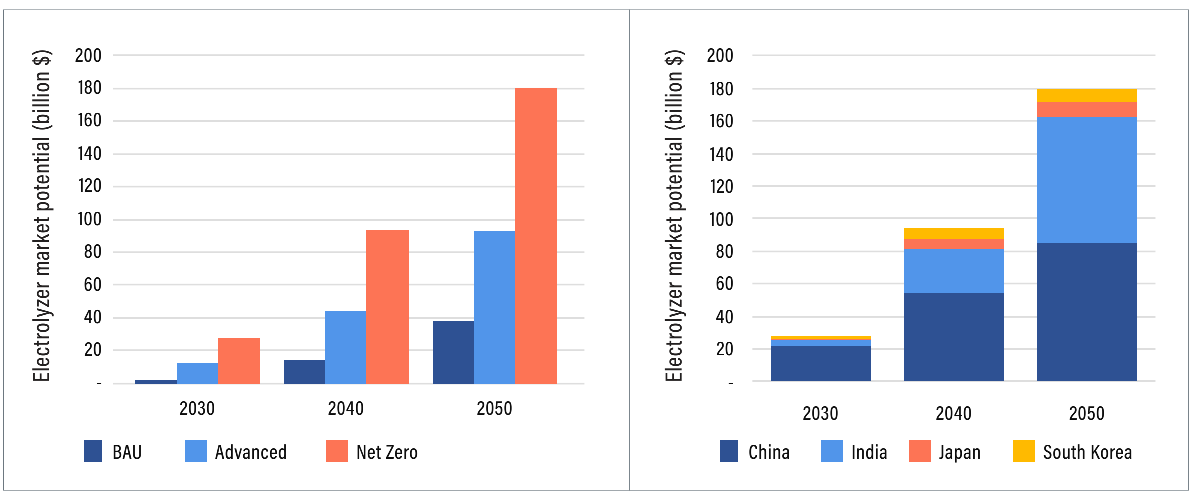


the highest growth. Japan's market potential will grow to $9 billion, and South Korea's to $8 billion by 2050, both at a compound annual growth rate (CAGR) of 10%. This growth is propelled by increased production targets under net zero commitments, government policies, investments in renewable infrastructure, and technological advancements. China's and India's aggressive hydrogen targets are reflected in their substantial projected outputs of 112 million metric tonnes (Mt) and 125 Mt of green H_2-DRI steel, 25.5 Mt and 25.8 Mt of green ammonia, and 38 Mt and 8 Mt of green methanol, respectively, by 2050, while Japan and South Korea are expected to have more moderate production figures due to challenges in domestic renewable electricity generation.

It should be noted that the total electrolyzer market opportunity in these four countries is much greater than what is estimated in this report, which only focuses on three key applications of green H_2, that is, green H_2-DRI steelmaking, green ammonia, and green methanol production.

In the iron and steel industry, the *declared net zero* scenario projects a substantial increase in green H_2-DRI steel production, particularly in China and India, with their electrolyzer market potential expected to rise dramatically by 2050, reaching $31 billion and $42 billion, respectively, to support H_2-DRI steelmaking. This surge is supported by an anticipated growth in green H_2-DRI steel production, with India's green H_2 steel production predicted to account for 25% of its total steel production in 2050. Similarly, China's green H_2-DRI production is forecasted to constitute 15% of its total steel output in 2050. In Japan and South Korea, more moderate growth is expected due to constraints in domestic renewable electricity generation, with their electrolyzer market potential to support H_2-DRI steelmaking reaching $7.8 billion and $6.6 billion, respectively, by 2050. This predicted growth in the electrolyzer market to support the steel industry underpins the ambitious decarbonization targets of these nations, reflecting the need for a significant shift to green H_2-DRI as a pivotal component in achieving net zero emissions in steel production.

FIGURE ES1 **TOTAL ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI, GREEN AMMONIA, AND GREEN METHANOL PRODUCTION IN CHINA, INDIA, JAPAN, AND SOUTH KOREA**



Note: Left shows electrolyzer market potential under different scenarios, and right shows the *declared net zero* scenario.

Under the *declared net zero* scenario, the combined market potential for electrolyzers in China, India, Japan, and South Korea is anticipated to undergo a significant rise, with projections reaching $180 billion by 2050. This growth trajectory is marked by a CAGR of 12% from 2030 to 2040, before stabilizing to an 8% CAGR from 2040 to 2050 as the adoption of these technologies broadens.

The landscape of hydrogen production and electrolyzer manufacturing in China, India, Japan, and South Korea showcases each country's distinct strategy in cultivating a robust green hydrogen economy. China's commitment is reflected in its substantial investment in electrolyzer capacity expansion, especially in alkaline technology, with plans to pivot toward proton exchange membrane (PEM) technology to capture a larger market share and meet the ambitious 80 GW capacity target by 2030. India, while still in nascent stages, is laying the groundwork for significant growth in green hydrogen production, propelled by policy incentives like the Production Linked Incentive (PLI) scheme and the National Green Hydrogen Mission, which aims for a 5 million tonne production capacity by 2030. Japan, with a goal to command a 10% share of the global electrolyzer market by 2030, is banking on its technological leadership and robust policy framework, including the Basic Hydrogen Strategy and the Green Innovation Fund. Meanwhile, South Korea is channeling investments into electrolyzer technology and scaling up its green hydrogen production, with governmental backing through financial incentives and an overarching Hydrogen Economy Roadmap. These strategies show a concerted effort by these Asian giants to enhance domestic manufacturing, support innovation, and establish themselves as pivotal players in the global transition toward green hydrogen energy.

The report presents a suite of recommendations aimed at accelerating the development and adoption of green hydrogen and electrolyzer technologies manufacturing and adoption in these four major Asian economies especially. These targeted strategies for policymakers, industry players, investors, and think thanks aim to collectively support a robust ecosystem for green hydrogen production and use in these countries toward a net zero industry. They may also be applicable to countries not included in this study.

TABLE ES1 RECOMMENDATIONS FOR ACCELERATING THE DEVELOPMENT AND ADOPTION OF GREEN HYDROGEN AND ELECTROLYZER TECHNOLOGIES IN ASIA'S INDUSTRIAL GIANTS

STAKEHOLDER GROUP	RECOMMENDATION	OBJECTIVE
Policymakers	Develop guidelines for hydrogen use in industry	To strategically deploy hydrogen for maximum decarbonization impact
	Implement regulatory frameworks	To support the adoption and development of green hydrogen technologies
	Invest in R&D	To enhance efficiency and reduce costs of electrolyzers
	Create financial incentives	To stimulate the green hydrogen market and local manufacturing
	Promote international cooperation	To share knowledge and standardize practices in the hydrogen economy
	Establish green hydrogen hubs	To concentrate resources and expertise for hydrogen production and use
	Promote education and workforce development	To develop skilled labor for the emerging green hydrogen industry
	Set decarbonization targets for industries	To provide a demand signal for green hydrogen production and use
	Facilitate access to renewable energy	To ensure efficient energy supply for hydrogen production
	Introduce green hydrogen certification	To maintain transparency about the environmental credentials of hydrogen
Industry	Expand manufacturing capabilities	To meet the growing demand for electrolyzers
	Innovate in product development	To create more efficient and cost-effective electrolyzer technologies
	Strengthen supply chains	To ensure the availability of essential materials and components
	Enhance collaboration	To integrate green hydrogen solutions across various sectors
	Adopt digitalization and Internet of Things (IoT)	To optimize electrolyzer operations
	Pursue technological diversification	To cater to a diverse market with varying needs
Investors	Support high-potential projects	To propel the market forward with innovative technology
	Promote risk-sharing mechanisms	To facilitate investment in early-stage projects
	Evaluate long-term market potential	To sustain investment decisions with a focus on decarbonization
	Invest in green hydrogen infrastructure	To build the necessary framework for hydrogen production and distribution
	Prioritize investments in supported regions	To capitalize on regions with strong green hydrogen policies
Think Tanks	Advocate for policy support	To drive the adoption of green hydrogen in line with environmental goals
	Facilitate knowledge sharing	To educate stakeholders on green hydrogen technologies and their benefits
	Monitor environmental and social impacts	To ensure sustainable and responsible development of the hydrogen economy
	Promote public awareness and inclusive policymaking	To engage the public and ensure diverse voices in policy development

INTRODUCTION

The goal of this report is to show the trajectory and potential of the green hydrogen (H_2 electrolyzer market under several decarbonization scenarios including current net zero targets in four Asian manufacturing giants: China, India, South Korea, and Japan. These countries are also the four largest economies in Asia by GDP. Specifically, the report investigates the application of green H_2 in three industries: steel, ammonia, and methanol production. The ammonia and methanol industries are two of largest consumers of H_2, which is currently produced from fossil fuels (natural gas or coal. The use of green H_2 as a reductant in the iron and steel industry is an emerging application of H_2 that can substantially contribute to the decarbonization of this sector. As nations globally set net zero emissions targets, the transition to low-carbon industrial processes has become a paramount objective. This report aims to serve as a critical resource for industry stakeholders, policymakers, and investors by assessing the market potential of H_2 electrolyzers and forecasting the adoption scenarios up to the year 2050.

Green H_2 emerges as an important tool for industrial decarbonization. With its production via water electrolysis powered by renewable energy sources, green H_2 can be used as a carbon-free feedstock and reductant to significantly reduce carbon emissions in several key industry sectors. Currently, the majority of the H_2 production in the world comes from natural gas (via steam methane reforming or coal (via coal gasification.

The steel industry, traditionally reliant on carbon-intensive blast furnace–basic oxygen furnace (BF-BOF processes, stands on the verge of a transition with the adoption of the green H_2 direct reduced iron (H_2-DRI process. Green H_2-DRI offers a viable route to producing steel with a drastically reduced carbon footprint. In this process, green H_2 replaces carbon-based reductants (produced from coal or natural gas in the iron-making process, eliminating CO_2 emissions from the reduction stages of steel production. This report investigates the implications of such a transformation, estimating the demand for green H_2 within this sector and analyzing the scale at which electrolyzers need to be deployed to meet this demand.

Similarly, the production of ammonia and methanol presents a substantial opportunity for decarbonization with green H_2. Ammonia production, which currently depends heavily on the Haber-Bosch process using fossil fuels, can shift toward a greener path by employing green H_2 as its main feedstock, thus significantly reducing the industry's CO_2 emissions. Methanol, which has applications ranging from fuel to industrial feedstock, can also be synthesized from green H_2 and (captured CO_2, offering a low-carbon alternative to current production methods.

All three industrial applications of green H_2 in the steel, ammonia, and methanol industry are fully commercial technologies and just need wider adoption. This report assesses the potential scale of such a transition and the resulting market potential for H_2 electrolyzers, considering the current and future landscape of each industry, technological advancement, and the policy climate that could facilitate this progress in each of the four countries studied.

GREEN HYDROGEN AND ELECTROLYZER TECHNOLOGIES

Green H_2 is produced via electrolysis—a process that splits water (H_2O) into its constituent elements—H_2 and oxygen, using electricity derived from renewable energy sources such as solar, wind, or hydroelectric power. This method ensures that the H_2 production process is free from CO_2 emissions.

The purity of H_2 produced through electrolysis is high, making it suitable for use in various sectors, including as a feedstock in chemical processes or reductant in the iron and steel industry. However, the overall sustainability of green H_2 production is contingent upon the carbon footprint of the electricity source. Therefore, coupling electrolysis with renewables is crucial for true green credentials.

Electrolyzers are the pivotal technology enabling the conversion of water into H_2 and oxygen. An electrolyzer consists of an anode and a cathode separated by an electrolyte. Water fed into the electrolyzer undergoes an electrochemical reaction when a direct current is applied. At the anode, water molecules are oxidized to release oxygen and protons, which then move to the cathode through the electrolyte. At the cathode, these protons are reduced to form H_2 gas.

Three types of electrolyzer technologies are primarily in use now: alkaline electrolyzers, proton exchange membrane (PEM) electrolyzers, and solid oxide electrolyzers (SOE). Alkaline electrolyzers, the most mature technology, use a liquid alkaline solution of potassium or sodium hydroxide as the electrolyte. PEM electrolyzers use a solid polymer electrolyte and are known for their higher efficiency, dynamic response, and ability to produce high-purity H_2. The SOE operates at high temperatures and has the potential for the highest efficiency among the three, but SOE units are not yet widely commercially available at scale, and their cost remains higher than that of alkaline and PEM technologies.

The field of electrolyzers is witnessing rapid advancements aimed at enhancing efficiency, reducing costs, and scaling up production capacities. Innovations include the development of advanced catalysts that reduce the amount of precious metals needed, thereby lowering costs and improving durability. Additionally, research is underway to integrate electrolyzers with renewable power sources more effectively, allowing for more responsive and flexible operation to match the intermittent nature of renewable energy.

The cost of electrolyzers has been on a downward trend, thanks to technological improvements, economies of scale, and increased manufacturing experience. The industry has witnessed a significant reduction in the cost of electrolyzers per kilowatt over the past decade. The cost is expected to keep dropping substantially in the coming years and decade. Efficiency improvements are also notable, with modern electrolyzers capable of converting more than 70% of electrical energy into chemical energy stored in H_2. Ongoing research promises further enhancements, potentially surpassing 80% efficiency in the future.

MARKET ANALYSIS FRAMEWORK

Our approach for estimating the demand for green H_2 and the corresponding market potential for H_2 electrolyzers in the steel, ammonia, and methanol industries within China, India, South Korea, and Japan is founded on a multistage analysis. This approach integrates industrial growth projections, technological adoption rates, low-carbon product production, and three scenarios developed with varying level of policy impacts to derive robust forecasts up to 2050.

Scenarios are created to reflect varying speeds of adoption due to economic, policy, and technological drivers. The *business-as-usual (BAU)* scenario provides a conservative estimate based on current growth and low adoption rates. The *advanced adoption* scenario accounts for the acceleration in technology uptake due to favorable policies and economic incentives. It uses much more aggressive technology adoption than the *BAU* scenario, but it does not take us to net zero emissions. The *declared net zero* scenario projects the most aggressive shift toward decarbonization, adhering to countries' current climate targets. This scenario represents a significant departure from the BAU, and accelerating these trajectories would more rapidly enlarge the H_2 electrolyzer market. The timelines to achieve the *declared net zero* scenario assumed in this study are different across countries, based on their current targets:

- **China:** to achieve net zero by 2060
- **India:** to achieve net zero by 2070
- **Japan:** to achieve net zero by 2050
- **South Korea:** to achieve net zero by 2050

Quantitatively, we employ a bottom-up modeling approach, first determining the amount of H_2 needed per unit of output in each industry. For the steel industry, this involves finding the kilograms of H_2 required to produce a ton of steel via the H_2-DRI process. For ammonia and methanol, we obtained the volume of H_2 needed to produce each metric ton.

We then project the future output of steel, ammonia, and methanol up to 2050 for each country under the three scenarios, using growth rates derived from industrial forecasts and potential shifts toward low-carbon production in each country based on information in the literature. These projections are then combined with the H_2 consumption rates per unit of output to estimate the total H_2 demand for each industry under the different scenarios.

It should be noted that the ammonia and methanol production for potential new uses such as maritime fuel or H_2 carrier (storing H_2 for easier transport) is not considered in this study since the extent of such new uses in the future is highly uncertain. Only current common applications of ammonia and methanol in each country are considered.

To evaluate the market potential for electrolyzers, we translate the H_2 demand into electrolyzer capacity requirements. We calculate the electrolyzer capacity needed to meet the projected H_2 demand by assuming average electrolyzer efficiency of 70% and an electrolyzer capacity factor of 50%.

Capital expenditure (CAPEX) values are applied to estimate the investment required to install the required electrolyzer capacity. This involves analyzing historical and current pricing data for electrolyzer units, considering the declining cost trend due to technological advancements and economies of scale. The CAPEX includes the equipment/hardware cost (both for electrolyzer and balance of plant (BOP), referring to the required supporting systems and infrastructure). The CAPEX used in this study to estimate electrolyzer market potential does not include engineering, procurement, and construction (EPC) costs, financing cost, contingency costs, and other soft costs of a project.

To estimate the electrolyzer market potential by 2050, we assumed alkaline and PEM electrolyzers would each take half of the total electrolyzer market by 2050. The average equipment/hardware cost for electrolyzers is assumed to drop by more than 40% in China and more than 50% in the other three countries by 2050. The reason is that China already has some of the lowest CAPEX cost for electrolyzers in the world. We did not account for solid oxide electrolyzers in our analysis, as they are still emerging technologies and their market share in the future is uncertain.

The outcome of this method is a set of detailed, scenario-based electrolyzer market potential forecasts for green H_2 electrolyzers. These forecasts are designed to provide industry stakeholders, policymakers, and investors with actionable insights into the future of green H_2 in Asia's transition to a low-carbon industrial hub and the economic opportunity that green H_2 electrolyzers can provide.

TABLE 1 ASSUMPTIONS USED IN ESTIMATING ELECTROLYZER MARKET POTENTIAL

	ASSUMPTION
Electricity needed to produce H_2	50 kWh/kg H_2
Efficiency of electrolyzer	70%
Electrolyzer capacity factor	50%
H_2 demand per tonne of H_2-DRI steel	58 kg H_2/t steel
H_2 demand per tonne of green ammonia	178 kg H_2/t ammonia
H_2 demand per tonne of green methanol	187 kg H_2/t methanol

It should be noted that the total electrolyzer market opportunity in these four countries for all applications is much greater than what is estimated in this report, which only focuses on three applications of green H_2, that is, green H_2-DRI steelmaking, green ammonia, and green methanol production.

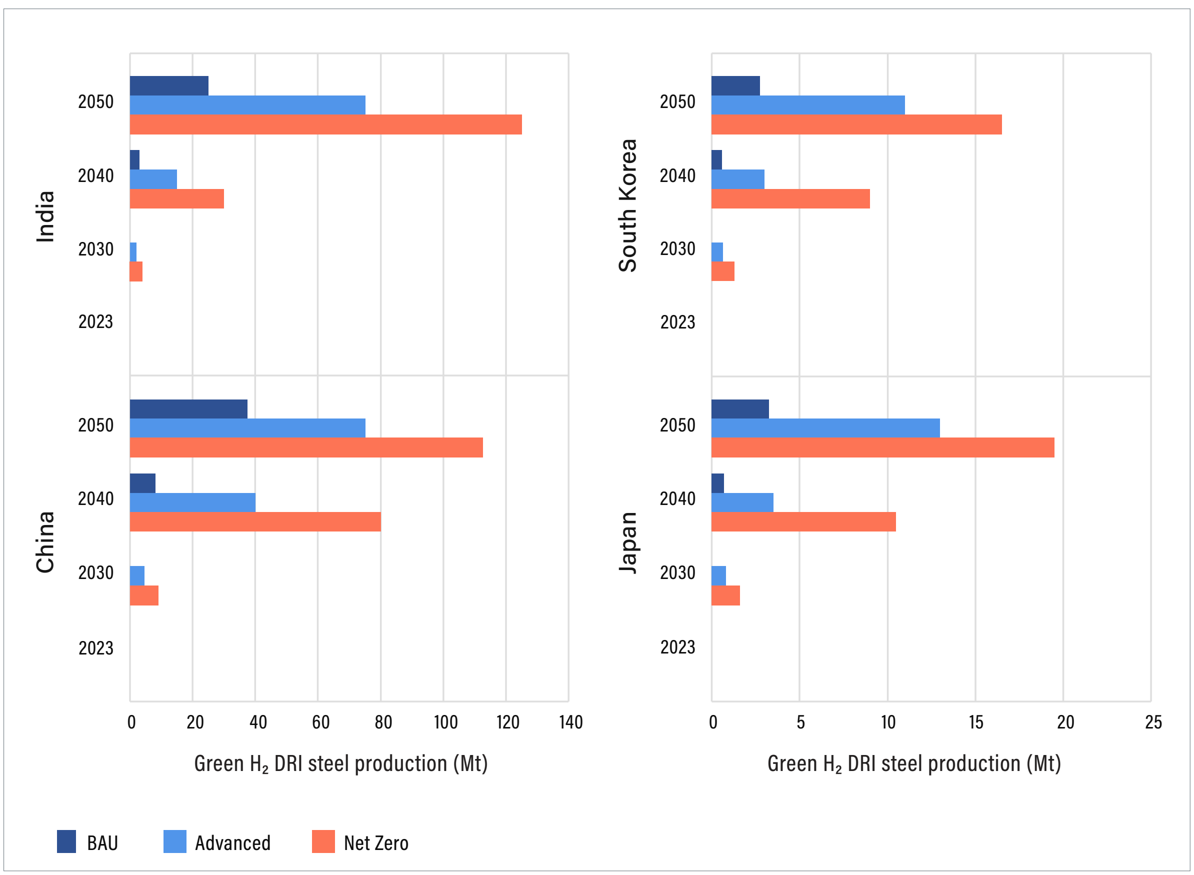
SECTOR-SPECIFIC ELECTROLYZER MARKET OPPORTUNITY

IRON AND STEEL INDUSTRY

The global steel industry emits more than 3.6 billion tonnes of CO_2 accounting for more than 7% of global GHG emissions and more than 11% of global CO_2 emissions. China, India, and Japan are the top three steel-producing countries in the world; South Korea ranks sixth. The shares of carbon-intensive blast furnace–basic oxygen furnace (BF-BOF) primary steelmaking in China, India, Japan, and South Korea are 90.5%, 46%, 73%, and 68%, respectively. It should be noted that in India a substantial portion of electric arc furnace (EAF) and induction furnace steelmaking is not using scrap and instead is using coal-based direct reduced iron, which is also a comparatively carbon-intensive production route.

The green H_2-DRI steel production across China, India, Japan, and South Korea is set to rise from 2023 to 2050, with the most substantial growth projected under the *declared net zero* scenario. In China, the *declared net zero* scenario forecasts green H_2 steel production to surge from 0 million tonnes (Mt) in 2023 to 112 Mt by 2050 accounting for 15% of the total production in China in that year. India's *declared net zero* scenario depicts

FIGURE 1 **GREEN H_2-DRI STEEL PRODUCTION IN EACH COUNTRY UNDER DIFFERENT SCENARIOS, 2023-2050**

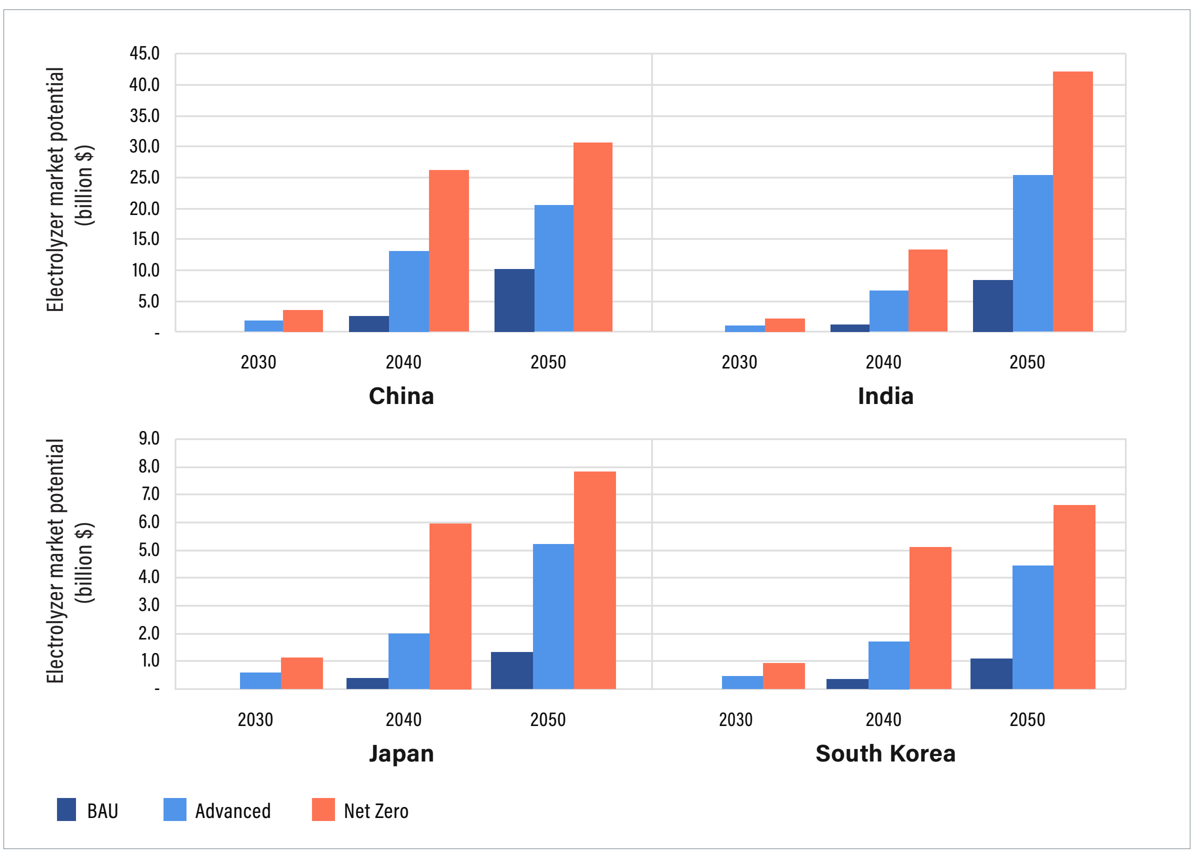


Note: The scale of the x-axis varies between the graphs.

a similar upward trend, with production anticipated to climb from 0 Mt in 2023 to 125 Mt by 2050, accounting for 25% of total production in India in that year. Japan's green H_2-DRI steel production is expected to see a rise to 19 Mt by 2050, and South Korea's production is projected to increase to 17 Mt in the same time frame under the *declared net zero* scenario. Under the *advanced* and *BAU* scenarios, smaller growth in green H_2-DRI steel production is assumed for each country.

In the *declared net zero* scenario, the electrolyzer market in China is anticipated to undergo substantial growth, with market potential forecasted to increase from $3.5 billion in 2030 to $30.7 billion by 2050, at a CAGR of 11%. This market expansion supports the corresponding rise in green H_2-DRI steel production, which is expected to soar from 9 Mt in 2030 to 112 Mt by 2050 in China in the *declared net zero* scenario. India's market potential for electrolyzers is set to surge from $2.2 billion in 2030 to $42.2 billion by 2050, with a CAGR of 16%, aligning with its projected green H_2-DRI steel production increase to 125 Mt in the same period in the *declared net zero* scenario. Japan's electrolyzer market potential is projected to grow from $1.1 billion to $7.8 billion, at a CAGR of 10% (2030–2050), supporting a rise in green H_2-DRI steel production to 19.5 Mt in 2050 under the *declared net zero* scenario. South Korea's market is also on an upward trajectory, expected to reach $6.6 billion by 2050, from $0.9 billion, growing at a CAGR of 10% (2030–2050), and steel production is anticipated to hit 17 Mt in 2050. One of the main reasons for the substantially higher growth rate in the electrolyzer market opportunity in India from 2030 to 2050 is the result of a significant growth in total steel production during that period, while the total steel production in China, Japan, and South Korea is expected to decline during the same period.

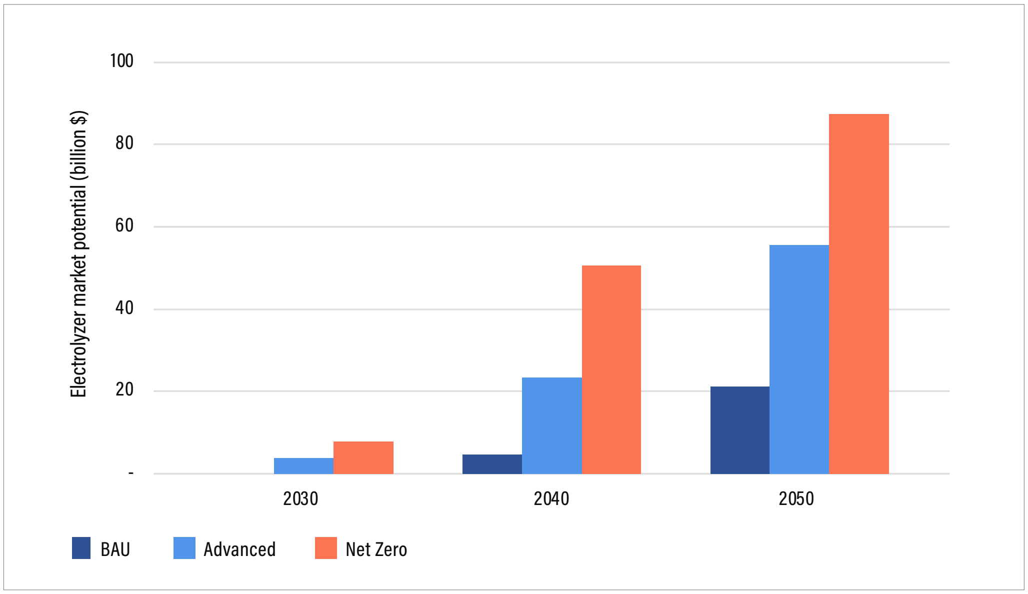
FIGURE 2 ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI STEELMAKING



Note: The scale of the y-axis varies between the graphs.

Collectively, the electrolyzer market potential across China, India, Japan, and South Korea is projected to expand from a total of $8 billion in 2030 to $87 billion by 2050, at a combined CAGR of 13% under the *declared net zero* scenario. The *advanced* scenario also depicts a remarkable upward trajectory, with the combined market potential of the four nations anticipated to increase from $4 billion in 2030 to $55 billion by 2050. These projections illustrate the expansive growth potential in the market for green H_2 technologies across these Asian countries to support green H_2-DRI steelmaking to decarbonize the steel industry.

FIGURE 3 **COMBINED ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI STEELMAKING IN CHINA, INDIA, JAPAN, AND SOUTH KOREA**

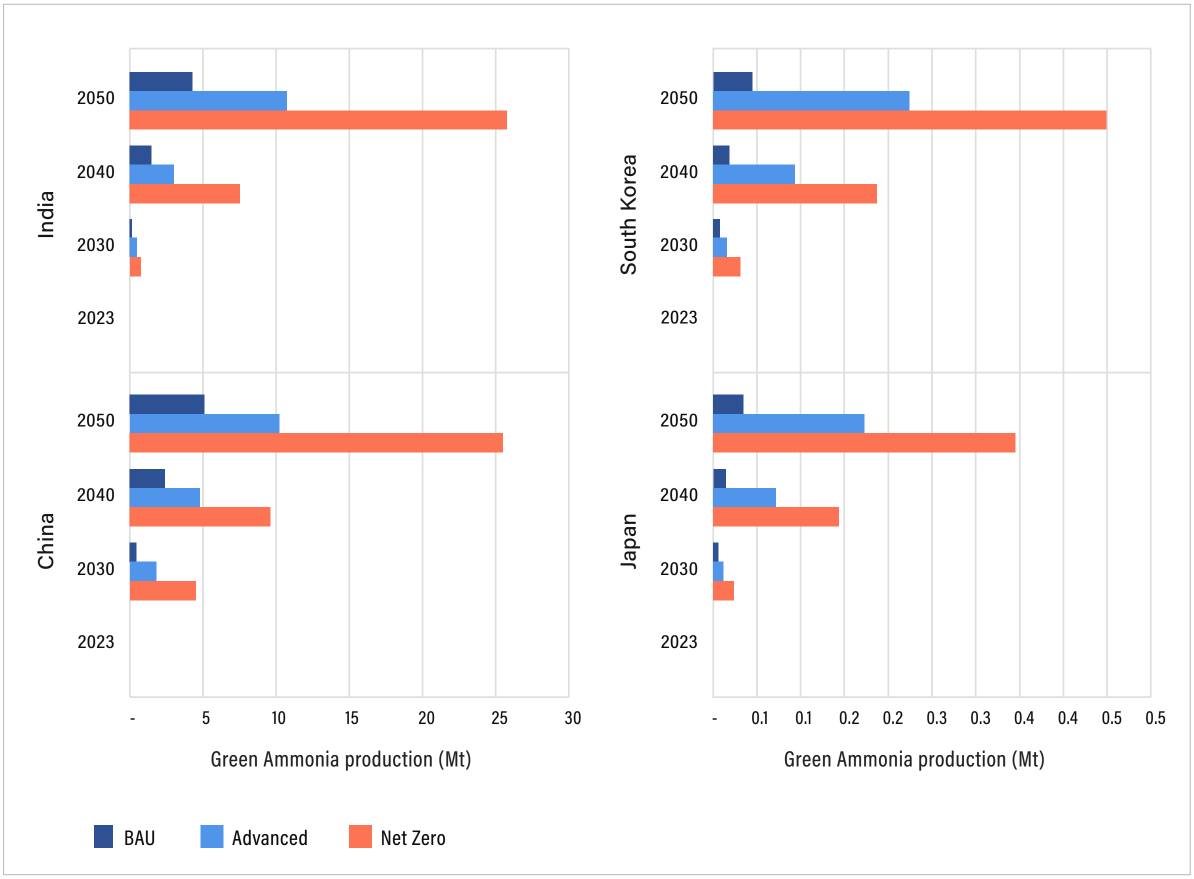


AMMONIA INDUSTRY

China is the largest producer and consumer of ammonia in the world with India ranking fourth. Japan and South Korea are not among the top 20 ammonia-producing countries, but each consumes more than a million tonnes of ammonia per year. Presently, all the ammonia production in these countries is derived from natural gas (through steam methane reforming) or coal (through coal gasification).

The production of green ammonia is set to rise significantly in China, India, Japan, and South Korea, with each country's growth trajectory mapped under different scenarios through 2050. For China, under the *declared net zero* scenario, ammonia production is projected to expand from 4.5 Mt in 2030 to 25.5 Mt by 2050, accounting for 50% of the total ammonia production in China in that year. India's net zero projections are similarly ambitious, with production estimated to grow from 0.8 Mt in 2030 to 25.8 Mt by 2050, accounting for 60% of total ammonia production in India in that year. In Japan, under the same scenario, green H_2 ammonia production is expected to increase from a modest 0.02 Mt in 2030 to 0.35 Mt by 2050, while South Korea's production is projected to rise to 0.45 Mt in 2050, with green H_2 ammonia accounting for 20% of the total ammonia production across both Japan and South Korea in that year. Smaller growth is projected under the *advanced* and *BAU* scenarios.

FIGURE 4 **GREEN AMMONIA PRODUCTION IN EACH COUNTRY UNDER DIFFERENT SCENARIOS, 2023-2050**

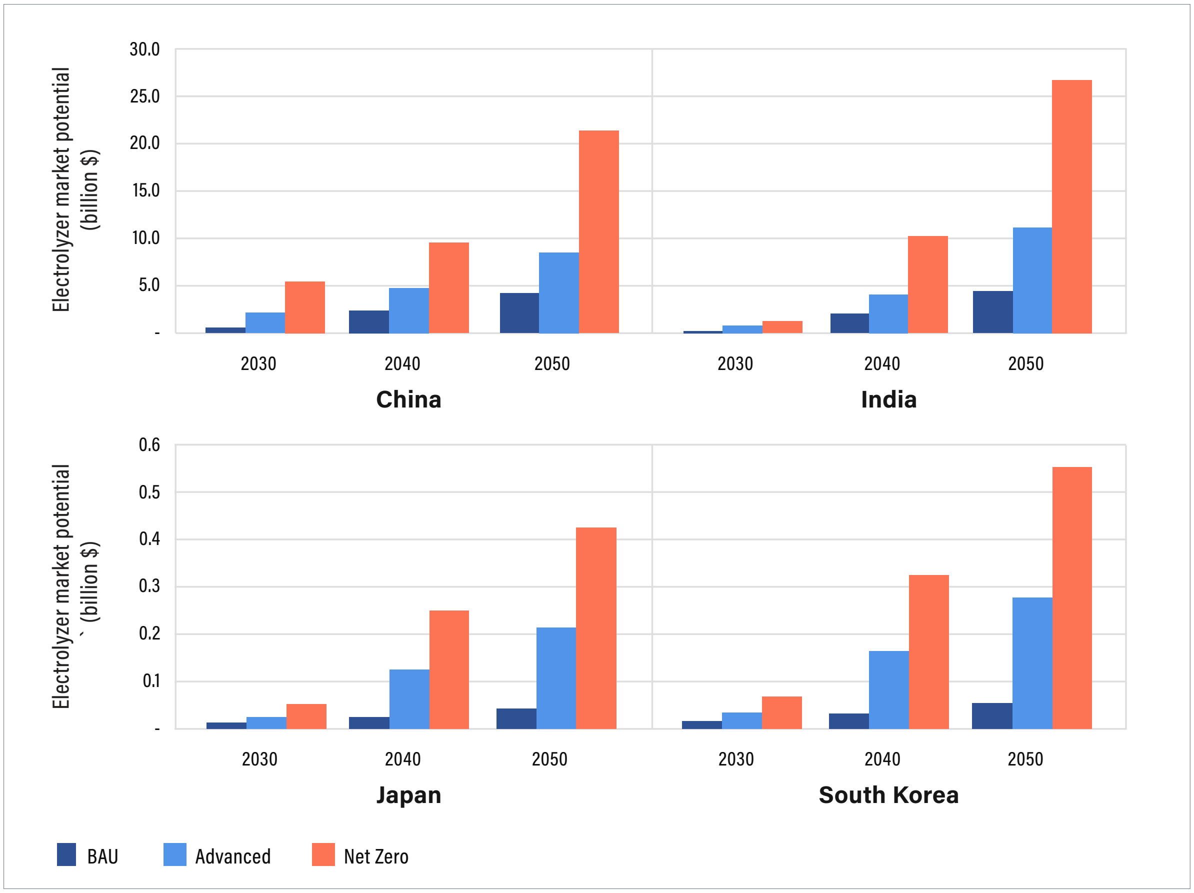


Note: The scale of the x-axis varies between the graphs.

The H_2 electrolyzer market in Asia, vital to producing green ammonia, is set to grow significantly under the *declared net zero* scenario. By 2050, China's electrolyzer market potential to supply green H_2 for ammonia production is expected to reach $21.4 billion, a growth underpinned by a CAGR of 7% from 2030 to 2050, to support an increase in green ammonia production from 4.5 Mt in 2030 to 25.5 Mt. India's market potential for electrolyzers to supply green H_2 for ammonia production is projected to grow to $26.7 billion in 2050, with a CAGR of 16% (2030–2050), in alignment with its anticipated green ammonia production surge to 25.8 Mt in 2050 under the *declared net zero* scenario. Japan and South Korea see their electrolyzer market potential to supply green H_2 for ammonia production reaching $0.4 billion and $0.6 billion, contributing to a growth in green ammonia production to 0.35 Mt and 0.45 Mt, respectively, in 2050 under the *declared net zero* scenario.

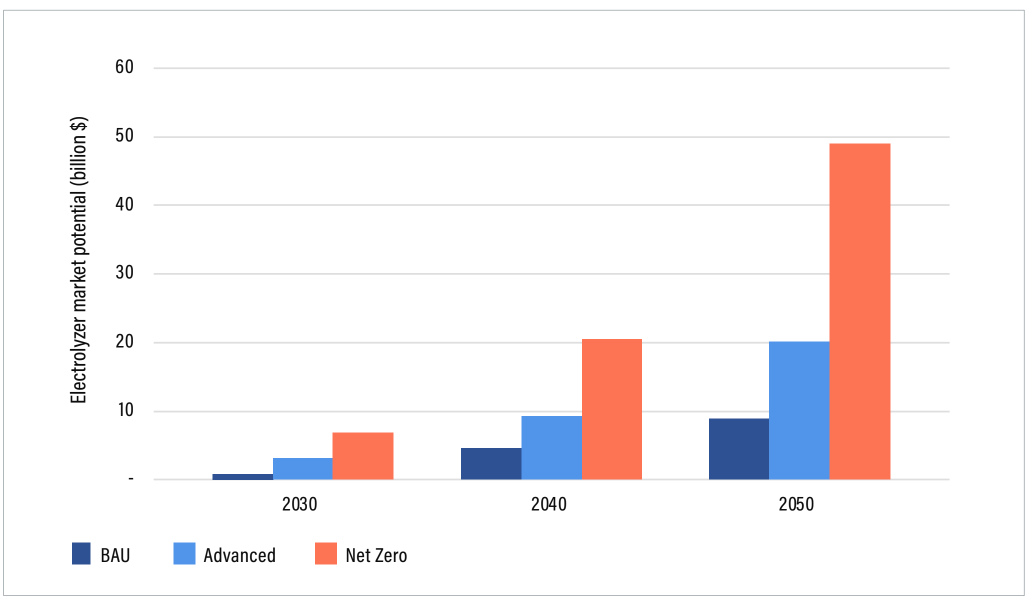
Combined, the electrolyzer market potential to supply green H_2 for ammonia production in China, India, Japan, and South Korea is forecasted to increase from $7 billion in 2030 to $49 billion by 2050, demonstrating a combined CAGR of 10% under the *declared net zero* scenario. This substantial growth reflects the huge potential for electrolyzers in the ammonia sector that could be supported by technological advancements, policy incentives, and the rising demand for green ammonia, mostly to produce low-carbon fertilizer.

FIGURE 5 ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H2 FOR AMMONIA PRODUCTION



Note: The scale of the y-axis varies between the graphs.

FIGURE 6 COMBINED ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR AMMONIA PRODUCTION IN CHINA, INDIA, JAPAN, AND SOUTH KOREA

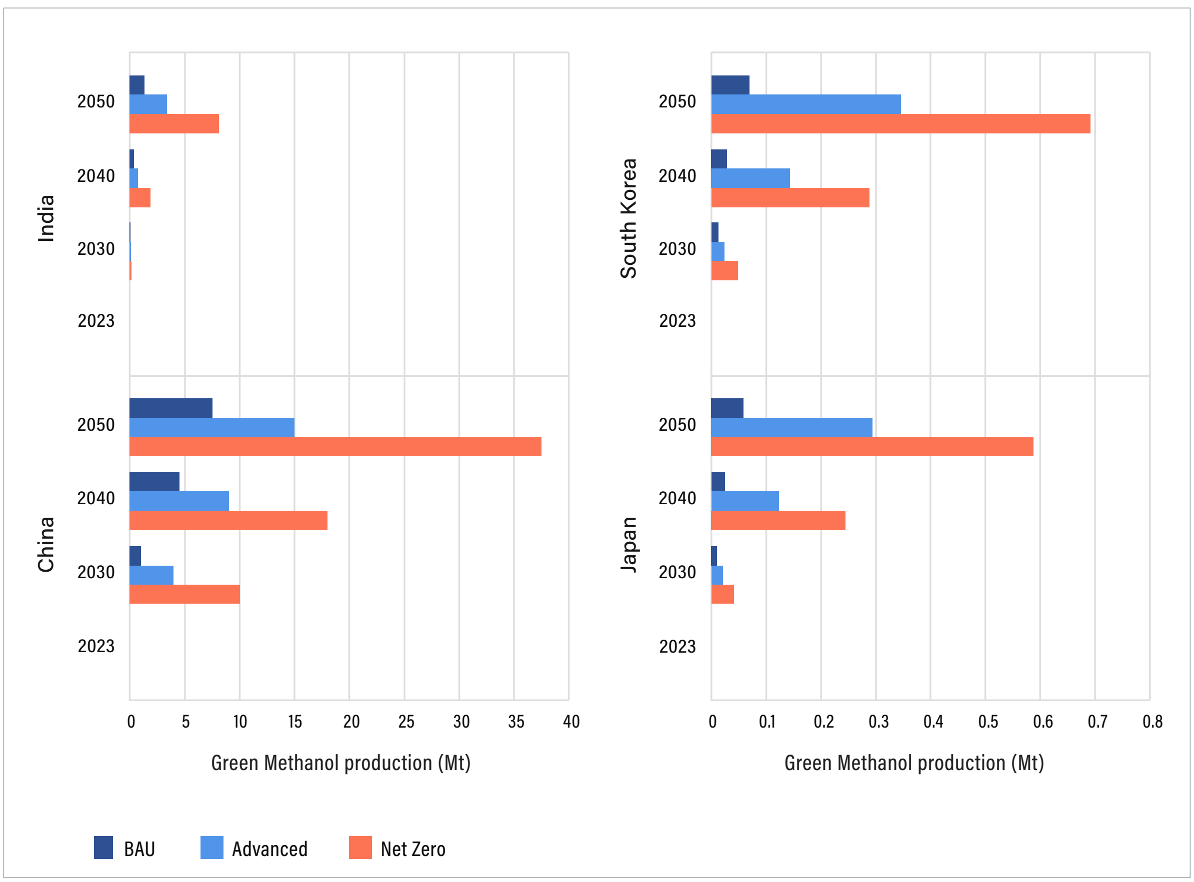


METHANOL INDUSTRY

China is the largest consumer of methanol and one of the top producers in the world. India, Japan, and South Korea are not among the top methanol-producing countries, but India consumes more than 2.8 Mt/year while Japan and South Korea consume 1.7 Mt/year and 2 Mt/year, respectively. Currently, all methanol production in these countries is derived from fossil fuels.

Green H_2 is set to play a crucial role in the low-carbon production of methanol in China, India, Japan, and South Korea, with projections extending to 2050. In China, the *declared net zero* scenario suggests an ambitious growth in green methanol production from 10 Mt in 2030 to 37.5 Mt by 2050, accounting for 50% of the total methanol production in China in that year. India, following suit in the net zero commitment, is expected to see production rise from 0.1 Mt in 2030 to 8 Mt by 2050, accounting for 60% of total methanol production in India in that year. Japan's focus on green practices in the *declared net zero* scenario forecasts an increase from 0.04 Mt in 2030 to 0.6 Mt by 2050, while South Korea anticipates a jump to 0.7 Mt in the same period, accounting for 20% of the total methanol production in Japan and South Korea in 2050. Even under the *advanced* scenario, all four countries are expected to experience substantial growth in green methanol production by 2050.

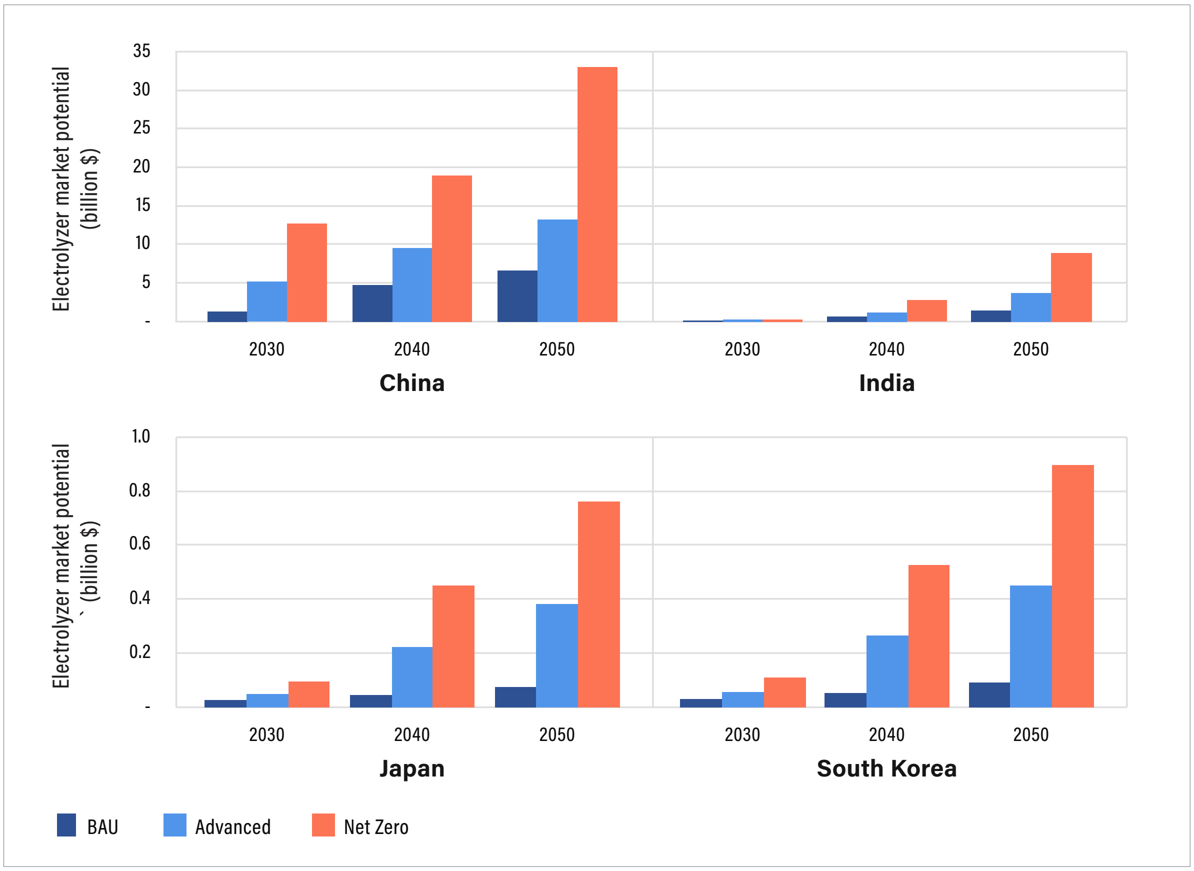
FIGURE 7 **GREEN METHANOL PRODUCTION IN EACH COUNTRY UNDER DIFFERENT SCENARIOS, 2023-2050**



Note: The scale of the x-axis varies between the graphs.

For the methanol sector, the electrolyzer market under the *declared net zero* scenario is forecasted to expand significantly in Asia, facilitating the production of green methanol. By 2050, China is expected to see its electrolyzer market potential to supply green H_2 for methanol production escalate to $33 billion, corresponding to a CAGR of 5% from 2030 to 2050, supporting an increase in green methanol production from 10 Mt in 2030 to 38 Mt in the *declared net zero* scenario. India's electrolyzer market is projected to grow to $8.8 billion, with a CAGR of 20% from 2030 to 2050, paralleling a rise in green methanol production to 8 Mt. In Japan and South Korea, the market potential is expected to reach $0.8 billion and $0.9 billion in 2050 under the *declared net zero* scenario.

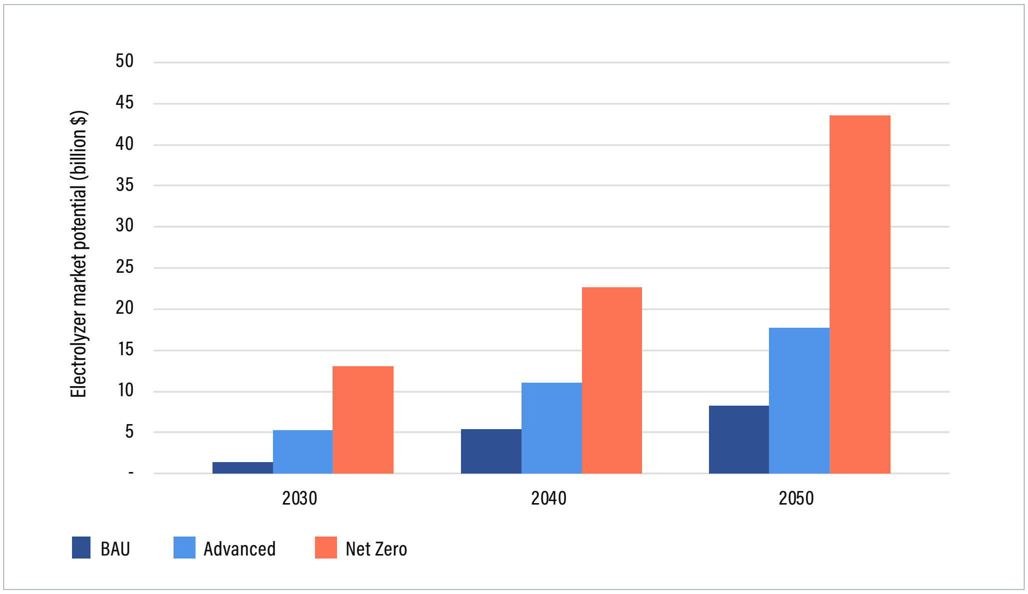
FIGURE 8 **ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR METHANOL PRODUCTION**



Note: The scale of the y-axis varies between the graphs.

When consolidating the market potentials of these four nations, the collective projection under the *declared net zero* scenario anticipates a total electrolyzer market potential to supply green H_2 for methanol production that expands from $13 billion in 2030 to $43 billion by 2050. The *advanced* scenario, while not as pronounced as the *declared net zero* scenario, still signals sizable growth, with the total market potential for the four countries expected to grow from $5 billion in 2030 to $18 billion by 2050. These figures clearly show a robust potential and the increasing adoption of green H_2 technologies within the methanol sector, in line with the global efforts toward net zero emissions in the industry sector.

FIGURE 9 **COMBINED ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR METHANOL PRODUCTION IN CHINA, INDIA, JAPAN, AND SOUTH KOREA**

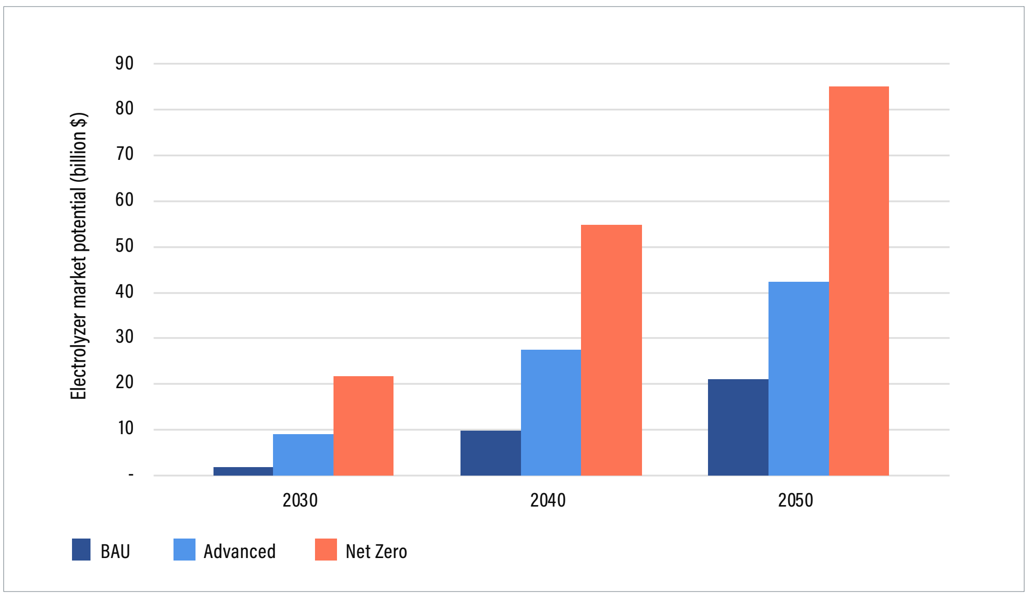


COUNTRY-SPECIFIC ELECTROLYZER MARKET OPPORTUNITY

CHINA

In China, the total electrolyzer market potential to supply green H_2 for H_2-DRI, green ammonia, and green methanol production is projected to experience remarkable growth, particularly under the *declared net zero* and *advanced* scenarios, driven by the projected increase in the production of H_2-DRI steel, green ammonia, and green methanol. Under the *declared net zero* scenario, the electrolyzer market potential is anticipated to soar from $22 billion in 2030 to an impressive $85 billion by 2050, with a CAGR of 7% from 2030 to 2050. This growth in electrolyzer market potential is to support 112 Mt H_2-DRI steelmaking, 25 Mt green ammonia production, and 38 Mt green methanol production in China in 2050 under the *declared net zero* scenario.

FIGURE 10 **TOTAL ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI, GREEN AMMONIA, AND GREEN METHANOL PRODUCTION IN CHINA**

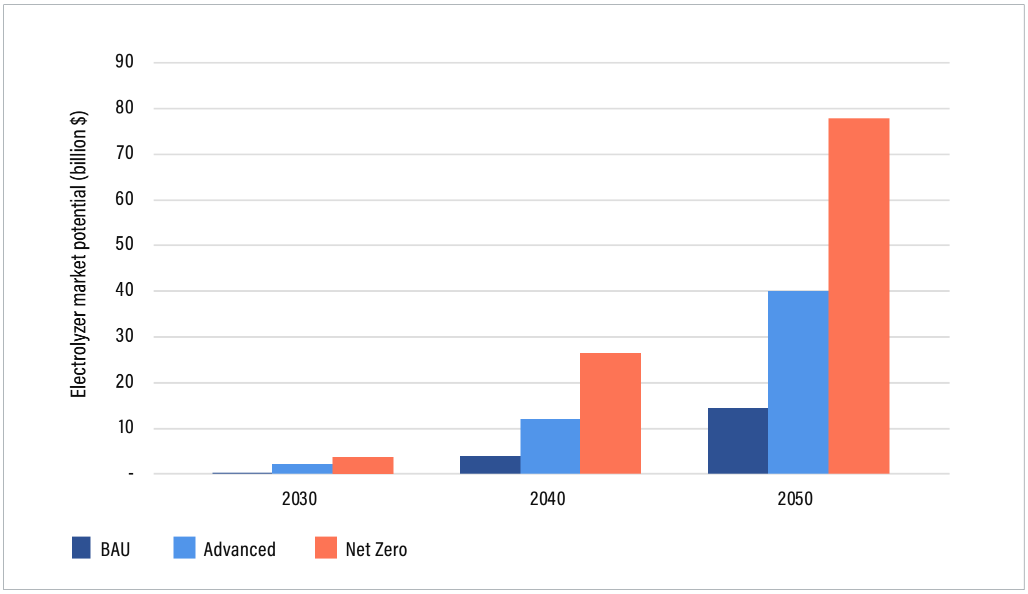


This expansion in the H_2 electrolyzer market within China for these three sectors is attributed to several factors. There is a national target toward decarbonization, supported by government policies and investments in renewable energy infrastructure. Additionally, technological advancements in electrolyzer efficiency and the scaling of green H_2 applications across various industries contribute to this growth. As China moves toward its target of carbon neutrality by 2060, the demand for green H_2 as a reductant for H_2-DRI steelmaking and feedstock for green ammonia and methanol production is expected to increase, further stimulating the electrolyzer market.

INDIA

India's electrolyzer market, essential for supplying green H_2, is expected to witness an exponential increase, particularly under the *declared net zero* scenario, as the country advances its manufacturing of green H_2-DRI steel, green ammonia, and green methanol. By 2050, the *declared net zero* scenario projects the electrolyzer market potential in India only to supply green H_2 for H_2-DRI, green ammonia, and green methanol production to reach $78 billion, an increase from $4 billion in 2030, progressing at a CAGR of 16% during this period. The expansion of the electrolyzer market is poised to underpin India's substantial production increase of 125 Mt for H_2-DRI steel, 25 Mt for green ammonia, and 8 Mt for green methanol by 2050 under the *declared net zero* scenario.

FIGURE 11 **TOTAL ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI, GREEN AMMONIA, AND GREEN METHANOL PRODUCTION IN INDIA**



JAPAN

Japan's electrolyzer market potential for green H_2, crucial for transitioning H_2-DRI, ammonia, and methanol production to cleaner processes, is also projected to grow notably, particularly under the *declared net zero* scenario. By the year 2050, the *declared net zero* scenario is expected to see the market potential in Japan increase to $9 billion. This progression is anticipated with a CAGR of 10% from 2030 to 2050. As Japan faces more challenges to produce domestic renewable electricity to support its domesic green H_2 production, more moderate assumptions were made for the production of green H_2 in Japan compared to those for China and India. In Japan's *declared net zero* scenario, the projected growth in the electrolyzer market is anticipated to support the production of 19 Mt of H_2-DRI steel, 0.35 Mt of green ammonia, and 0.6 Mt of green methanol in 2050.

FIGURE 12 **TOTAL ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI, GREEN AMMONIA, AND GREEN METHANOL PRODUCTION IN JAPAN**

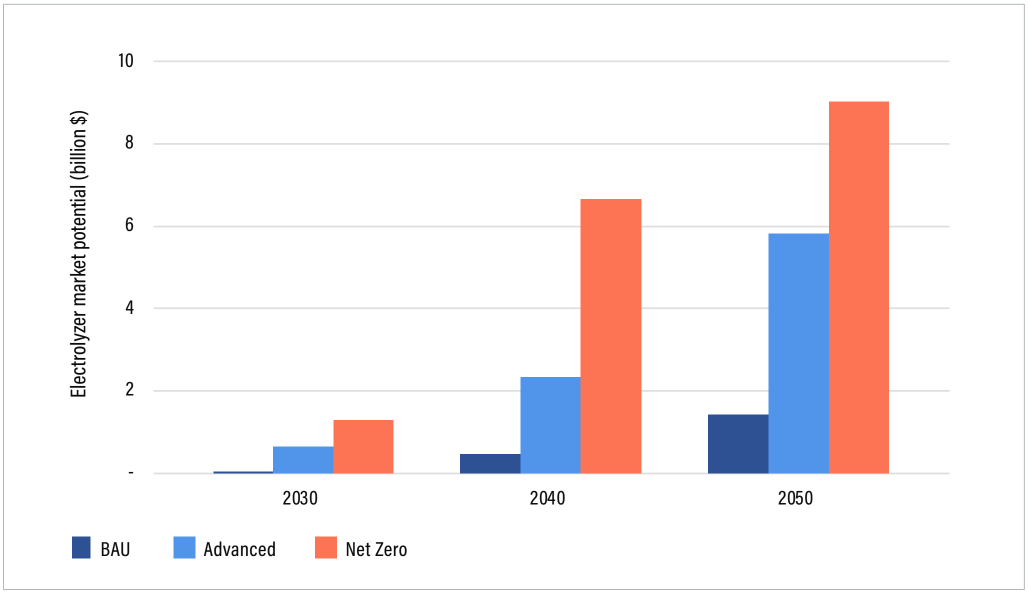
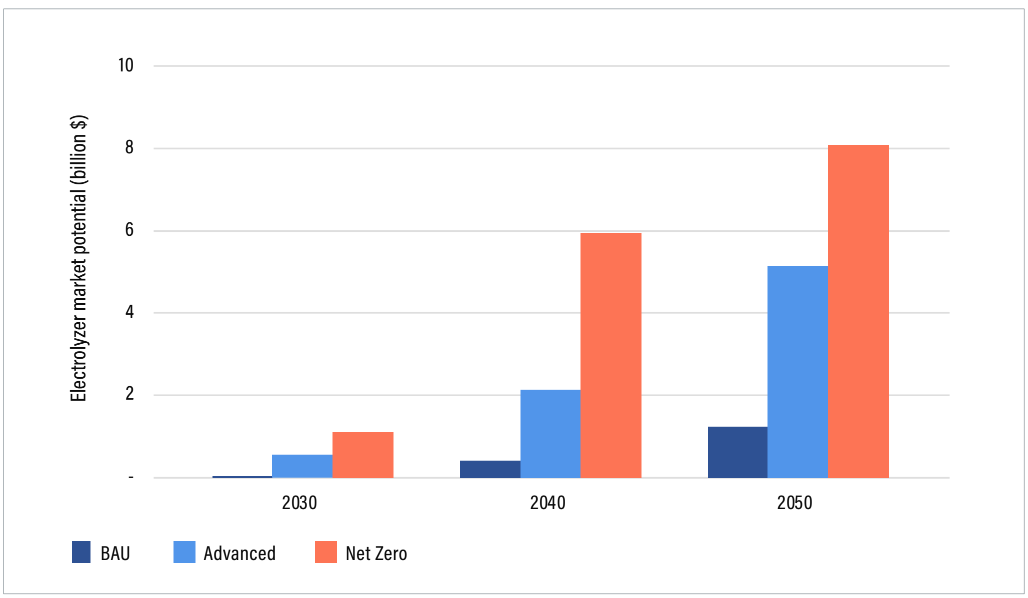


FIGURE 13 **TOTAL ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI, GREEN AMMONIA, AND GREEN METHANOL PRODUCTION IN SOUTH KOREA**



SOUTH KOREA

In South Korea, the electrolyzer market to support the production of green H_2 for industries such as H_2-DRI steelmaking, green ammonia, and methanol, is projected to witness growth similar to that of Japan. Under the *declared net zero* scenario, the market potential is forecasted to rise from $1 billion in 2030 to $8 billion by

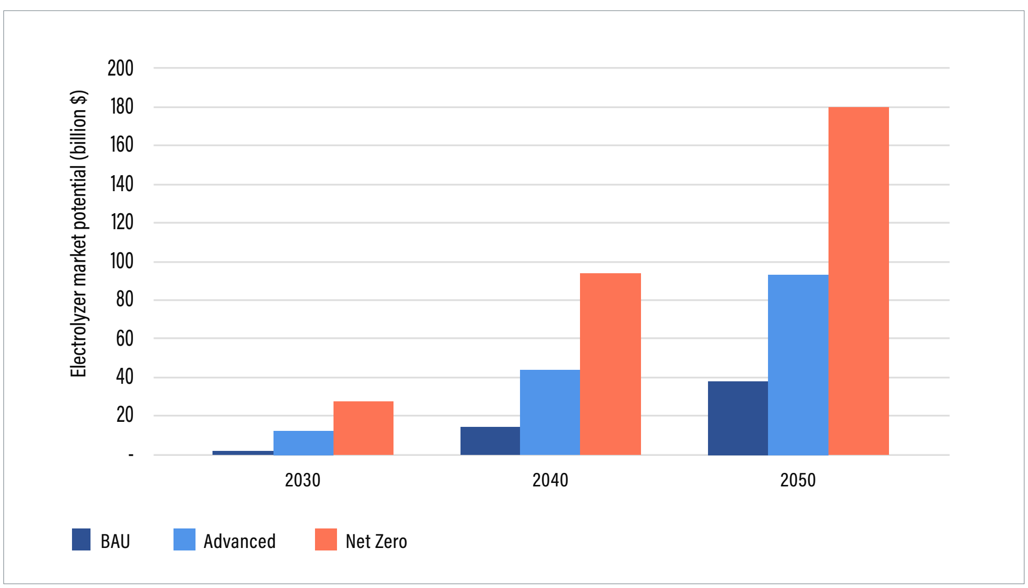
2050. This reflects a CAGR of 10% from 2030 to 2050, signaling robust growth during this period. Like Japan, given the constraints in domestic renewable electricity generation capabilities, South Korea's forecasts for green H_2 production are slightly conservative. This approach considers the unique challenges the country faces in scaling up its green energy infrastructure to meet the demands of H_2 production, resulting in more measured assumptions about its future green H_2 output relative to the relatively more aggressive projection targets for China and India under the *declared net zero* scenario. The anticipated growth of the electrolyzer sector is set to support South Korea's escalating production of 17 Mt of H_2-DRI steel, 0.45 Mt of green ammonia, and 0.7 Mt of green methanol by 2050, to support the nation's net zero target.

TOTAL MARKET POTENTIAL

Across China, India, Japan, and South Korea, the collective market potential for electrolyzers vital for green H_2 production is on an impressive upward swing, with the *declared net zero* scenario illustrating the most substantial growth. By 2050, under this *declared net zero* scenario, the total market potential is expected to dramatically increase to $180 billion. This significant growth is characterized by a CAGR of 12% from 2030 to 2040, which then adjusts to 8% from 2030 to 2050, indicative of an aggressive scale-up followed by more stable growth as the technologies become widespread.

In the *advanced* scenario, the collective market potential is also predicted to witness remarkable growth, climbing from $12 billion in 2030 to $93 billion by 2050. The *BAU* scenario, representing the most conservative growth pattern, nonetheless forecasts considerable growth, projecting the market potential to reach $38 billion by 2050, up from $2 billion in 2030. These projections underscore the significant economic opportunities presented by the transition to green H_2 in these pivotal Asian economies, driven by a combination of policy initiatives, technological advancements, and increasing demand for low-carbon products and industrial decarbonization.

FIGURE 14 **TOTAL ELECTROLYZER MARKET POTENTIAL TO SUPPLY GREEN H_2 FOR H_2-DRI, GREEN AMMONIA, AND GREEN METHANOL PRODUCTION IN CHINA, INDIA, JAPAN, AND SOUTH KOREA**



ASIAN MANUFACTURING CAPABILITY AND GREEN H_2 OPPORTUNITIES

This section looks into the landscape of green H_2 production and electrolyzer manufacturing across these four Asian countries, spotlighting the strategic initiatives and technological advancements underway in China, India, Japan, and South Korea. Each subsection offers a unique glimpse into how these countries are navigating the green H_2 terrain—China's ambitious scaling of electrolyzer capacity amid global market dynamics, India's emerging status fueled by policy incentives and inherent cost advantages, Japan's technological edge aiming for a significant share in the global market, and South Korea's ambitious targets for technological development and green H_2 production capabilities. We discuss the diverse approaches these nations are adopting to secure a pivotal role in the green H_2 economy, highlighting their efforts to balance domestic needs with global market opportunities, the development of local manufacturing capabilities, and the enactment of policies to foster growth and innovation in this critical sector.

CHINA

China is on track to significantly build its H_2 electrolyzer manufacturing capacity. Chinese manufacturers have historically focused on alkaline electrolyzer technology due to its cost-effectiveness. However, there is a growing shift toward developing PEM technology, despite the higher costs associated with precious metals including platinum used in PEM electrolyzers. This shift is partly driven by the global push toward more efficient and responsive green H_2 production technologies.

China has ambitious growth goals in green H_2 production. The Green Hydrogen Energy Plan set an installed electrolyzer capacity target of 80 GW by 2030. This is supported by the expected decrease in renewable energy costs and advancements in electrolyzer technology and economies of scale in the cost of electrolyzers, contributing to making green H_2 cost-competitive with grey H_2 and black H_2, which are produced via fossil fuels.

China's dominance in the electrolyzer market, particularly in alkaline technology, coupled with its aggressive expansion plans, poses a challenge to global competition. The focus on quantity over R&D for next-generation technologies is a concern that may hinder technological diversity and innovation in the long term. However, recent investments in PEM technology and large-scale green H_2 projects indicate a shift toward addressing these challenges.

China's strategy to increase its electrolyzer manufacturing capacity aims to establish a dominant position in the global market, potentially affecting global pricing and supply chains. This positions China as a key player in the green H_2 economy, potentially leading to significant employment opportunities within China in this sector.

China's approach to green H_2 and electrolyzer production is influenced by national policies focusing on decarbonization and renewable energy adoption. The significant investment in renewable energy infrastructure and green H_2 projects underscores the government's commitment to achieving carbon neutrality by 2060. In March 2022, the Chinese government unveiled a comprehensive plan for the development of green H_2 energy spanning from 2021 to 2035, outlining ambitious goals to propel the country into leadership in the green H_2 sector by 2035. This strategy encompasses the creation of a centralized innovation platform for the

R&D of cutting-edge green H_2 technologies; the expansion of hydrogen energy infrastructure including production, storage, and transportation; and the promotion of hydrogen use across transport, energy storage, and heavy industries. Furthermore, the plan calls for the establishment and refinement of policies related to hydrogen infrastructure construction and the pricing of electricity for green H_2 production, alongside setting standards for hydrogen quality, safety, infrastructure, and applications.

INDIA

India's green H_2 and electrolyzer market is in an early stage but poised for significant growth. The country's ambition to enhance green H_2 production capacity to 5 Mt per year by 2030 underpins a concerted effort to scale up electrolyzer manufacturing. India's strategy involves leveraging its cost advantages and strong policy frameworks to catalyze domestic electrolyzer production, aimed at not only fulfilling domestic needs but also tapping into export markets, given the cost competitiveness of Indian-made electrolyzers against global counterparts.

Supply chain development for electrolyzers in India is currently focused on building domestic manufacturing capabilities to reduce dependency on imports. The government's Production Linked Incentive (PLI) scheme for electrolyzer manufacturing under the Strategic Interventions for Green Hydrogen Transition (SIGHT) aims to stimulate local production. India's inherent advantages in labor and material costs are instrumental in its strategy to position itself as a global hub for electrolyzer manufacturing, mirroring the country's previous success in the IT and solar PV sectors.

India's National Green Hydrogen Mission outlines a vision for an H_2 economy, with specific emphasis on green H_2. The mission, which is the January 2023 update to a policy first announced in 2021, includes ambitious targets for electrolyzer capacity and green H_2 production, supported by financial incentives for domestic manufacturing and deployment of electrolyzers. The government's commitment is further underscored by proposals for large-scale demonstration projects to accelerate the adoption of green H_2 in various sectors, including refineries, ammonia/fertilizer production, methanol production, and the steel industry.

The focus on establishing a domestic electrolyzer manufacturing ecosystem is expected to lower costs and improve the competitiveness of green H_2 in India. The country's cost structure and policy environment present a unique opportunity to become a significant player in the global electrolyzer market, potentially rivaling China's dominant position. India's $2.1 billion initiative to foster local electrolyzer manufacturing and green H_2 production has garnered keen interest from large companies, signaling a positive start to the country's green H_2 ambitions. The SIGHT program, although a crucial move, requires further refinement to broaden its appeal to startups and global entities. Incentives and policy support are projected to reduce the levelized cost of green H_2 in India significantly, by up to 40%. The scheme promises to lower system costs for electrolyzer manufacturers initially, but adjustments are needed for long-term investment appeal and project sustainability.

The push for green H_2 is anticipated to create substantial market value within India, fostering new opportunities in manufacturing, R&D, and ancillary services. Employment prospects in the sector are high, given the government's focus on skill development and job creation within the renewable energy and green H_2 domains.

Key policies influencing India's green H_2 trajectory include the PLI scheme, which directly supports electrolyzer manufacturing, and the broader National Green Hydrogen Mission. These policies are designed to accelerate India's transition to a low-carbon economy, with green H_2 playing a pivotal role. Additionally, collaborations with international partners and investment in R&D are likely to enhance India's technological capabilities and global competitiveness in green H_2 production.

JAPAN

Japan aims to secure a 10% share of the global electrolyzer market by 2030, with a strategic focus on enhancing its domestic electrolyzer production capabilities. The country has set a target to deploy 15 GW of H_2 electrolyzer capacity by 2030, involving Japanese-related companies both domestically and globally. This ambitious goal underlines Japan's effort to leverage its technological edge and manufacturing heritage to scale up the production of green H_2 via electrolysis.

Japan is concentrating efforts on advancing electrolyzer technologies, specifically alkaline, PEM, and SOEC (solid oxide electrolyzer cells). The nation's strategy emphasizes reducing the cost of H_2 electrolyzer systems by 75% and pursuing enhanced technical specifications. Through collaborations between industry giants and research institutions, Japan is working to overcome current technological limitations and achieve significant cost reductions in electrolyzer production.

The Japanese government's H_2 strategy, encapsulated in the Basic H_2 Strategy, the Green Growth Strategy, and the 6th Strategic Energy Plan, aims to create an "H_2 society." This vision is supported by considerable budget allocations and the establishment of the Green Innovation Fund, which dedicates substantial resources to green H_2 projects. The Fukushima H_2 Energy Research Field (FH_2R) was the world's largest green H_2 production facility when launched in 2020.

Despite limited domestic renewable energy resources, Japan is actively exploring international supply chains to ensure a steady supply of green H_2 for its domestic market. The country's strategy also involves developing large-scale H_2 electrolyzer technologies to enhance green H_2 production capabilities.

Japan's policies are designed to foster innovation, reduce costs, and accelerate the adoption of green H_2. The government's financial incentives, including the Green Innovation Fund and specific allocations for H_2 projects, aim to stimulate private R&D and investment. Additionally, Japan's international collaborations and efforts to standardize H_2 technologies further solidify its position in the global H_2 economy.

SOUTH KOREA

South Korea has set ambitious targets for the development and deployment of H_2 electrolyzer technology, aiming to establish itself as a key player in the H_2 sector. The country plans to develop and demonstrate 100 MW–class H_2 electrolyzer technology. South Korea's strategy encompasses significant investment in electrolyzer technology development, including high-efficiency alkaline, PEM, and SOEC. Efforts to enhance the domestic supply chain for electrolyzer components are crucial to this strategy.

The South Korean government has outlined a comprehensive roadmap to foster the growth of the H_2 economy, with a particular focus on green H_2. This includes significant financial investment in R&D, as well as the establishment of pilot projects to demonstrate the viability and scalability of green H_2 technologies. The government's plan also emphasizes international collaboration and the development of policy frameworks to support the H_2 industry's expansion.

While the country's current green H_2 production is low, it is set to increase with the government's push for renewable energy–powered electrolysis. South Korea is actively working on improving electrolyzer efficiency and reducing production costs, which are essential steps toward making green H_2 a competitive alternative to fossil fuels and for South Korean electrolyzers to compete in the market.

The development of the green H_2 sector in South Korea is expected to create substantial market value, driving innovation and creating job opportunities across various segments of the economy. The government's investment in green H_2 and electrolyzer technology is poised to enhance South Korea's position in the global market, contributing to the country's economic growth and competitiveness.

South Korea's H_2 policy framework, including its H_2 Economy Roadmap and subsequent updates, provides a strategic direction for the sector's development. Key policy measures, such as financial incentives for R&D, support for domestic manufacturing of electrolyzers, and the establishment of green H_2 production targets, are instrumental in driving the country's transition to an H_2 economy. Additionally, policies aimed at increasing the use of H_2 in various industries, including the steel and chemical sectors, further catalyze the growth of the green H_2 sector.

RECOMMENDATIONS

This section lists a suite of recommendations aimed at accelerating the development and adoption of green H_2 and electrolyzer technologies in these four major Asian economies. These targeted strategies for policymakers, industry players, investors, and think tanks collectively support a robust ecosystem for green H_2 production and use in these countries especially, though they may also be applicable to countries not included in this study. By implementing supportive regulatory frameworks, investing in research and innovation, creating targeted financial incentives, and promoting international cooperation, these countries can move toward an economically viable green H_2 economy. The recommendations not only address technological advancements and market expansion but also emphasize education, workforce development, and environmental sustainability, marking a significant step toward decarbonizing key industrial sectors and transitioning toward a net zero emissions industry.

RECOMMENDATIONS FOR POLICYMAKERS

- **Develop guidelines for the appropriate use of hydrogen in industry:** Governments should establish clear guidelines to ensure the strategic deployment of H_2 within the industrial sector, aiming to maximize its contribution to decarbonization. These guidelines should critically assess where hydrogen use is most beneficial and environmentally sustainable, particularly in processes in which direct electrification is less feasible or efficient. The aim is to avoid the "hydrogen hype" by preventing investments in hydrogen applications when other solutions, such as direct electrification, offer a clearer path to decarbonization. This approach would help prioritize green hydrogen use in areas such as H_2-DRI steelmaking, green ammonia and green methanol production, and other sectors where black and/or grey H_2 is currently being used. This ensures that hydrogen deployment aligns with broader net zero goals and efficiency principles.
- **Implement and enhance supportive regulatory frameworks:** Develop and refine regulations that encourage the adoption of green H_2 and electrolyzer technologies. This includes providing incentives for green H_2 use in industrial processes; streamlining approval processes for new projects; and establishing clear standards for hydrogen purity, safety, and infrastructure.
- **Invest in research and development:** Allocate significant resources to R&D in advanced electrolyzer technologies, focusing on increasing efficiency, reducing costs, and enabling the integration with renewable energy sources. Support collaborative projects between research institutions and industry to foster innovation.
- **Create targeted financial incentives:** Introduce subsidies, tax credits, and other financial mechanisms to lower the investment risk for green hydrogen projects and electrolyzer manufacturing. These could include incentives for domestic production of electrolyzers to build local supply chains and reduce dependencies on imports.
- **Promote international cooperation:** Engage in bilateral and multilateral agreements to share knowledge, technologies, and best practices for green hydrogen production and use. This includes participation in international forums and initiatives focused on hydrogen economy standards and policies.
- **Establish dedicated green H_2 hubs:** Develop and support the creation of regional green H_2 ecosystems that bring together manufacturing, R&D, and application of green H_2 within specific suitable geographical zones, offering infrastructure, tax benefits, and regulatory support to attract investments.

- **Promote education and workforce development:** Launch educational and vocational training programs specifically designed to develop skills in green H_2 and electrolyzer technology fields, addressing the current and future needs of the industry workforce.
- **Set clear decarbonization targets for industries:** Introduce specific mandates for carbon-intensive industries such as the steel, chemical, and petrochemical industries to incorporate green H_2 into their processes as a low-carbon reductant (in steelmaking) or low-carbon feedstock (in the chemical industry), providing a clear demand signal for green H_2 production and utilization, thus stimulating the market.
- **Facilitate access to renewable energy:** Implement policies that ensure electrolyzer operations have priority access to renewable energy sources at competitive prices, encouraging the coupling of electrolyzer infrastructure with renewable energy projects.
- **Introduce standards for green H_2 certification:** Develop a certification scheme for green H_2 to ensure transparency regarding the environmental credentials of H_2 used in various sectors.

RECOMMENDATIONS FOR INDUSTRY AND ELECTROLYZER MANUFACTURERS

- **Invest in capacity building:** Expand manufacturing capabilities to meet the growing demand for electrolyzers, focusing on scaling production and achieving economies of scale to reduce costs. This includes investing in automated manufacturing processes and quality control.
- **Innovate in product development:** Prioritize the development of next-generation electrolyzer technologies that offer higher efficiencies, lower costs, and better integration with intermittent renewable energy sources. Explore the potential of emerging technologies such as solid oxide electrolyzers for high-temperature applications.
- **Strengthen supply chains:** Develop robust supply chains for critical materials and components needed for electrolyzer manufacturing. This involves diversifying sources of raw materials and investing in recycling technologies to reduce reliance on scarce resources.
- **Enhance collaboration:** Engage in partnerships with energy companies, industrial users (e.g., steel or chemicals sectors), and technology providers to create integrated solutions for green H_2 production and use. Collaborate on pilot projects to demonstrate the viability and scalability of green H_2 in various sectors.
- **Adopt digitalization and IoT technologies:** Leverage digital technologies to optimize the operation of electrolyzers, including predictive maintenance, operational efficiency, and integration with renewable energy sources, enhancing overall performance and reliability.
- **Pursue technological diversification:** Invest in a broad portfolio of electrolyzer technologies to cater to different market needs, including low-temperature PEM electrolyzers for flexibility and high-temperature SOEC for efficiency in large-scale applications.

RECOMMENDATIONS FOR INVESTORS

- **Identify and support high-potential projects:** Focus on investments in projects and companies that are at the forefront of electrolyzer technology innovation and green H_2 production. This includes startups with breakthrough technologies and established players expanding their green H_2 activities.

- **Promote risk-sharing mechanisms:** Participate in public-private partnerships and financing consortia that share the investment risks associated with early-stage green H_2 projects. Consider the use of green bonds and other innovative financing instruments to raise capital for large-scale projects.
- **Evaluate long-term potential:** Assess investment opportunities not only based on current returns but also considering the long-term potential of the green H_2 market and the role of electrolyzers in decarbonizing key industrial sectors.
- **Support innovation in electrolyzer design and materials:** Invest in companies and startups that focus on innovative electrolyzer technologies, including advanced materials and design approaches that promise higher efficiency and lower costs.
- **Encourage ventures in green H_2 infrastructure:** Invest in the development of infrastructure for green H_2 production, storage, and distribution, recognizing the importance of comprehensive ecosystems for the scalability of green H_2.
- **Prioritize investments in regions with strong policy support:** Focus investment activities in regions where local governments provide substantial support for green H_2, leveraging favorable regulatory environments to mitigate risks.
- **Back integration with renewable energy projects:** Fund projects that directly integrate electrolyzer operations with renewable energy generation, ensuring a stable and cost-effective supply of green electricity for H_2 production.

RECOMMENDATIONS FOR THINK TANKS

- **Advocate for policy support:** Push for policies that promote the adoption of green H_2 for appropriate uses and deployment of electrolyzer technologies. This includes advocating for financial incentives, regulatory support, and international cooperation on H_2 policy.
- **Facilitate knowledge sharing:** Organize forums, workshops, and publications to disseminate knowledge on best practices, technological advancements, and market trends in the green H_2 sector. Support educational initiatives to build skills and capacities in the workforce.
- **Monitor environmental and social impacts:** Ensure that the development of the green H_2 economy adheres to sustainability principles, including the responsible sourcing of materials, minimizing environmental impacts, and ensuring social benefits. Advocate for transparency and accountability in green H_2 projects.
- **Monitor environmental compliance of green H_2 projects:** Conduct independent assessments of green H_2 projects to ensure they adhere to environmental standards and truly contribute to decarbonization efforts.
- **Promote public awareness and acceptance:** Organize public awareness campaigns to educate the broader society about the benefits and proper applications of green H_2, increasing public support and acceptance.
- **Advocate for inclusive policymaking processes:** Ensure that policy development for green H_2 involves a wide range of stakeholders, including communities, environmental groups, and industry, to create balanced and effective policies.

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