REPORT

SCALING HYDROGEN FINANCING FOR DEVELOPMENT

THE WORLD BANK
IBRD • IDA

ESMAP
Energy Sector Management Assistance Program

OECD

Global Infrastructure Facility
A G20 INITIATIVE

Hydrogen Council

In Support of
BREAKTHROUGH AGENDA

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ABOUT ESMAP

The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and over 20 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets. Learn more at: https://esmap.org

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Contents

List of Figures, Tables, and Boxes

Figures

Tables

Boxes

Abbreviations

BOP	balance of plant
CAPEX	capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CO_2	carbon dioxide
COP28	28th Conference of the Parties (to the United Nations Framework Convention on Climate Change)
DFI	development finance institution
ECA	export credit agency
EMDC	emerging markets and developing countries
EPC	engineering, procurement, and construction
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FEED	Front-end engineering and design
FID	final investment decision
GDP	gross domestic product
FX	foreign exchange
GHG	greenhouse gas
Gt	gigatonne
GW	gigawatt
H4D	Hydrogen for Development Partnership
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
kt	kilotonne
LCOH	levelized cost of hydrogen
MDB	multilateral development bank
MW	megawatt
MWh	megawatt hour
Mt	million tonne
OECD	Organisation for Economic Co-operation and Development
O&M	operations and maintenance
PV	photovoltaic (solar)
R&D	research and development
RFP	request for proposal
SAF	sustainable aviation fuel
SCDI	Southern Corridor Development Initiative
UN	United Nations
WACC	weighted average cost of capital
WTP	willingness to pay

All currency is in United States dollars (US$, USD), unless otherwise indicated.

Preface

This flagship report, prepared by the World Bank in collaboration with the Organisation for Economic Co-operation and Development (OECD) and the Global Infrastructure Facility (GIF), and with the support of the Hydrogen Council, is intended to inform deliberations at the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC). The report is a contribution to the Breakthrough Agenda adopted at COP26.[1]

The World Bank is currently closely involved in the roll-out of the global hydrogen economy, as part of a bigger international effort to support this transition. The Bank's principal components—the International Bank for Reconstruction and Development, International Finance Corporation, and Multilateral Investment Guarantee Agency—are in close consultations with client countries and private sector players on how to realize their hydrogen ambitions. To date, the World Bank Board has approved $1.65 billion in clean hydrogen loans in 2023. The Hydrogen for Development Partnership (H4D), established at the 27th conference of parties (COP27) through the work of the Energy Sector Management Assistance Program (ESMAP) at the World Bank, provides client countries with practical advice and technical assistance on how to develop policies in order to advance clean hydrogen efforts in their respective economies.

This report's analysis provides detailed information on the global hydrogen market and the cost of producing hydrogen. It quantifies the gap between the costs of financing clean hydrogen projects and the benefits such a project can be expected to yield in the short term.

The study explores measures to minimize the need for government financing by making hydrogen investments attractive to the private sector. Chiefly, those measures involve managing and mitigating risk. Major risk categories such as those related to offtake have been identified through an extensive survey.

This study reviews best practices for accelerated clean hydrogen deployment in emerging markets and developing countries with an eye to key risks in all project stages. Different types of risk are analyzed and split into project-enabling factors and factors that must be managed to reduce the cost of capital. The potential of each type to reduce the cost of hydrogen is quantified.

[1] https://www.irena.org/Publications/2023/Sep/Breakthrough-Agenda-Report

The report lays out how multilateral development banks and development finance institutions can help to accelerate and de-risk clean hydrogen projects. However, at this stage of the clean hydrogen industry's development, financial de-risking is insufficient. Policies are necessary to de-risk investments and increase the volume and scale of projects coming on stream.

We will continue to work closely with our client countries and our development partners, including financing institutions and the private sector to accelerate clean hydrogen deployment. We look forward to an impactful hydrogen investment and financing agenda based on the insights and recommendations generated by the deliberations at COP28 and beyond.

Acknowledgments

This report was prepared by the Energy Sector Management Assistance Program (ESMAP) of the World Bank's Energy and Extractives (EEX) Global Practice jointly with the Organisation for Economic Co-operation and Development (OECD), the Global Infrastructure Facility (GIF) and with support from the Hydrogen Council.

The inter-agency team was led by Dolf Gielen (Senior Energy Economist, ESMAP). The primary authors consisted of Priyank Lathwal, Silvia Carolina Lopez Rocha, Michelle Hallack, Sandhya Srinivasan (World Bank), Deger Saygin, Joseph Cordonnier, Moongyung Lee (OECD), and Giulia Motolese (GIF).

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Key Findings

- **STATUS.** Clean hydrogen—hydrogen[2] produced from renewable energy, and fossil fuel with safe and responsible carbon capture and storage—can play an important role in the global transition from polluting fuels to low- or no-carbon energy, helping to achieve universal access to affordable and reliable energy by 2030 (Sustainable Development Goal 7). Hydrogen is an energy carrier that can be used to store, move, and deliver energy and, if produced from clean sources, is particularly promising for use in hard-to-decarbonize sectors such as steel production, long-haul transport, and others. The challenge today, however, is that current global production of clean hydrogen is limited, representing less than 2 percent of total hydrogen production. While clean hydrogen trade can change the geopolitics and security aspects of energy, this is a very capital-intensive industry. Therefore, to increase the number of clean hydrogen projects globally, they need to be commercially attractive. To achieve this, a focus on financing and risk mitigation is needed to create viable investment opportunities. In response to strong country interest, $1.65 billion in World Bank funding has been approved for green/renewable hydrogen loans so far in 2023, with more to come. Presently, 39 percent of all global clean hydrogen projects under development are in emerging markets and developing countries (EMDCs). However, so far only six large renewable hydrogen projects (>100 MW capacity) in EMDCs have reached the final investment decision (FID) stage.
- **OUTLOOK.** To meet global climate goals, emerging markets and developing countries must play a key role and supply half of global production, equivalent to 20 Mt/year by 2030. That is equivalent to 100 NEOM projects, the largest hydrogen project under construction in Saudi Arabia, projected to come onstream in 2026. Production of ammonia, methanol, and steel are among the main hydrogen applications. Modeling studies suggest that 25 to 31 percent of hydrogen production will be traded internationally by 2050. However, funding needs are significant to realize this vision. EMDCs require around $ 100 billion per year in investments between now and 2030 – a huge sum that makes private sector participation critical.
- **ACTION PLAN.** A four-point action plan to accelerate clean hydrogen deployment in EMDCs is suggested. It centers on a series of renewable hydrogen lighthouse projects designed to increase investor confidence. We propose a 10 GW initiative, aiming to develop projects (between 100 MW and 1 GW in size) across different nations and different settings to demonstrate viability for all stakeholders, reduce financing cost premiums, and create scalable solutions. Given its urgency, the effort should begin with promising projects currently in the global pipeline, keeping in mind aspects such as

[2] Hydrogen is the most abundant element in the universe and occurs naturally on earth in compound form with other elements in liquids, gases, or solids. Hydrogen combined with oxygen is water (H_2O).

technology and application diversity, replicability, and cost effectiveness. A general capacity-building and knowledge-sharing effort is also needed to bring governments up to speed on clean hydrogen opportunities and challenges.

- **HYDROGEN COST.** The information presently available on costs and prices for clean hydrogen is insufficient to guide policymaking and investment decisions. More transparent price information should be created. For renewable hydrogen (hydrogen produced from renewable power such as wind and solar), today's lowest production cost is $3/kg for best-in-class projects; that cost can rise to more than $10/kg under less favorable conditions. In most locations, these costs are well above those for conventional hydrogen (generated from fossil fuel energy without carbon capture) and blue hydrogen (generated from fossil fuel energy with carbon capture). The external financial support needed to close clean hydrogen's economic viability gap is estimated between $10 and $40 billion per year between now and 2030. This amount is known as the 'financing gap,' i.e., the gap between product value and production cost. The wide range stems from the uncertainties and challenges that surround the hydrogen industry's development.
- **DE-RISKING.** Large clean hydrogen projects in EMDCs face high financing costs derived from actual and perceived risks, deterring investors to enter this nascent industry. Six key categories of risks have been identified, in order of priority: (1) offtake risks; (2) equally weighted political and regulatory risks; (3) infrastructure risks; (4) permitting risks; (5) technology risks; and (6) macroeconomic risks. The three categories of risks that were given a lower priority are: design, construction, and completion risks; operational and maintenance risks; and supply risks. Implementing cost-effective and efficient de-risking mechanisms could substantially decrease the weighted average cost of capital, making projects economically viable and thus accelerating deployment and reducing the financing gap. Only through application of dedicated risk mitigation mechanisms can large-scale clean hydrogen projects in EMDCs achieve financial viability. It is critical that EMDC governments choose reputable partners for project development.
- **FIRST MOVERS.** Policies promoting clean hydrogen in a few first-mover countries can spur development elsewhere and begin to decrease costs. Governments' willingness to share and absorb risks is critical to accelerating investment. Benefits await the competitive EMDCs that choose to participate in this process as first movers. Clean hydrogen production in EMDCs would strengthen the international value chain, yielding substantial socioeconomic development benefits and increasing countries' energy security. Multilateral development banks (MDBs) and development finance institutions have a strategic role to play in supporting EMDCs willing to become first movers. They can support governments to attract private sector investment by improving enabling conditions, de-risking investments, reducing costs, and promoting adequate financing instruments. Moreover, they can support countries in defining policy frameworks that catalyze local socioeconomic benefits and climate mitigation to align with national development agendas. Better coordination among participating international institutions will reduce transaction costs and speed up approvals such as through the harmonization of approval and due diligence procedures.


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Executive Summary

Clean Hydrogen Will Be a Key Part of the Future Global Energy System

Clean hydrogen[3] is widely seen as a key component of the global energy transition, notably for its potential to decarbonize hard-to-abate sectors, such as heavy industry (cement, steel, and chemicals), and heavy-duty transport (trucking, shipping, and aviation). A global hydrogen economy will change the geopolitics of energy and could become an engine for sustainable economic growth in emerging markets and developing countries (EMDCs). Several EMDCs are well positioned to become first movers in the development of this new value chain, both for domestic consumption and for export. Many countries have already issued strategies and roadmaps to operationalize their ambitions. As a next step, well-aligned policies adapted to those strategies are necessary to leverage private financing and mitigate the risks of first movers' investments.

The cost of clean hydrogen is a major sticking point in its widespread adoption and deployment. While most attention to date has focused on innovation strategies to lower technology costs, financing costs have received less attention. This report analyzes the importance of the cost of financing, identifies the project risks that drive up such financing cost, and proposes risk-mitigation measures. The report describes how governments can support deployment by reducing the costs of both technology and financing.

Successful projects in the coming years will typically require a combination of strong sponsors, robust regulation, long-term offtake arrangements, and financial support. Governments have a key role to play in this early phase. Hydrogen policies on both the supply side and the demand side must be well integrated for the greatest effect and efficiency. A careful selection of early hydrogen projects can reduce the need for government financing.

Clean Hydrogen Production Must Grow Twenty-Fold by 2030

Realizing hydrogen's potential means first replacing today's fossil fuel-based hydrogen production with a cleaner variety. To meet the 2050 climate goals, today's levels of clean hydrogen production must increase 20-fold (~40 Mt) through 2030. Today, less than

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[3] "Clean hydrogen" includes hydrogen produced from fossil fuels coupled with carbon dioxide capture and storage (combustion based) or carbon storage (pyrolysis based). These are also known as low carbon hydrogen or "blue hydrogen." Hydrogen produced from water electrolysis using renewable electricity or from biomass is known as renewable hydrogen or "green hydrogen." "Conventional hydrogen" refers to fossil fuel-based production without carbon dioxide capture and storage.

2 million tonne (Mt) of clean hydrogen is produced each year. Current projections suggest that of the 40 Mt of clean hydrogen production needed by 2030, an estimated two-thirds would come from renewables while the rest would be of the low carbon variety.

Clean hydrogen today is more expensive than conventional hydrogen produced from fossil fuels. This cost gap is the main factor why clean hydrogen projects are often viewed as unviable. Rule of thumb cost estimates for best-in-class projects with optimistic assumptions in favorable locations is $1/kilogram (kg) to produce conventional hydrogen, $2/kg for low carbon hydrogen, and $3/kg for renewable (green) hydrogen, respectively, though clean hydrogen (hydrogen from fossil fuels with carbon capture/storage) can already compete under certain favorable circumstances. Costs vary widely, however, especially for renewable hydrogen. Some EMDCs can be among the lowest-cost producers of clean hydrogen worldwide owing to their favorable renewables resource endowment. Moreover, their resource potential is very significant. This is a key reason why they should be part of early hydrogen development efforts. Existing country cost rankings from literature and modelling studies are of limited value as changing project specifics, market dynamics, and enabling environments can affect cost significantly. There is a need to develop more accurate hydrogen cost and pricing information for today and the coming years.

When hydrogen is traded internationally, the transportation cost can be as great as the production cost. That is a major reason why there is no international hydrogen commodity market. No significant shipping capacity for liquid hydrogen exists at present. Instead, hydrogen is being shipped in the form of ammonia, a globally traded commodity. Other synthetic hydrocarbon shipping options are being explored, and costs are projected to fall in the coming years. Pipeline transportation can be significantly cheaper than shipping for distances up to several thousand kilometers.

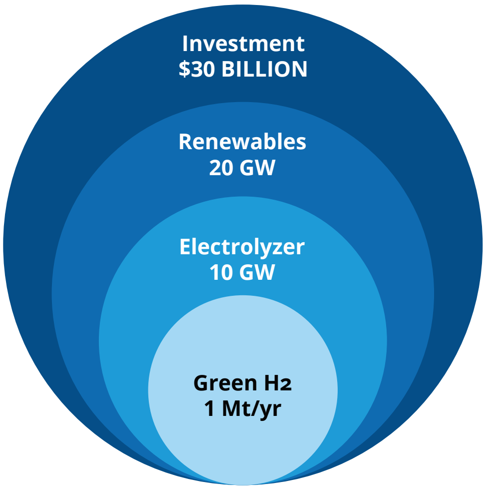
EMDCs Will Need $100 Billion in Investment Annually for Projected Growth in Clean Hydrogen

Existing hydrogen import policies, national plans, project pipelines, and model analyses indicate that 25 to 50 percent of clean hydrogen production is likely to come from EMDCs.[4] The upper end of the range was used for this analysis (20 Mt of clean hydrogen production from EMDCs in 2030). These projections are uncertain; policy and regulatory frameworks will have a profound impact on choices of production locations and volumes for first movers.

[4] China, the world's largest hydrogen market, set up two large renewable hydrogen projects in 2023. The country is aiming for 5 Mt of renewable hydrogen by 2030, 20–25% of total EMDC production. However, China's clean hydrogen supply ambitions need further elaboration, and no massive exports are foreseen. Given the magnitude and particular characteristics of China's hydrogen policies (the country has ambitious hydrogen vehicle plans, notably at the subnational level), the country is treated separately from other EMDCs in this analysis.

FIGURE ES.1

Key Characteristics of Renewable Hydrogen Production by Component



Source: Authors' analysis.

Scenario studies and the project pipeline suggest that EMDCs have the potential to attract clean hydrogen investments in the order of $100 billion per year between now and 2030, more than a ten-fold increase from present levels. Renewable hydrogen, which is more capital intensive than other forms, will account for 80 percent of the clean hydrogen production investment and financing needs.[5]

The external financial support needed to realize these investments in EMDCs and to close the economic viability gap is estimated between $10 and $40 billion per year between now and 2030. This amount is known as the "financing gap."[6] These amounts stand out in light of the fact that development financing worldwide presently totals just $200 billion per year. A number of strategies can be deployed to mobilize these investments, however, individual projects costing billions or tens of billions of dollars can pose particular challenges.

It will be essential to mobilize private sector financing for clean hydrogen to minimize dependence on scarce international and public financial support. Initiatives such as the World Bank's recently launched Private Sector Investment Lab[7], the blended finance principles

[5] All investment and financing numbers in this publication include the renewable power component, which is not included in some other sources.

[6] The "financing gap" refers to the difference between the level of financing needed and the level that is commercially justifiable. The gap is calculated based on the disparity between product value and production cost. The gap is equal to 10-40% of total financing needs.

[7] The Private Sector Investment Lab aims to address obstacles to private sector investment in emerging markets, with a focus on renewable energy and climate goals. It brings together private finance leaders and experts to develop solutions for mobilizing private capital to combat climate change and reduce poverty in these regions. The MDBs' blended finance approach is described here.

embraced by multilateral development banks (MDBs), and the Blended Finance Principles of the Organisation for Economic Co-operation and Development[8], as well as public-private partnerships to mobilize more private finance will be crucial to get initial projects off the ground.

The EMDC Project Pipeline is Full of Projects Stuck in Early Stages

Around 39 percent of today's project pipeline is in EMDCs, with important activity concentrated in the Middle East, Latin America, India and China, followed by sub-Saharan Africa and other Asia. But translating high-quality renewable endowments into hydrogen production investments remains a challenge.

The main challenge for EMDCs is to push projects toward the front-end engineering design (FEED) stage. There is a relatively low representation of EMDCs (7 percent) at that stage, compared with developed countries (93 percent). To date, very few large projects have entered the final investment decision (FID) stage worldwide. The value of clean hydrogen projects in EMDCs that have reached the FID stage is less than $20 billion.

The share of investments in EMDCs is 44 percent, including China's 18 percent share. However, the 44 percent figure is largely dependent on a few projects, such as NEOM in Saudi Arabia.

Because risk-mitigation measures are not far advanced, cost of capital is high and it is challenging to find offtake; many announced projects are stuck in early stages of development, struggling to complete the FEED studies.

Low-Cost Financing Must Be Combined with Lower Investment Costs

Projections of falling production costs for renewable hydrogen depend critically on two factors: lower installed costs of electrolyzer systems[9] and competitive costs of renewable power. From the export perspective, transportation costs are also critical.

The production costs of clean and conventional hydrogen are expected to converge around 2030, provided greenhouse gas emissions are priced properly and the unit investment cost for renewable hydrogen maintains its downward trend. The convergence also depends on

[8] The OECD's Blended Finance Principles are a policy tool for donor governments, development cooperation agencies, philanthropies, and other stakeholders to design and implement effective and transparent blended finance programs. More details are available from OECD's Blended Finance Guidance and Principles.
[9] An electrolyzer system consists of an electrolyzer stack and balance of plant (BOP).

whether the cost of capital declines as technology matures, as project developers gain experience, and as financiers become more comfortable with clean hydrogen projects. These factors can be mutually reinforcing.

To achieve 2030 convergence, a virtuous circle is needed in which governments support first movers' projects by financing the technology, education, and scale needed to accelerate deployment and create a viable market.

The near-term prospects for reductions in electrolyzer cost remain uncertain. Today's costs vary significantly by market, based on variations in costs in China, Europe, India, and the United States. The same uncertainty can be observed for the cost of electricity used to produce renewable hydrogen. The costs incurred by renewable electricity and the hours of electrolyzer operation will depend on the carbon standard that hydrogen production must meet. Initially, the interpretation of "low carbon" should be flexible enough to yield affordable hydrogen; the standard can be tightened in later years as the costs of renewable electricity and electrolyzers fall and as demand rises. But internationally traded hydrogen and hydrogen derivatives may have to comply with global standards and regulations, which can be complex and challenging. Clean hydrogen definitions and standards that have recently been set in Europe and ongoing discussions in the United States can provide relevant insights. EMDCs will have to balance standard setting and continue their dialogue with offtakers.

The relative cost differential between clean and conventional hydrogen is less pronounced for hydrogen derivatives, such as ammonia, steel, methanol, and jet fuel. Moreover, the ease of transporting these commodities creates an opening for the deployment of clean hydrogen in EMDCs, and the increase in value added makes a strong development case. Bringing manufacturing companies, shipping, and airline companies, for example, on board can accelerate hydrogen production in early stages and enable EMDCs to internalize a larger share of the hydrogen value chain.

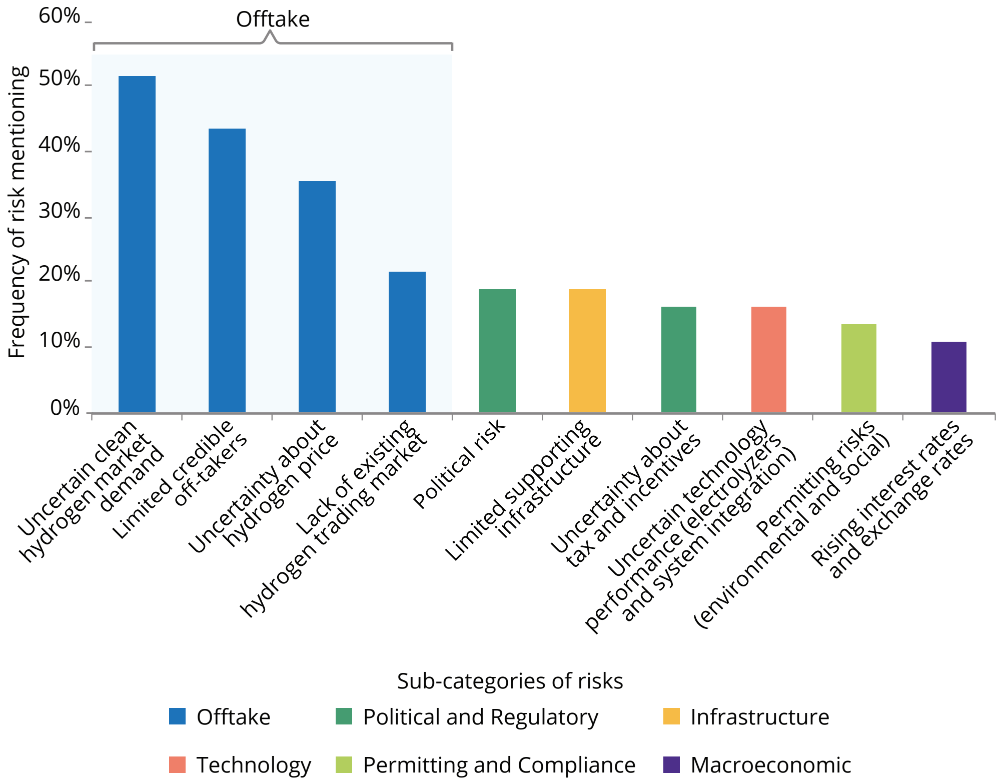
The cost of capital affects both the levelized cost of electricity and the levelized cost of hydrogen production. Rich resource endowments in EMDCs compensate somewhat—but not entirely—for the higher cost of capital in EMDCs. Even high-quality projects with reputable partners and accompanied by sovereign risk guarantees typically require double-digit cost of capital in EMDCs.

Managing Risk Well Will Accelerate Clean Hydrogen Deployment

Certain essential factors must be present before a clean hydrogen project can make it to the FID stage. Secure offtake in terms of volume, price, and project duration must be in place. Infrastructure to handle hydrogen, water, electricity, carbon dioxide, and hydrogen derivatives must also be in place when production begins. In addition, the product must be recognized as 'clean hydrogen' by established standards and certification systems.

FIGURE ES.2

Top 10 Identified Risks for Clean Hydrogen Projects in EMDCs



Source: Authors' analysis.

Post-FID risks center on construction overruns, offtake default, technology issues, political risk, and exchange risks, all of which affect the cost of capital and thus competitiveness. Once a project has reached the FID stage, targeted policies and risk-mitigation measures that reduce the cost of capital can decrease the cost disparity between conventional and clean hydrogen.

Some risks are country and actor dependent. These include the creditworthiness and credibility of the project sponsor; of the contractor responsible for engineering, contracting, and procurement; of the primary technology provider; and of the offtaker. All of these, of course, feature prominently in any risk assessment. Some aspects of political risk can be mitigated through well-established mechanisms offered by MDBs and development finance institutions (DFIs), such as political risk guarantees.

Clean hydrogen also carries perceived technology risks. Such risks can be mitigated by insurance or guarantees—for example, from export credit agencies in countries that produce electrolyzers. First-mover risk is also significant, where production costs are projected to fall in the coming years and product prices are likely to rise.

Governments Can Reduce Risk by Building Enabling Frameworks

Governments will play a vital role in the realization of clean hydrogen projects for the rest of this decade. They must create enabling policy frameworks and find solutions to close the financing gap for early projects.

Effective government policies can lessen the need for public financial support by creating the right enabling environment for investments, increasing pricing transparency, and reducing risk. Developed countries have already launched extensive mission-oriented strategies, with more than $100 billion in announced subsidies. EMDCs do not have the same financing power. However, careful selection of early hydrogen applications or an export-oriented strategy benefiting from partnerships with countries offering end-user incentives can substantially reduce financing needs.

Above all, governments must carefully choose the projects they wish to support in light of the projects' quality and likelihood of success. Development of hydrogen hubs that cluster suppliers and producers can reduce the size of individual projects and eliminate the need for extensive transportation infrastructure. Whereas export projects are likely to be very large, smaller scale opportunities exist for hydrogen use nationally, such as in refineries or for fertilizer production. National uses can complement exports.

Given the complexity of the hydrogen sector, governments should consider the appointment or establishment of an agency responsible for national hydrogen development. Adequate policies, regulation, and financial instruments will be essential to lower risks and to attract patient capital such as pension funds and sovereign wealth funds. In this context, refinancing projects upon completion is a way to lower the cost of investment capital and to unlock sources of funding with a higher risk appetite.

International Financial Institutions Can Accelerate Hydrogen Financing

MDBs and DFIs should strengthen their support for EMDCs that are taking steps to advance the energy transition on their territory—for example, through support for carbon pricing schemes and rapid rollout of renewable power generation.

Equally deserving of support are knowledge sharing, capacity building, and promotion of international cooperation. Here, examples include certification schemes' implementation, evolution of the market and pricing models, technical standards, and use of a single platform for channelling clean hydrogen development and climate funding and support. The World Bank's Hydrogen for Development Partnership, established at COP27 and managed by WB/ESMAP, is an example of such an effort.

For governments willing and able to become first movers, MDBs and DFIs can provide guarantees and deploy instruments to mitigate risks. This type of support includes technical assistance, development policy financing, infrastructure loans (e.g., for ports and pipelines), facilitation of offtake arrangements (including demand aggregation), and strengthened matchmaking between EMDC governments and international hydrogen initiatives.

MDBs and DFIs are well positioned to support so-called lighthouse production projects designed to encourage further investment in EMDCs. This type of support includes (1) prioritizing and enhancing the quality of project proposals; (2) supporting the initial stages of project development; (3) pooling international development funding for investments to lower financing costs and raise investor confidence; (4) participating in blended finance arrangements; (5) offering risk-mitigation instruments; and (6) monitoring and quantifying the climate change and development benefits of clean hydrogen projects.

To date, international support has concentrated on making EMDCs attractive sites for hydrogen production by improving the enabling environment for incoming investment (most of it export oriented) and ensuring the adequacy of essential infrastructure. But such supply-side assistance could be strengthened on the demand side by devising the right mix of tax incentives, regulations, and policies to entice local companies to decarbonize their activities through the use of clean hydrogen. Stimulating local demand would widen the path to clean hydrogen investment by lessening the logistics and infrastructure costs associated with export-oriented investment.

Better coordination among participating international institutions can reduce transaction costs and speed up deployment—for example, through harmonization of approval and due diligence procedures. MDBs should consider developing a joint strategy to ensure that limited amounts of concessional and development financing are used to their maximum effect, notably for projects in the early stages of development.

Advancing Support for Renewable Hydrogen Financing

COP28 will provide an opportunity to discuss support for renewable hydrogen lighthouse projects facilitated by MDBs and DFIs acting in concert. Lighthouse projects are necessary to accelerate the scaling up of the clean hydrogen market. Active government and financing institution support will be needed to operationalize a pilot program, tentatively with a 10-gigawatt (GW) electrolyzer capacity reaching the operational stage. Such a program can increase investor confidence in various EMDC settings, leading to lower financing costs and easier access to capital. Given its urgency, the effort should screen projects from the existing pipeline, using criteria such as diversity, replicability, project size, and cost effectiveness.

Scaling Up Clean Hydrogen Financing

Solutions for Development and Decarbonization

<2 Mt/yr. clean H_2 produced globally in 2022

<1 GW in global installed electrolyzer capacity for clean H_2 in 2022

Global clean H_2 production: **27 Mt** renewable and **13 Mt** low-carbon by 2030 **260 GW** in new solar and wind capacity needed

Global financing gap of **$500B** until 2030. Need for policy measures to close gap

Renewable H_2 accounts for **80%** of production investment. Renewable power accounts for **60%** of EMDC investment needs

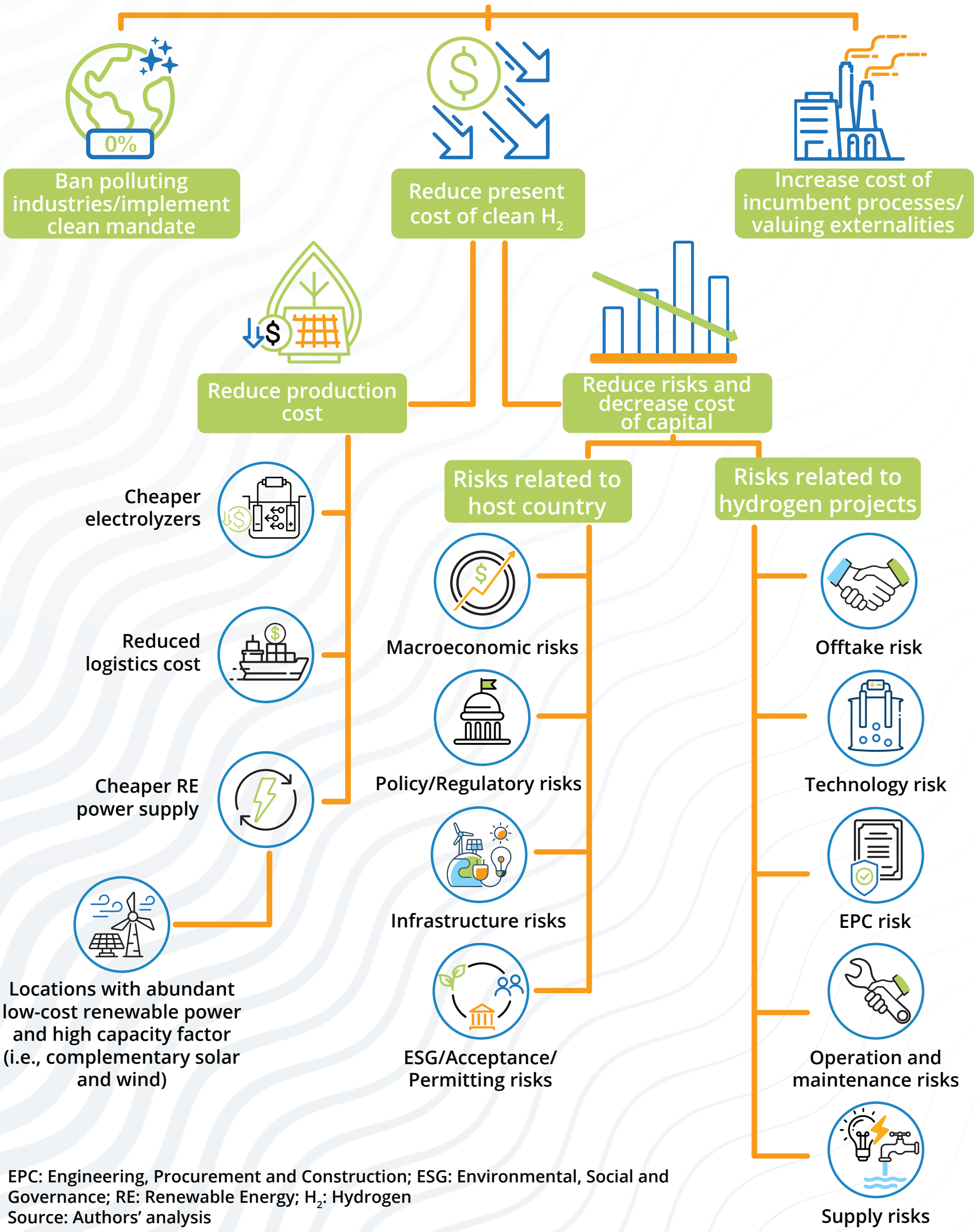
Global investment need until 2030: **$2T**
$1T (production);
$0.5T (transport infrastructure);
$0.5T (end-use sectors)

Global Clean H_2 demand (and production) **40 Mt** until 2030 with **20 Mt** expected in EMDCs

Total annual EMDC financing needs until 2030: **$100B/yr.**
Annual EMDC financing gap until 2030: **$10B-$40B/yr.**

EMDC: Emerging Markets and Developing Countries; $ refers to USD
Source: Authors' analysis

Business Case for Clean Hydrogen



EPC: Engineering, Procurement and Construction; ESG: Environmental, Social and Governance; RE: Renewable Energy; H_2: Hydrogen
Source: Authors' analysis

About this Report

Clean hydrogen has the potential to play a significant role in decarbonizing energy and achieving climate goals, notably by decarbonizing certain energy-intensive industries and transport applications that cannot be electrified. The term clean hydrogen encompasses two types of hydrogen: (1) low carbon hydrogen (also known as *blue* hydrogen), produced from fossil fuels accompanied by carbon capture and storage (combustion based) or carbon storage (pyrolysis based); and (2) renewable hydrogen (also known as *green* hydrogen), produced via water electrolysis, using renewable electricity or using biomass. Neither type of clean hydrogen is widely deployed today; together they account for about 2 percent of total hydrogen production. Many projects are under development, but major upscaling is needed.

Context of the Report

There are multiple reasons why clean hydrogen deserves attention from a development perspective. First, electricity from renewable power generation sources will become the fundamental basis of our future energy system. Hydrogen is a clean energy vector that can transmit low-cost renewable electricity across time and space. This will be an indispensable part of any large energy system in the future. As noted above, clean hydrogen and its derivatives can be used to apply renewable electricity to the decarbonization of hard-to-abate sectors in industry and transport.

Second, energy-intensive industries tend to locate where energy is abundant and cheap. Clean hydrogen thus raises the industrialization potential of countries with abundant renewable energy resources. Already, ammonia and steel producers with roots in coal- or gas-producing areas are seeking out low-cost locations worldwide.

Third, first movers will gain critical experience early on. They will be able to claim relatively large shares of the limited amounts of concessional finance available and gain a foothold in supply chains in a sector that shows exponential growth. Possessing critical infrastructure before others and joining global supply chain networks early will create economic opportunities that may become more difficult to capture later.

Fourth, renewable hydrogen production is capital intensive. EMDCs will require vast amounts of financing to develop their hydrogen economies. As a rule-of-thumb, producing 1 million tonne (Mt) of renewable hydrogen per year requires approximately 10 GW of electrolyzers, 20 GW of renewable power, and $30 billion in investments. Policies that support clean hydrogen deployment through public and private investment need to be crafted in such a manner that hydrogen financing by MDBs is scaled up dramatically from the current level of less than $5 billion annually in EMDCs.

Fifth, clean hydrogen is based on new technologies with high perceived risk, which can push up the cost of capital in EMDCs, where financing costs are already generally higher. Given lack of experience in designing and implementing clean hydrogen projects, investors will require a risk premium. Higher financing costs, in combination with high capital intensity, complicate the business case for clean hydrogen. This situation needs to be shifted to a virtuous cycle in which new deployments result in technology learning, which, in turn, accelerates deployment, as has already occurred for solar and wind energy production.

Sixth, public intervention is needed in order to overcome both the wide funding gap on the supply side and high switching costs (costs incurred for replacing current end-use technologies with hydrogen) on the demand side. Public authorities and national governments have an essential role to play in pursuing these goals, as do public policy banks.

Rationale and Objective of the Report

This report proposes actions to ramp up clean hydrogen investments in EMDCs. It identifies barriers to accessing financing for clean hydrogen projects and identifies best practices for accelerating hydrogen deployment. Furthermore, it recommends key government actions that can serve as a basis for political commitment and strengthened bilateral and multilateral coordination at the global, national, and institutional levels. The report presents vital new information gathered through stakeholder interviews and surveys, supplemented with analyses of projects, and drawing on a wide range of public and internal sources. Because the sector is very dynamic and fluid, all information presented here must be considered in light of its source and date.

This report will serve as guideline to increase and strengthen the support for clean hydrogen that the World Bank is already providing to EMDCs. ESMAP launched the Hydrogen for Development (H4D) partnership at COP27 to promote knowledge sharing, capacity building, and financing in EMDCs. This report has benefitted from the valuable inputs and suggestions of H4D partners. In the financing sphere, as of June 2023, the World Bank Board had approved two lending operations, a $1.5 billion development policy loan in India and a $150 million investment project loan in Chile. This report will inform future investment decisions of the World Bank and other MDBs.

The report recommends a collaborative approach led by governments to tackle today's financing gap. As of August 2023, only 10 percent of global projects under development have reached the stage known as "final investment decision." Despite the fact that governments worldwide are committing more than $100 billion to financing and support clean hydrogen projects, the bulk of this financing is concentrated in developed countries, and available funds are insufficient to make hydrogen energy economically viable in the long term. It is imperative that we choose the most effective and efficient mechanisms to close the financing gap and overcome the first movers' risk.

Project financing depends on good policy frameworks. Governments must build enabling frameworks to stimulate demand, develop infrastructure, create an economically viable hydrogen market, and reduce the risk perceptions of developers and investors. These public policies may include fiscal instruments, binding net-zero commitments, and emission targets. Policies are also needed to scale up and transform clean hydrogen markets.

The report also recommends that government support and international concessional financing focus on the initial development stage. The level of risk decreases as projects move into the construction and operation phases. Blended finance is a possible solution, but it is not a one-size-fits-all remedy.

The report concludes that MDBs can play a defining role in kickstarting clean hydrogen project investments in EMDCs and are critical in unlocking private capital by providing innovative financing schemes and de-risking mechanisms. MDBs are likewise well positioned to provide technical assistance supporting the legal, regulatory, and institutional frameworks required to enable investments in the nascent clean hydrogen industry. They can also share best practices with client country governments, build institutional knowledge, and facilitate learning as clean hydrogen projects are financed and implemented. To increase the share of successful projects in the hydrogen sector, it is critical that every project be monitored, and best practices and failures documented.

ONE
CLEAN HYDROGEN: STATUS, PROJECTIONS, AND SCENARIOS

Key Points

- Clean hydrogen can play an important role in the energy transition, but current global production is very limited, representing less than 2 percent of total hydrogen production. Replacing the 100 Mt of fossil-based hydrogen now produced each year with clean hydrogen would cut annual CO_2 emissions by a gigatonne (Gt).
- A global supply of 40 Mt of clean hydrogen is expected by 2030. Projects announced to date would produce 25 Mt of renewable hydrogen a year and 13 Mt of low carbon hydrogen. For this report, it is assumed that clean hydrogen production from emerging markets and developing countries (EMDCs) will grow to 20 Mt by 2030.
- To comply with the 1.5°C scenario under the 2015 Paris Agreement on climate change, global clean hydrogen production needs to reach 500 Mt by 2050, which would require global investments of $25 trillion between 2023 and 2050, or annual investments of almost $1 trillion, to finance clean hydrogen production, transport infrastructure, and end-use equipment. In contrast with these massive capital needs, worldwide clean hydrogen investment totaled just $6 billion in 2022.
- As of August 2023, less than 10 percent of all projects announced worldwide have reached the stage known as “final investment decision” (FID). These projects represent investments of $29 billion and will produce 2 Mt a year of clean hydrogen: 1.1 Mt of low carbon hydrogen (all in North America) and 1 Mt of renewable hydrogen.
- Presently, 39 percent of all global clean hydrogen projects under development are in EMDCs, but only 20 of these (outside China) have reached the FID stage, and most are comparatively small. Six large renewable hydrogen projects (>100 MW capacity) in EMDCs have reached the FID stage, three of them in China.
- Announced projects in EMDCs would require $450 billion in investment between now and 2030. The projected hydrogen growth need translates into an investment need of $100 billion per year between now and 2030.
- Clean ammonia projects amounting to 133 Mt have been announced in EMDCs. Of the total capacity, only 1.6 Mt is under construction (representing 1.2 percent of the announced projects).
- A quarter of the 4.5 Mt e-methanol projects that are expected worldwide by 2027 is set to be produced in EMDCs.
- Total global renewable steel production capacity announced as of August 2023 could amount to 40 Mt by 2030, which would imply hydrogen demand of around 4 Mt. Capacity announcements in developing countries are growing fast.
- Modeling studies suggest that 25 to 31 percent of hydrogen production will be traded internationally by 2050, roughly half through pipelines and half as hydrogen or hydrogen-derived commodity shipments. The prospect of such trade is a production opportunity for EMDCs.
- Some EMDCs are developing substantial capacity to produce clean hydrogen. Apart from China, several countries of the Gulf Cooperation Council stand out (Oman, Saudi Arabia, United Arab Emirates). Others include Brazil, Chile, Egypt, and India. Colombia, Mauritania, Namibia, and South Africa are still at an earlier development stage while the

project pipeline is significant in these countries. Central Asia, the rest of Sub-Saharan Africa, and most Southeast Asian countries are lagging. The capacity under development represents less than 10 Mt of hydrogen by 2030, but the number of projects under development is growing.

- Based on a large number of cases, four business models appear to drive hydrogen development. The case studies point to certain best practices that may help to design successful projects and portfolios.

Recent Developments and Outlook in the Short to Medium Term

Globally, about 100 Mt of hydrogen is produced and consumed each year. This accounts for nearly 2.5 percent of global final energy consumption and 1 Gt of energy-related CO_2 emissions. Around 98 percent of hydrogen is produced from fossil fuels without CO_2 capture. Three-quarters of this amount is produced from natural gas, and one-quarter from coal (almost exclusively in China) (World Economic Forum 2023).

Today's hydrogen consumption is dominated by refining (for oil desulfurization and hydrogenation of heavy products) and production of synthetic nitrogen fertilizer (for use as a feedstock in ammonia manufacturing). These two market segments are of similar size and account for about two-thirds of current global hydrogen use.

Decades of experience with CO_2 capture from fossil fuel-based hydrogen production provide a good starting point for low carbon hydrogen production. Around 1 percent of all hydrogen is currently produced from fossil fuels with CO_2 capture and storage. An estimated seven projects exist where the CO_2 from natural gas steam reforming during hydrogen production is captured and used for enhanced oil recovery. Thirteen similar projects are under consideration in the Middle East, several with contracts for engineering, procurement, and construction in place (Moati 2023). In Texas (USA), hubs are being planned that could produce 5 to 7 Mt of low carbon hydrogen by 2035 (McKinsey & Company 2022). Global projections for 2030 total 11 Mt of low carbon hydrogen.

The advancement of the low carbon hydrogen industry is prompted by growing experience with underground CO_2 storage. Today's steam methane reforming technology may yield 70 percent capture rates. New technologies such as auto thermal reforming or partial oxidation can, theoretically, can achieve 90 to 99 percent CO_2 capture efficiency at economically attractive costs, but practical experience is still limited, as is experience with permanent CO_2 storage. Other remaining challenges include the fact that the production and transport of natural gas for low carbon hydrogen production can result in significant methane emissions, another potent greenhouse gas. Therefore, a thorough technical assessment to control and prevent methane emissions must be implemented as a precondition for low carbon categorization.

As of mid-2023, only 0.5 GW of dedicated electrolysis capacity was in operation, while 1.2 GW was under construction (EH2 analytics 2023). This operational capacity can produce less than 0.1 Mt of clean hydrogen per year (0.1 percent of total global hydrogen production). Existing projects are at megawatt (MW) scale (Table 1.1). However, dedicated electrolyzer capacity is expected to ramp up quickly in the coming years, with GW-scale applications.

The future of renewable hydrogen is closely intertwined with the future of renewable power. Renewable power is the prime cost component of renewable hydrogen, which is viable only because of the rapidly declining cost of solar and wind power generation. But replacing the conventional hydrogen produced today with hydrogen produced from renewable energy would require the entirety of the solar and wind power generation capacity in operation today. The growth of hydrogen produced from renewable sources will have a profound reciprocal effect on the growth of renewable power.

The average size of renewable hydrogen production plants is growing fast. In July 2023, Sinopec's Kuqa Plant came into operation with a capacity of 260 megawatts (MW) and 20 kilotonnes (kt) per year, while a 390 MW and 30 kt per year plant is scheduled to come into operation later this year. China's largest renewable hydrogen project in Songyuan—a $4 billion, 640 MW ammonia/methanol facility—has broken ground, as discussed further on in this chapter. Many gigawatt-scale projects have been announced around the world but only a few are under construction, such as Saudi's NEOM project, scheduled to come online in 2026 (Box 1.1). The projects are assembled from modular electrolyzers with a capacity of 5 to 10 MW each. Despite this modularity, the economies of scale favor a rapid scale-up as cost-reduction synergies are achieved in power and gas treatment.

TABLE 1.1

Clean Hydrogen Projects with a Final Investment Decision in EMDCs (excluding China), as of January 2023

NAME	COUNTRY	COMMISSIONING	APPLICATION	ELECTROLYZER CAPACITY (MW)
Power-to-Gas Coquimbo	Chile	2022	Grid injection	0.15
NTPC-Technip-L&T MeOH Project, Vindhyachal	India	2022	Methanol	5
Simhadri Microgrid	India	2022	Power	0.24
GAIL Vijaipur Project	India	2023	Other industry	10
Unigel, Phase I (Camacari)	Brazil	2023	Ammonia	60
Renewable Falcon, Phase I	Argentina	2024	Synfuels	6.7
Haru Oni	Chile	2022	Synfuels	1.2
Egypt Renewable OCI/Fertiglobe/Scatec	Egypt	2022/2024	Ammonia	10 (phase 1)/100
NEOM	Saudi Arabia	2026	Ammonia	2,000

Source: IEA 2022 and World Bank Data.

BOX 1.1

PROSPECTS FOR INTERNATIONAL TRADE IN CLEAN HYDROGEN

The global potential for production of renewable hydrogen is more than 46 Gt per year, exceeding global primary energy consumption by a factor of nine (Franzmann et al. 2023). However, the production cost varies by region and country. Because of these cost differences, trade and economic specialization makes economic sense. For clean hydrogen, low-cost natural gas in combination with carbon storage and the availability of high-quality, low-cost renewable energy resources are critical factors.

Three recent trade studies project that 25 to 31 percent of hydrogen production will be traded internationally by 2050, roughly half through pipelines and half as hydrogen or hydrogen-derived commodity shipments (Hydrogen Council & McKinsey 2023; AFRY's Global Hydrogen Trade Model 2022; International Renewable Energy Agency 2022). These projections make a strong case for the engagement of EMDCs in the global hydrogen economy.

Long-Term Clean Hydrogen Scenarios

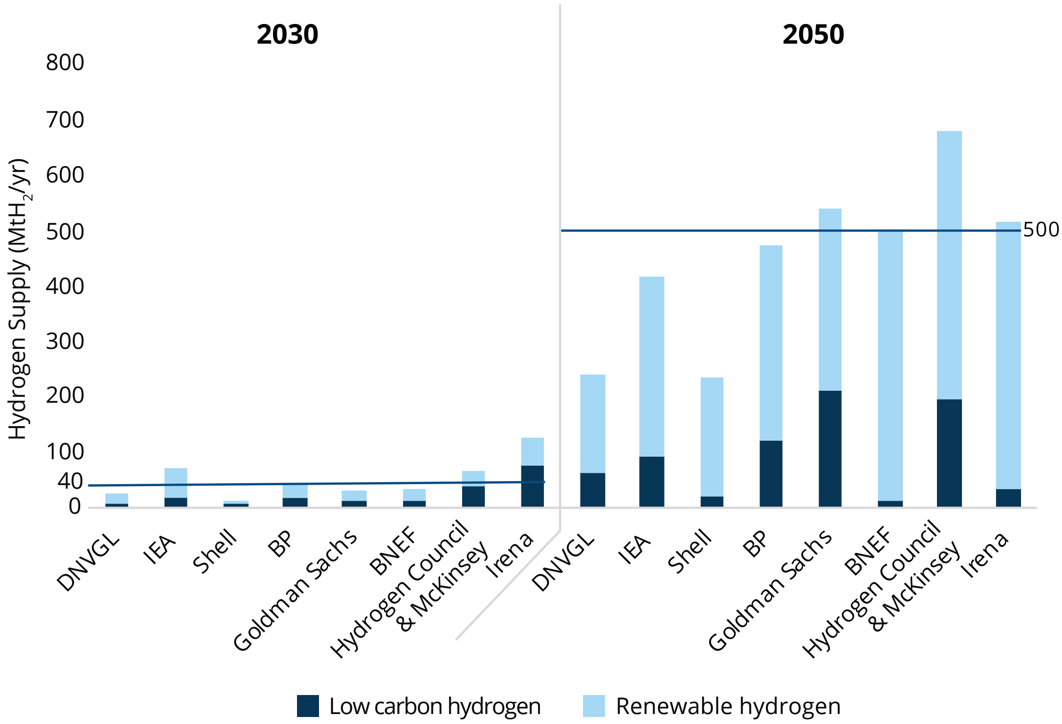
A variety of scenarios describe how clean hydrogen deployment should or could develop in the medium (2030) and long term (2050). This report reviews eight leading scenario studies that explore the role of hydrogen in the global energy transition. Seven are normative 1.5°C scenarios; one is a forecast (DNVGL; Figure 1.1).

In Figure 1.1, the eight bars on the left show the scenario results for 2030, while the eight bars on the right show results for 2050. The contributions of low carbon and renewable hydrogen are shown separately. Supply projections for 2030 range from 11 Mt to 90 Mt per year. The range is narrower in relative terms in 2050, from 235 to 240 Mt (Shell and DNV GL) to 682 Mt (Hydrogen Council). In any scenario, demand for clean hydrogen in 2050 is much greater than total hydrogen demand today.

The clean hydrogen projections for 2050 translate into 5 to 15 percent of total final consumption. Hydrogen is thus part of the broader energy transition and should be

FIGURE 1.1

Hydrogen in the Global Energy Transition and Decarbonization Scenarios



Sources: (Shell 2023; International Renewable Energy Agency 2023; International Energy Agency 2023; Goldman Sachs 2022; DNV 2022; BP 2023; Hydrogen Council & McKinsey 2023; International Energy Agency 2023).

included as part of a portfolio of decarbonization solutions. There is unanimity that renewable hydrogen will dominate by 2050, with the share of renewable hydrogen varying from 62 percent (Goldman Sachs 2022) to nearly 100 percent (BloombergNEF 2023). Three scenarios—those of BloombergNEF, the International Renewable Energy Agency, and the Hydrogen Council—project a renewable hydrogen production of about 500 Mt by 2050.

The World Bank estimates that scaling up clean hydrogen worldwide requires an accumulated investment of $25 trillion between 2023 and 2050—nearly $1 trillion each year.[10] Around half of this investment is for hydrogen production, a quarter for infrastructure, and a quarter for end-use investments.

[10] This is similar to the studies from Goldman Sachs and Financial Times.

Markets for Clean Hydrogen

The assumptions of high- and low-demand scenarios have been assessed in detail. The Shell/DNV GL and Hydrogen Council-Net Zero scenarios were used to produce Figure 1.2. For 2020, nearly all hydrogen is fossil fuel based; for 2050, all hydrogen is clean. The analysis shows the importance of applications in industry and transport.

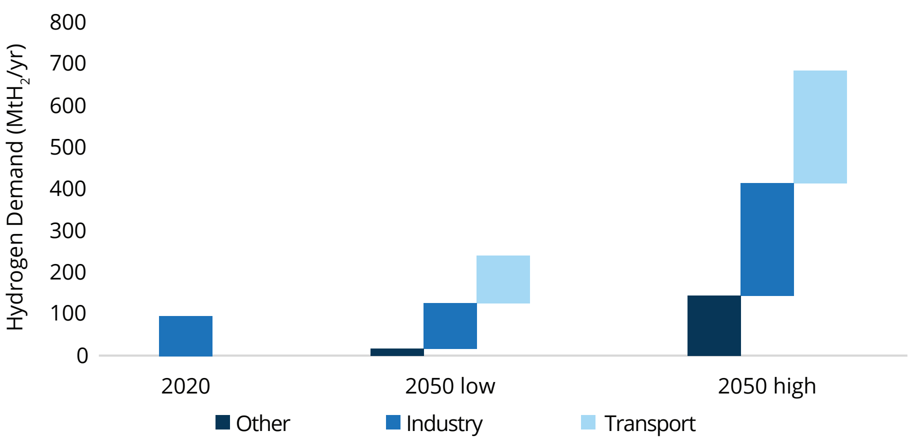
Hydrogen is difficult to transport because of its physical characteristics, so most hydrogen is processed and consumed on site. It is likely that local processing into derivatives (discussed below) will remain dominant in the near future; for that reason, the hydrogen economy has an important industrialization and development dimension.

Transport applications will include significant hydrogen derivatives such as ammonia, methanol, and sustainable aviation fuels (SAF). Hydrogen use in transport holds great potential, but its prospects are relatively uncertain compared to competing direct electrification and biofuel options.

In terms of industrial applications, clean hydrogen can also be used in refineries, but this application is likely to fade in coming decades under the 1.5°C scenario as oil demand falls. The production of ammonia, largely for fertilizer today, may grow as a shipping fuel and clean energy vector. Methanol production as a shipping fuel and feedstock for olefins may also grow. Finally, the use of hydrogen in the production of iron, steel, and sustainable aviation fuels is likewise projected to grow.

FIGURE 1.2

Global Hydrogen Consumption across End-Use Sectors



Source: Shell/DNV GL and Hydrogen Council & McKinsey Net Zero scenario.

Note: The industry and transport use cases include hydrogen derivatives such as ammonia, methanol, and synthetic jet fuel.

The four major hydrogen derivatives are ammonia, methanol, steel, and aviation fuel. Given their importance for global hydrogen sector developments they are discussed separately.

Ammonia. The Ammonia Energy Association maintains a database of clean ammonia projects (Ammonia Energy Association 2023). The database shows that 45 Mt of renewable ammonia capacity and 20 Mt of low carbon ammonia production capacity should be operational by 2030. In total, 133 Mt clean ammonia projects are under development in EMDCs (excluding China), half of all such projects under development worldwide. Of these, 1.6 Mt of capacity is under construction (Table 1.2). Combined, all projects currently under development worldwide represent hydrogen demand of around 40 Mt (the projects targeting 2030 represent 13 Mt), indicating the importance of ammonia for global hydrogen deployment through 2030.

Methanol. The Methanol Institute (Methanol Institute 2023) reports that 63 e-methanol projects are under development as of 2023; all are set to begin operations by 2027. These projects will produce 6.2 Mt e-methanol, representing 1.5 Mt of hydrogen demand. They include two projects in the Magallanes region of Chile (one being Haru Oni, at a total of 626 kt per year). Fifteen projects are under development in China, two in India (27 kt total), and one in South Africa (120 kt). In total, known e-methanol projects in EMDCs account for less than 1 Mt methanol in 2030.

Steel. Worldwide, 42 hydrogen-powered steelmaking projects have been announced (Leadership Group for Industry Transition 2023). At least three renewable steel plants are being constructed in the Middle East, with more under development in Brazil, Namibia, and South Africa, among other countries. Green steelmaking is being deployed on a commercial scale in Sweden and Spain (see below). Elsewhere in Europe and in China, a large number of renewable steel projects are under development. Renewable steel capacity could total 40 Mt by 2030, representing a hydrogen demand of around 2 to 4 Mt. Around half would be in EMDCs (excluding China).

TABLE 1.2

Renewable Ammonia Plants Under Construction in EMDCs (excluding China)

PROJECT NAME	CAPACITY (KILOTONNES)	COMMISSIONING
Oman Acme Duqm	105	2024–25
Brazil UNIGEL Camacari (Phase 1)	10	2023
Morocco GAP Jorf Lasfar	1.4	2024
India Renewable Himachal Pradesh	100	2024
Vietnam Tra Vinh	134	2026
Saudi Arabia NEOM	1,200	2026

Source: Ammonia Energy Association (2023).

Aviation Fuel. Blending mandates and production goals worldwide have the potential to trigger at least 12.8 Mt sustainable aviation fuel supply by 2030. The majority will be biofuel, of which around 1 Mt will be e-fuel, which translates into less than 0.5 Mt per year of hydrogen demand worldwide. E-fuels are expected to ramp up quickly after 2030.

Investment Needs Through 2030

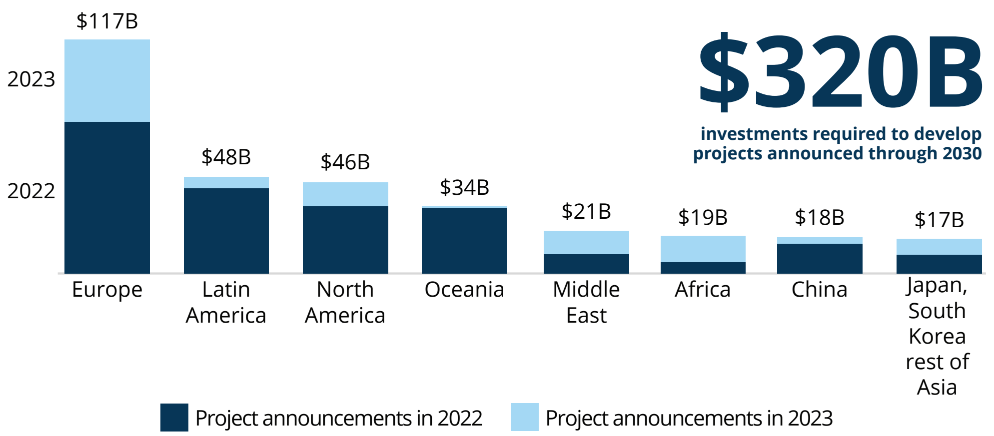
The number of renewable and low carbon hydrogen production projects in the pipeline grew from 230 in 2022 to 435 in 2023. Among these projects, the vast majority center on renewable hydrogen (412 projects, versus 23 low carbon hydrogen projects). About a quarter of all projects—115—are in EMDCs (excluding China) (Figure 1.3).

The Hydrogen Council estimates global clean hydrogen production financing needs between now and 2030 at $700 billion (excluding China and the renewable power generation component); only 4 percent of the required capital has been committed thus far. If renewable power in included, EMDC will need an investment of $700 billion between now and 2030, which translates into $100 billion per year (Figure 1.4). This compares with $450 billion of investments implied in the project pipeline. Only a fraction of these projects has reached the investment decision stage.

About 20 clean hydrogen projects in EMDCs outside China have reached the FID stage. Table 1.1 provides data on some of these. A much larger number are at various stages

FIGURE 1.3

Investment Needed to Develop Announced Projects Covering the Hydrogen Value Chain Through 2030 (billions of U.S. Dollars), and Project Investment Volume Growth 2020–23

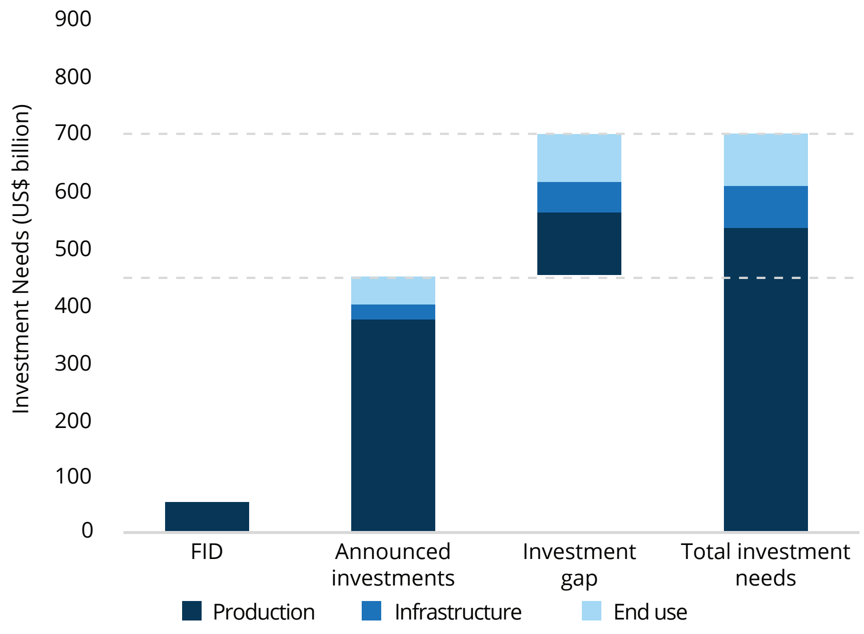


Source: The figure was adapted from Hydrogen Council 2022.

Note: Dark blue represents project investments in 2022; light blue, project announcements in 2023 across the value chain. Excludes the renewable power component.

FIGURE 1.4

Emerging Markets and Developing Countries Investment Needs Through 2030



Source: World Bank analysis based on Hydrogen Council and McKinsey (2023).

of preparation. These projects include production processes, as well as enabling infrastructure and end-use projects.

The largest and most advanced of the projects announced in developing countries is the $8.5 billion NEOM project in Saudi Arabia, which has reached financial closure. Oman has recently signed six agreements worth $20 billion with international developers to build renewable hydrogen production plants inside the country. Around 65 projects have been announced across the Middle East and North Africa (MNA) region. The World Bank is currently supporting deployment efforts in more than 10 countries, including Brazil, Chile, India, Mauritania, and Namibia.

Hydrogen Deployment

Global demand for hydrogen projects is high, but progress varies by region. So far, investment decisions are not commensurate with the 1.5°C pathways. At the end of January 2023, 1,046 clean hydrogen projects around the globe with a size in excess of 1 MW (production, infrastructure, and end-use) were in various stages of development (Hydrogen Council & McKinsey 2023). Less than 10 percent of all announced projects around the globe (production, infrastructure, and end-use) reached FID between 2022 and 2023, which represent $29 billion of investments (excluding the renewable power component). Most of these projects will be implemented in North America ($10 billion), Europe ($7 billion), China ($5 billion), and MNA ($5 billion).

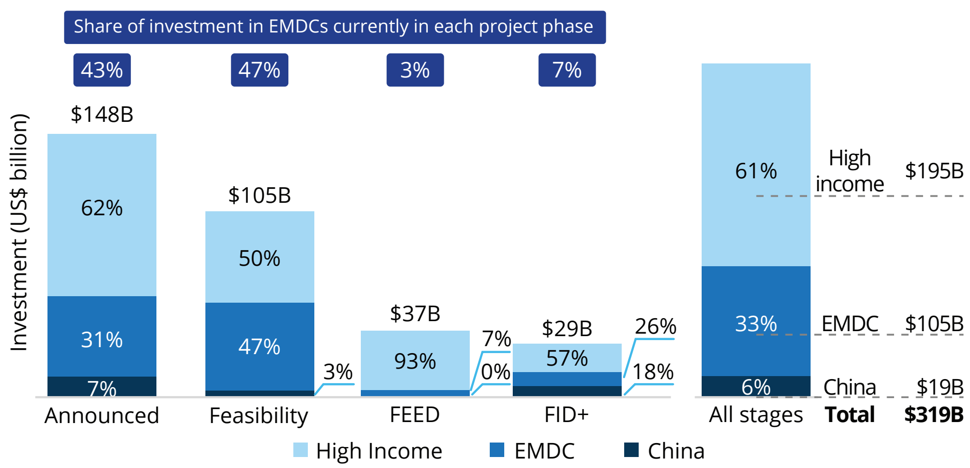
Companies around the globe have announced hydrogen production projects that would potentially produce about 25 Mt per year of renewable hydrogen and about 13 Mt per year of low carbon hydrogen by 2030. Sixty-six clean hydrogen production projects have reached the FID stage, 30 percent more than the previous year. These projects represent 2.1 Mt per year of clean hydrogen supply: 1.1 Mt of low carbon hydrogen (all in North America) and 1 Mt of renewable hydrogen (35 percent from China, about 20 percent from North America and the Middle East, and 10 percent from Europe).

In 2022, the number of announced production projects increased by 47 percent, and the number of projects at the FEED stage increased by 12 percent, while projects that had reached the FID stage increased by just 9 percent. Projects that had moved beyond the FID stage are slated to produce 1.5 Mt per year of hydrogen; another 1.5 Mt was at the FEED study stage.

Figure 1.5 shows the breakdown of projects by stage, differentiating high-income countries, EMDCs, and China. It shows that EMDCs are well represented in the early stages but underrepresented in the FEED and FID stages. More specific comments on the main stages of the projects follows.

FIGURE 1.5

Breakdown of the Global Clean Hydrogen Project Pipeline by Country Group and Project Phase Through 2030 (in US$ billion)



Source: Hydrogen Council (2023); McKinsey (2023).

Note: Investment numbers exclude the renewable power component. FID+ refers to any project at or beyond the FID stage.

Feasibility Stage

- The vast majority of gigawatt-scale projects have not yet moved beyond the stage in which feasibility is determined, indicative of the relative immaturity of the industry.
- Almost all gigawatt-scale projects announced in EMDCs are designed for export, implying that the opportunities and challenges of these projects depend on the development of an international market (Box 1.1).
- Estimates of unit investment cost vary widely because the definition of project boundaries varies from project to project, notably whether renewable power supply will be included and, if it is, at what cost.

Front-End Engineering Design Stage (FEED)

- Most FEED projects are less than 300 MW in scale. The number of large-scale projects in advanced stages of maturity is limited. So far, only one project (Hyphen) of more than 1 gigawatt (or more than $1 billion) is at the FEED stage.
- FEED-stage information is often not publicly announced. For that reason, the data appearing in this report should be viewed as indicative rather than exact. Because the market for hydrogen is still limited, real-world information on hydrogen pricing and production costs is scarce and in flux. More and better information is needed for policy makers, investors, and financiers.

Final Investment Decision Stage (FID)

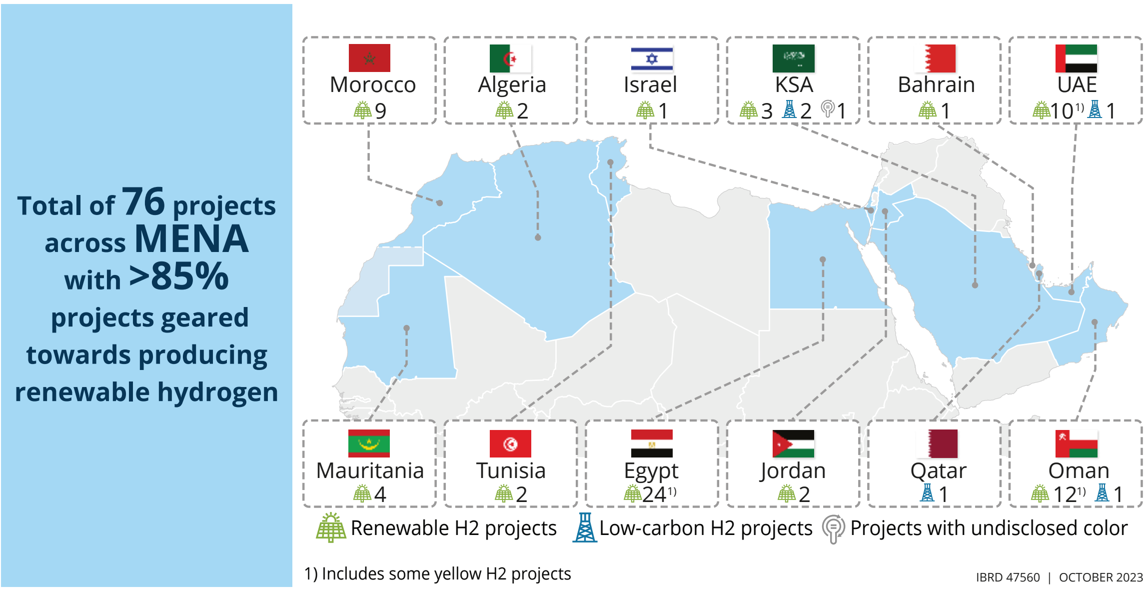
- One small low carbon hydrogen plant is in operation in the EMDCs (excluding China). The Al Reyadah plant in the United Arab Emirates produces 0.2 Mt hydrogen per year from an investment of $140 million.
- $6.2 billion has been committed in FID projects in EMDCs, exclusive of the capital cost of renewable power supply. If the latter is included, the commitment rises to $18 billion.
- Across the EMDCs (excluding China), there are only five renewable hydrogen projects of more than 10 MW, three of which have an electrolyzer capacity of more than 100 MW. As noted, only one product of more than 1 GW is in the FID stage.
- In EMDCs, only three existing post-FID renewable hydrogen projects with an investment volume of more than $100 million will be operational by 2030. These are NEOM in Saudi Arabia (2 GW electrolyzer), a green ammonia plant in Ba Tri, Vietnam (240 MW electrolyzer), and the Greenko green ammonia plant in Una, India (140 MW electrolyzer). These are trailed by the UNIGEL Camacari project in Brazil (60 MW, $80 million).
- More than half of the investments that have reached the FID stage in EMDCs are for production of hydrogen (55 percent). Much less investment has been made in infrastructure and end uses, both of which are needed to create an effective market.

One of the most active regions is MNA, where 76 clean hydrogen production projects were at various stages of development as of April 2023 (Figure 1.6). More than $70 billion in hydrogen projects have been announced since mid-2020. Egypt, Oman, Saudi Arabia, and the United Arab Emirates are at the vanguard of the growing renewable hydrogen economy in the region. Around two-thirds of proposed projects focus on ammonia production. The total clean hydrogen production capacity under development is 13 Mt by 2030; government targets account for about 4 Mt by that same year.

Chile and Brazil are the leading countries for hydrogen in Latin America, with Colombia emerging. H2Brazil has identified 42 hydrogen projects in the country, mainly concentrated in export hubs (Pecem in Ceara, Rio Grande do Norte, Bahia, and Porto do Acu). In Chile, important developments are concentrated in the north (Antofagasta) and south (Magallanes). Chile is home to some 36 renewable hydrogen projects. In Colombia, 28 hydrogen projects with 15 GW electrolyzer capacity are under development.[11] Total regional production estimates range from 2.2 to 6.3 Mt per year by 2030.

FIGURE 1.6

Clean Hydrogen Project Announcements in the Middle East & North Africa, by Country (as of Q3 2023)



Source: Dii and Roland Berger 2023.

[11] Hydrogen Colombia (2023) Colombia, a strategic country for hydrogen future. Projects report 2023.

India is targeting 5 Mt of renewable hydrogen production by 2030. Initially aimed at export, discussions are ongoing to obligate national consumption in industries such as refineries and steelmaking.

Mauritania, Namibia, and South Africa are the most active countries in Sub-Saharan Africa in terms of gigawatt-scale projects. Namibia has one major project (Hyphen) that has reached FEED stage, and several others in the pre-FID stage. In Mauritania, four megaprojects are being developed, while in South Africa, seven projects are under development. The World Bank is actively engaged in all three countries. Hydrogen efforts are spreading with activity in Angola, Djibouti, Democratic Republic of Congo, Ethiopia, Kenya, Uganda, and Zambia.

China is a particular case because of the existing size of its hydrogen economy (National Energy Administration China 2023; Chinese Government Network 2021). Of the 34 Mt hydrogen that China produced in 2021, 80.3% was produced from fossil fuels, 18.5% was industrial by-product (coke oven gas etc) and 1.2% was from electrolysis. This includes 0.1% from dedicated water electrolysis for hydrogen production (World Economic Forum, 2023).

As of the end of 2022, China has planned more than 300 renewable hydrogen production projects, 36 completed and operational projects, and the cumulative annual renewable energy hydrogen production capacity is approximately 56,000 tonnes. Among them, 23 new renewable hydrogen energy projects were completed and operational by 2022 (China Hydrogen Alliance, 2022). Two large production projects are scheduled to come onstream in 2023 (see elsewhere in this Chapter).

By 2025, the goal is to develop a hydrogen system where consumption is located close to demand, be it industrial by-product or renewable hydrogen production. The aim is to produce 50,000 hydrogen fuel cell vehicles per year and to develop an adequate refueling infrastructure. The target is 100–200 kt renewable hydrogen production per year yielding 1–2 Mt CO_2 emissions reduction per year (National Development Plan 2021–2035).

By 2030, the annual demand for hydrogen is expected to reach 37 Mt, accounting for approximately 5 percent of final energy consumption; renewable hydrogen production is projected to grow to 5 Mt, with 80 GW electrolyzer capacity.

According to the “China Hydrogen Energy and Fuel Cell White Paper” (2020) the number of hydrogen refueling stations in China will reach 1,500 in 2035 and more than 10,000 in 2050. By 2050 the production capacity of fuel cell systems target is 5.5 million units per year, the number of hydrogen refueling stations is 12,000, and the fuel cell vehicles stock will reach 30 million units.

Under the 2060 carbon neutrality vision, the annual demand for hydrogen will be expected to increase to about 130 Mt, 70 percent of which is renewable hydrogen. The industrial sector accounts for the largest proportion of hydrogen use, about 78 Mt, accounting for 60 percent of the total hydrogen demand; the transportation sector uses 41 Mt of hydrogen.

Business Models and Project Case Studies: Lessons from Global Best Practices

Project developers' expectations about how a hydrogen supply project can add value to its business varies. Depending on the business model, the design and scope of a project and its size may differ substantially. Because project developers have vastly different financing capabilities, their need for government support varies. A large number of case studies was categorized and assessed for this report, the goal being to identify best practices that may inform new projects. Only the highlights are presented here, followed by details of four projects.

Key lessons include the following:

- **Offtakers should be involved in the supply project, notably those further down the line, where sensitivity to the price differential between conventional and clean hydrogen is less.** The utility of this lesson is apparent in hydrogen steel production projects that involve car makers, or fuel projects being developed in cooperation with shipping companies. The model can be extended to aviation and other sectors.
- **Production of hydrogen derivatives adds complexity, but it yields products that are easier to transport** and where the price increase compared with conventional production is smaller in relative terms.
- **Involve financially strong partners in initial projects.** This refers to the equity owners and project developers, but also to the engineering, procurement, and construction contractors and offtakers.
- **Consider replicable project designs.** Evidence reveals key success factors such as locations with good solar and wind resources in combination with good infrastructure; they endeavor to develop similar projects. Experience from one project informs others and helps to create economies of scale.
- **Consider the presence and accessibility of fundamental infrastructure**, including electrical grids and transportation networks. These reduce project capital requirements and enhance economic viability.
- **Ensure the presence of resources to parry the risks that emerge at different stages of project design and production.** Effective policies and public support play a pivotal role in addressing immediate risks, but each risk requires separate solutions. In the early stages of the market, upfront capital grants may be needed to meet initial capital expenditure requirements.

Governments can better gauge the viability of a project if they understand its business drivers. Basic business models are categorized in Table 1.3, which does not purport to be comprehensive, as hundreds of companies are active in the hydrogen field. There may be some overlap between models 1 and 2; this is a subject for further work.

To expand on the general categorization, four case studies are presented below. The case studies illustrate important best practices in their financing structures, offtake arrangements, and selection of partners. Also, these projects are at an advanced stage of development, which makes it possible to make fact-based observations.

TABLE 1.3

Categorization and Examples of Business Models

MODEL 1	MODEL 2	MODEL 3	MODEL 4
DECARBONIZING EXISTING PROCESSES	**EXPORT MODEL**	**UTILITIES AND OEMs GOING DOWNSTREAM TO CREATE LARGER MARKETS**	**HYDROGEN HUBS**
• Oil refineries deploying clean hydrogen *Examples:* Adnoc, Ecopetrol, Exxon Mobil, Reliance, Saudi Aramco, Shell, Sinopec • Gas producing and transporting companies deploying clean hydrogen *Examples:* Gassco, Qatar Energy, SNAM • Fossil fuel-based power producers deploying hydrogen or ammonia in existing power plant *Examples:* Utilities in Japan and Korea • Ammonia producers deploying clean hydrogen *Examples:* Fertiglobe, OCI, Yara<	• Existing fossil fuel companies moving into clean hydrogen production *Examples:* BP Australia, Equinor/Scatec Egypt, Sasol South Africa, Shell Oman, Total Eren Mauritania • New players entering the clean hydrogen industry *Examples:* CWP Mauritania, Hyphen Namibia, Renewable Solutions (TSG) Vietnam	• OEMS and renewable project developers: *Examples:* Electricity utilities ACWA power (NEOM Saudi Arabia, Cambodia, Uzbekistan), Engie, Iberdrola Orsted (offshore wind projects) and Vestas (wind turbines) plan to go into offshore hydrogen production; some Chinese photovoltaic manufacturers and the Chinese wind turbine manufacturer Enlit have entered hydrogen manufacturing.	• Hydrogen hubs are networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy carrier and feedstock. The hubs are not single facilities but refer to a collection of linked assets that will work together to develop the domestic hydrogen economy. *Examples:* The Mission Innovation hydrogen Valleys platform counted 83 hydrogen valleys or hubs worldwide across 33 countries with a total investment volume of $140 bln as of September 1st https://h2v.eu/

NEOM Ammonia (Saudi Arabia)

NEOM Green Hydrogen Company (NGHC, https://www.nghc.com/) is building the world's largest green hydrogen plant to produce green ammonia at scale in 2026. Located in Oxagon, Saudi Arabia, the $8.4 billion plant includes 4 GW of renewable energy generation and will produce 219,000 tons of carbon-free hydrogen per year using electrolyzer technology provided by ThyssenKrupp Nucera. Ammonia will be generated using Air Products' air separation technology. Baker Hughes will provide hydrogen compression units.

NGHC is a joint venture in the form of a public-private partnership between ACWA Power (a private power generation developer and investor from Saudi Arabia), Air Products (a global provider of industrial gases and engineering, procurement, and construction contractor) and NEOM (a private company from Saudi Arabia building a $500 billion urban project). The joint venture was formed as a vehicle to develop, build, own, operate, and finance the project.

NGHC is funded by a mix of 27 percent cash contributions and shareholder loans from the sponsors, and 73 percent non-recourse project financing, according to Air Product's financial statements. Financial closing was announced in May 2023, including $6.1 billion in non-recourse financing from 23 local, regional, and international banks and financial institutions. This is divided into $5.8 billion in senior debt, with the remainder from mezzanine debt facilities. The Saudi government has played a fundamental role in the financing, contributing more than 40 percent of the total financing. This includes $1.5 billion from the National Infrastructure Fund and $1.25 billion in financing from the Saudi Industrial Development Fund.

The project has several additional competitive advantages, the main one being the production of low-cost electricity, owing to the availability of abundant and high-quality renewable resources (wind and solar). The complementarity of these resources onsite plays an important role and is a condition that the developer takes into account when searching for new project locations.

Access to European and Asian markets is another competitive advantage. Logistics play a relevant role in green hydrogen's cost structure, and NGHC will have access to a large-scale seaport in the Red Sea.

In addition, NGHC has solid de-risking instruments. One of the project's main advantages is that equity providers are also in charge of carrying other project risks, such as a technology risks (Air Products, ACWA Power) and project completion risks. The integration of technologies along the value chain is provided by major industry players, such as Thyssenkrupp Nucera (electrolysis), Topsoe (green ammonia), and Baker Hughes (hydrogen compression). Offtake risk has been mitigated by the 30-year offtake agreement signed by Air Products. The long-term agreement allowed the partnering corporations to structure non-recourse, project financing debt, thus minimizing guarantee and liquidity risks. Country risk is also being partially mitigated through the participation of the Saudi government as an equity investor (through NEOM) and as main provider of project financing.

NGHC will produce green ammonia in an end-to-end processing facility covering all technologies in the value chain from renewable power generation and desalinated water to hydrogen and green ammonia production. The scale of the project, aided by favorable power resource availability, suggest that NGHC will be able to produce green hydrogen at costs lower than $3/kg, which makes the project highly competitive, and to produce green ammonia at around $700/tonne.

H2 Green Steel (Sweden)

H2 Green Steel, founded in 2020 by Vargas (also the founders of Northvolt), is establishing a large-scale green steel production facility in Boden, Northern Sweden. The company is focusing on using green hydrogen in industrial applications with the purpose to speed up the decarbonization of high emitting sectors. It chose green steel as its initial application for its advanced technical and commercial readiness compared with other alternatives. The project includes a ~800 MW electrolysis capacity, to be supplied by OEM ThyssenKrupp Nucera, a direct reduced-iron plant capable of producing 2.1 Mt per year, a steel melt shop, and downstream production lines capable of producing 2.5 Mt of finished steel products annually. The latter should ramp up to almost 5 Mt before 2030 in a phase 2 investment.

Affordable and stable renewable electricity is vital for H2 Green Steel, influencing the decision to position energy-intensive plants near Sweden's hydropower resources and fast-growing wind power capacity. Efficient logistics infrastructure and deep-sea harbors are crucial for the steel trade. Other factors considered by the company were a transparent and credible permitting processes, regulatory stability, and positive community engagement, all of which reduce country risk for lenders. The project's positive reception by the local municipality and Sweden's high awareness and engagement in climate change in general, had an impact on investment decisions.

H2 Green Steel follows a typical industrial governance structure, utilizing a holding company for equity investors and establishing individual project companies for each new project. As the company will focus on industrial offtake of green hydrogen, it may concentrate on hydrogen production, potentially exploring vertically integrated projects with green electricity suppliers and green hydrogen offtakers.

H2 Green Steel is financing its initial project through a blend of equity at the holding level and debt at the level of the Boden project, targeting a gearing ratio similar to other capital-intensive industry and infrastructure projects. The full financing of the project is greater than 5 billion Euros with the debt package from a large bank consortium covering 3,5 billion Euros. The company's equity investors are, in addition to the Boden project, investing in the overall ambition to decarbonize heavy industries. More than 50 percent of project Boden's planned first 5–7 years phase 1 production, is already contracted. The plan is to start operation in late 2025 reaching full production in 2026.

Hyphen Hydrogen Energy (Namibia)

Namibia's government has an ambitious plan to develop green hydrogen for deployment of renewable energy at scale, facilitating both energy independence and green economic growth in the country led by industrialization. In August 2021, the government issued a request for proposals to develop green hydrogen production facilities in two parcels of land in the Kharas region, which has the highest resource potentials worldwide for the combined production of wind- and solar-based electricity. The request for proposal (RFP) was part of the Southern Corridor Development Initiative (SCDI), the umbrella program for the development of a green hydrogen industry in southern Namibia. The government was responsible for designing and administering the tender in an open and transparent manner. In evaluating the tenders, the government drew on international expertise from two advisors appointed by the European Union Global Technical Assistance Facility on Sustainable Energy and the United States Department of Energy.

Although SCDI is a government-led process, public financing of such large projects is constrained by the size of the Namibian economy. The government aimed to hold a 24 percent equity share in the project, allowing international actors to acquire stakes. However, most of the financing would be sourced from debt instruments.

Hyphen Hydrogen Energy, a partnership between its two shareholders, Nicholas Holdings and Enertrag, was selected by the Namibian government in November 2021 to develop a large-scale vertically integrated greenfield green hydrogen project in the Tsau/Khaeb national park (SCDI area). The allocated area is owned by the government and co-located with the deep-water port of Lüderitz. The company's governance structure is based on a public-private partnership. The financial closure is expected in 2024, and the Namibian government, potentially through the Welwitschia Sovereign Fund, aims to be a strategic equity partner.

Development finance institutions and commercial lenders have shown substantial interest in blended finance solutions to facilitate the project's financial closure. This approach addresses the challenges of accessing local currency debt instruments and paves the way for the project to reach its financial goals.

Hyphen Hydrogen Energy is a Namibian registered green hydrogen development company working with the government to develop Sub-Saharan Africa's largest—and only fully vertically integrated—green hydrogen to green ammonia project.

Government support has been a critical enabler for the development of the Hyphen project. The government has defined its ambition, set a clear strategy for the development of its green hydrogen industry, initiated the request for proposals, and is providing the land. A clear master plan fostered confidence in the project despite it being a complex cross-ministerial endeavor. In addition, the government facilitated an early stakeholder engagement to address the environmental, social, and governance issues. In addition, the government established the Green Hydrogen Council, comprising key ministers responsible for the country's green hydrogen strategy.

The transformative impact potential of this project on Namibia and its economy is considerable. The total project capital investment of more than $12 billion is roughly equivalent to the country's annual gross domestic product (GDP). This project alone will cut 5 to 6 Mt (annually) of global CO_2 emissions. (Namibia's total emissions in 2021 were 4.01 Mt.)

The project will be built on ~4,000 km^2 of land. Hyphen is targeting annual production of 1 Mt of green ammonia to become available by the end of 2027, expanding to 2 Mt by the end of 2029. Much of the green ammonia produced will be exported to the international market and the ammonia demand centers of Europe, South Korea, and Japan. The project integrates approximately 5 GW of wind and solar energy capacity with 3 GW of electrolyzer capacity.

As a part of the project, Hyphen will develop a common user infrastructure, encompassing a desalination plant, water pipelines, electricity transmission lines, hydrogen pipelines, and an ammonia storage and export facility. The establishment of the common user infrastructure will benefit all subsequent projects, facilitating the scale-up of hydrogen production in the SCDI project portfolio and potentially leading to up to 3 Mt of green hydrogen production per annum. This represents one-fifth of Namibia's total green hydrogen production potential of 15 Mt per year (5–10 percent of expected global hydrogen demand in 2030).

This project is designed to act as a catalyst for the establishment of an entirely new industry in Namibia. Located in the south, it is one of what could become dozens of equivalent-sized hydrogen projects across Namibia's three hydrogen valleys along the country's 1,500 km coastline.

The country has the potential to produce up to 15 Mt of green hydrogen each year and to sustain ~200,000 direct jobs, making it one of the largest potential producers of renewable hydrogen globally.

With no international precedent for the development of a large-scale green hydrogen project between a host government and a developer available, the government and Hyphen worked closely together over 16 months to develop a concession agreement that can be considered a global benchmark for equitable and environmentally sustainable green hydrogen projects. The concession agreement, which governs the process under which Namibia's first renewable hydrogen project will be operated for a 40-year term, was signed in May 2023.

This agreement sets out the project's financial obligations to the government for the duration of the concession term (land rentals, environmental levies, royalties). It also crucially details the process of enabling a legislative and fiscal regime for the build-out of the entire Namibian renewable hydrogen industry.

The Namibian government's 24 percent equity interest in the project will be held through SDG Namibia One, a blended financing infrastructure fund that will initially be wholly owned by the government. The government has raised €40 million from the Dutch government to fund the costs of the project through financial close and has secured a letter of intent from the European Investment Bank of €500 million in funding, which should be sufficient to fund 100 percent of the government's equity requirements for phase one of the project.

Green Solutions (Vietnam)

Green Solutions is an energy company in Vietnam founded in 2016, undertaking multiple local projects, including a liquefied natural gas terminal, biomass plants, wind and solar power plants, and green hydrogen production plants.

The company is developing two green hydrogen projects in southern Vietnam, each with 260 MW of electrolyzer capacity. The projects will produce hydrogen using surplus renewable electricity, with the first project in Tra Vinh Province expected to generate 48,000 m^3 of hydrogen per hour. The corresponding green hydrogen output of 32 kt will be used to produce 220 kt of ammonia each year. The projects reached the FID stage in 2021 and are set to be operational by early 2026.

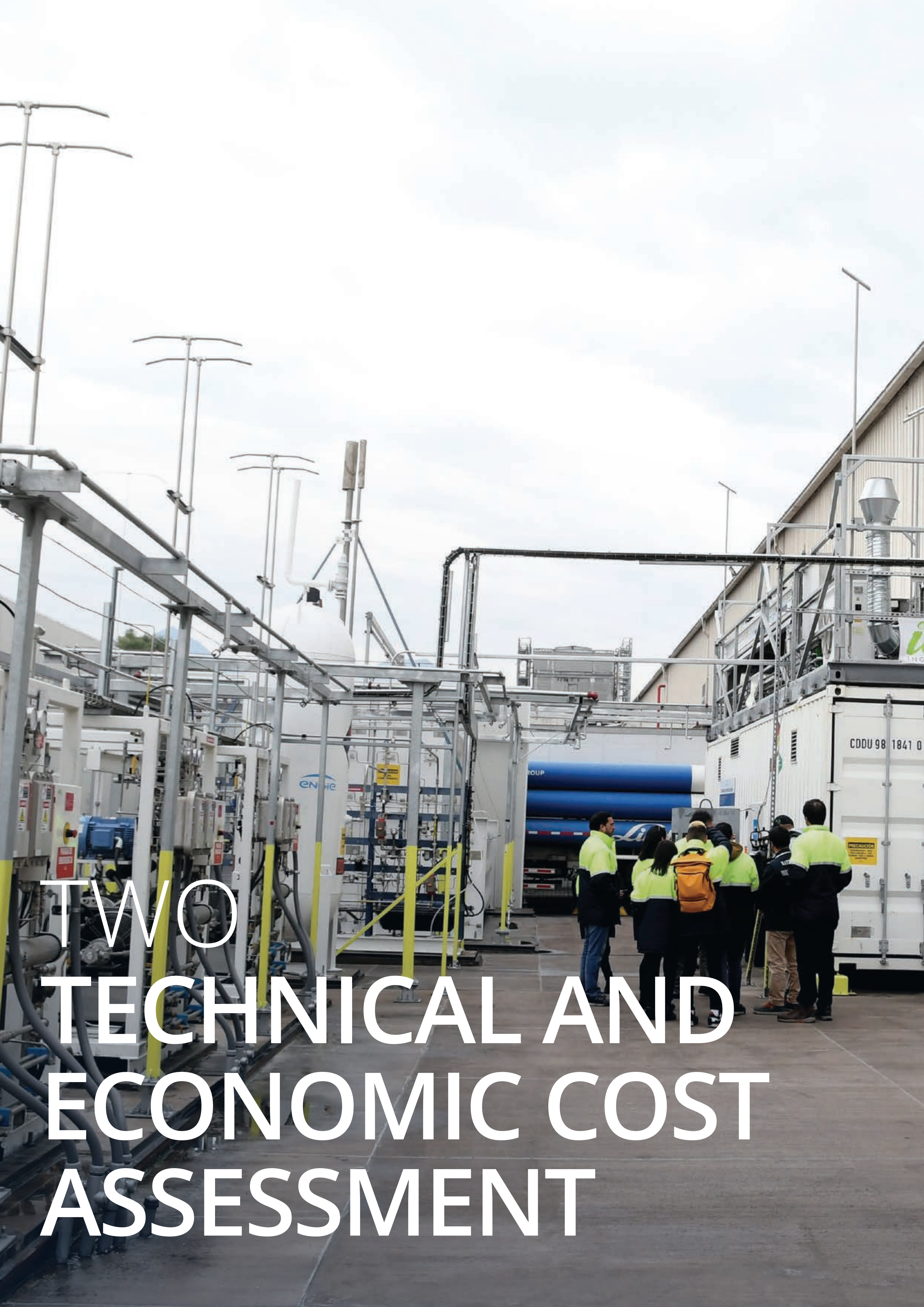
Each project will be carried out by a special purpose vehicle with Green Solutions as the parent company and majority shareholder. The special purpose vehicles will focus on project development, construction, and operations, while the financing and commercial discussions with offtakers will be done at the Green Solutions group level.

Green Solutions intends to export most of its green hydrogen and has received interest from potential offtakers in Japan, South Korea, Singapore, and Europe. The company is also exploring local market development and is developing port infrastructure with ECONNECT Energy.

For its first projects, Green Solutions is working on project finance solutions with a flexible mix of equity and debt. The company remains the majority shareholder and intends to raise debt from development finance institutions at concessional rates. For future projects, it will explore flexible co-investment opportunities for renewable electricity production, green hydrogen, and green ammonia plants.

In addition, as the green hydrogen and green ammonia markets become more mature, Green Solutions plans to issue green bonds to finance future projects or raise capital by undertaking an initial public offering in a well-established stock market.

eNGie
PELIGRO ELECTRICIDAD
PLUG POWER
2069
9755
Walmart Chile
GENDRIVE



TWO
TECHNICAL AND ECONOMIC COST ASSESSMENT

Key Points

- The information presently available on costs and prices for clean hydrogen is insufficient to guide policymaking and investment decisions. More accurate information is urgently needed.
- Clean hydrogen prices vary widely by region and project type. The production cost of conventional hydrogen is correlated with the price of natural gas, which is volatile. As a reference value, $1/kilogram (kg) is commonly used for conventional hydrogen produced under favorable conditions; this price can rise to $2/kg in regions with higher gas prices.[12] For low carbon hydrogen (produced from gas or other fossil fuels), the production cost is $2/kg. Finally, for renewable hydrogen (i.e., hydrogen produced from renewable power, such as wind and solar), today's lowest production cost is $3/kg for best-in-class projects with an average of $5/kg; that cost can rise to more than $10/kg where renewable resources are inadequate, and equipment and financing costs are high.
- Policymakers—particularly in emerging markets and developing countries (EMDCs) that are in the process of developing and implementing national hydrogen strategies—must consider the developments of real projects and not design policies based on optimistic projections or theoretical project scenarios. Presently, achieving $3/kg production cost for renewable hydrogen is only possible with a combination of factors, including very low-cost renewable power supply, low capital cost of electrolyzers, and access to low-cost financing. Renewable hydrogen production could fall to as little as $2/kg if the costs of renewable power generation electrolyzers decrease. However, the trends in the last two years suggest stable or even rising costs.
- Global cumulative investment of $1 trillion (including in renewable power supply) is needed to reach a clean hydrogen production capacity of 40 Mt per annum by 2030. Adding the costs of related infrastructure and end uses, this amount may double to $2 trillion. Realizing these investments could create significant socioeconomic benefits and make a compelling case to transition to renewable hydrogen in EMDCs.
- A quarter to half of the total global financial support needed between now and 2030 to scale up clean hydrogen would be directed to EMDCs. If we account for production, transport, and end use, the central estimate for the global gap between the financing needed and the financing available is $0.5 trillion (with a best-case scenario of $174 billion). The EMDCs' share of the financial support need translates to $10 to 40 billion annually between now and 2030. The wide range stems from the uncertainties and challenges that surround the hydrogen industry's development.
- Transport and storage costs will affect the competitiveness of renewable hydrogen in countries considering importing hydrogen. Intercontinental shipping of hydrogen can double the landed cost of renewable hydrogen. Pipeline supply is a more cost-effective solution over distances up to several thousand kilometers, especially in the European

[12] These reference cost data exclude any environmental external costs related to natural gas. However, the cost of CO_2 treatment can push the cost up to $2 per kg.

context. High transport costs may lead to the relocation of industrial production of green hydrogen derivatives such as renewable ammonia and green steel production.

- National governments can reduce the financial support required for the development of domestic hydrogen markets through: (1) innovation, (2) careful choice of project location, (3) developing and supporting niche markets willing to pay a premium for clean hydrogen, (4) pricing the externalities of emissions greenhouse gases, and (5) access to low-cost financing. Early action could set in motion a virtuous cycle of cost reductions and lower needs for financial support.

A Breakdown of Clean Hydrogen Production Costs Today

There is no single estimate of the cost of clean hydrogen today. Real-world hydrogen cost metrics are complex, and generalized comparisons can be misleading. This assessment takes cognizance of existing metrics such as the levelized cost of hydrogen (LCOH) while pointing to their limitations for making financial decisions.

What is known to be true is that costs vary widely by region, country, and project. In the most-favorable production locations, LCOH is estimated at $1/kg for conventional hydrogen, $2/kg for low carbon hydrogen, and $3/kg for renewable hydrogen. Especially the cost of renewable hydroegn vary widely and can be much higher, depending on local circumstances.

Beyond these generalities, comparing results from various studies requires a good understanding of how costs have been calculated. Simplified LCOH calculations tend to underestimate the real-world costs of project implementation, which may include "project-specific infrastructure needs, taxes, royalties, concession payments and local content requirements" (Agora 2023). More clarity and a uniform basis for comparison are needed. In a promising development, the European Energy Exchange features a new real-time listing of renewable hydrogen trading prices in Germany every week (European Energy Exchange 2023). Trading prices do indicate a combination of LCOH and market circumstances, but robust policymaking and investment decisions require real LCOH data, as well as data on transport costs.

LCOH can be misleading for policymaking and investment decisions because it excludes transport costs, which vary from one region to another. If shipped intercontinentally, the transport costs can be double the production cost of best-in-class renewable hydrogen projects.

Eventually, clean hydrogen will be a widely traded commodity. For that reason, the costs of transport and storage must be added to the production cost. For the end user, after all, what matters is the delivered cost of the commodity—the supply cost. Therefore, for a country with a choice between producing renewable hydrogen domestically or importing it, the cost of transport can make production at home the economically preferable solution. These costs must be assessed on a case-by-case basis.

Accurate cost information is also scarce because very little clean hydrogen is traded today. A significant body of literature discusses hydrogen production, and end-user costs. Its overwhelming focus is production costs; analyses rarely address the costs of transport, storage, and processing.

Since most hydrogen is presently produced and consumed on site, trading generally occurs under bilateral contracts that tend to be confidential. So, there is little information about the actual cost of producing hydrogen from real projects. Most of the available literature uses modeled cost estimates. A comparison of modeled cost estimates with the few real-life project data available suggests that desktop research underestimates actual costs (Agora 2023). Site-specific analyses to produce renewable hydrogen and its derivatives at the regional level is needed to produce reliable cost estimates that reflect the actual conditions in countries. Data from real projects would be even better.

Transparent markets exist for hydrogen derivatives such as ammonia, the price of which is determined chiefly by hydrogen production costs. Ammonia prices rose to unprecedented levels in the last two years but fell recently—to around $275 per tonne in end-June 2023 from a peak of more than $1,000 per tonne in early 2022 (DTN 2023). The current ammonia price translates to around $1/kg of hydrogen.

For low carbon hydrogen, the cost of CO_2 pressurization, transport, and storage are in the range of $25 to 75/t CO_2.[13] Given emissions of at least 10 kg of CO_2 per tonne of conventional hydrogen, this translates into a low carbon hydrogen production cost of $1.25 to 1.75/kg. The cost of low carbon hydrogen depends on the effectiveness of CO_2 removal. Today's steam methane reforming technology is not suited for deep CO_2 reductions. Auto thermal reforming technology is better suited, but the costs are somewhat higher. Also, upstream methane emissions can be significant in the total greenhouse gas (GHG) balance; these need to be addressed to achieve significant mitigation. But this process will not change the economics significantly. For today's low carbon hydrogen, a production cost of $1.5 to 2/kg is assumed in low-cost locations.

For low carbon hydrogen, the cost drivers are natural gas prices and financing. Forward prices for natural gas have dropped since last year, making the average LCOH for low carbon hydrogen projects around 60 percent less expensive than renewable hydrogen projects being financed in 2023. Despite this incidental short-term trend, renewable hydrogen will likely be less expensive than low carbon and conventional hydrogen in the coming decade.[18]

As noted, the cost of renewable hydrogen production depends on the cost of renewable power and the capital cost of equipment, notably electrolyzers, as well as financing costs. In today's best locations and under optimistic assumptions, the production cost can be

[13] While CO_2 enhanced oil recovery can create benefits that offset these costs, this option was excluded from this analysis as the additional oil production nullifies the CO_2 reduction efforts.

as low as \$3/kg. This level can by no means serve as a benchmark for national policies or hydrogen strategies, however, since the LCOH could be significantly higher because of lower quality renewable resources and high capital costs of equipment. For example, the cost of an electrolyzer system varies significantly from less than \$500 per kilowatt (kW) in China to as much as \$2,000/kW elsewhere. Differences in capital costs are explained by economies of scale, which in turn are based on the production capacity of the manufacturer and the size of the electrolyzer unit, as well as the type and quantity of materials used in different electrolyzer technologies. Technical and operational parameters of technologies also affect cost ranges. Whereas electrolyzer cost were projected to fall rapidly this has not happened in recent years for various reasons. However manufacturers remain confident that innovation will bring down cost in the coming years.

It is essential to understand the breakdown of production costs and the extent to which production cost factors apply across countries and regions. As noted in the previous paragraph, cost estimates depend on assumptions related to the technical and economic characteristics of the equipment. But the starting point for renewable hydrogen is the availability of renewable electricity and desalinated water. Around 55-kilowatt hours (kWh) of alternating current are needed per kilogram of hydrogen, as well as 9 liters of desalinated water. The cost of electricity varies. Using a general estimate of \$0.02/kWh, which is rather optimistic under today's conditions, the cost of electricity would be \$1.1/kg of hydrogen produced. In fact, electricity supply cost will be higher in most locations. The expectation is that electrolyzer costs will fall rapidly in the coming years and that future projects will benefit from large-scale, less expensive electrolyzers, leaving electricity as the determining cost factor. Operational factors, such as capacity utilization factors of renewable power plants and electrolyzers, will continue to contribute to the production costs.

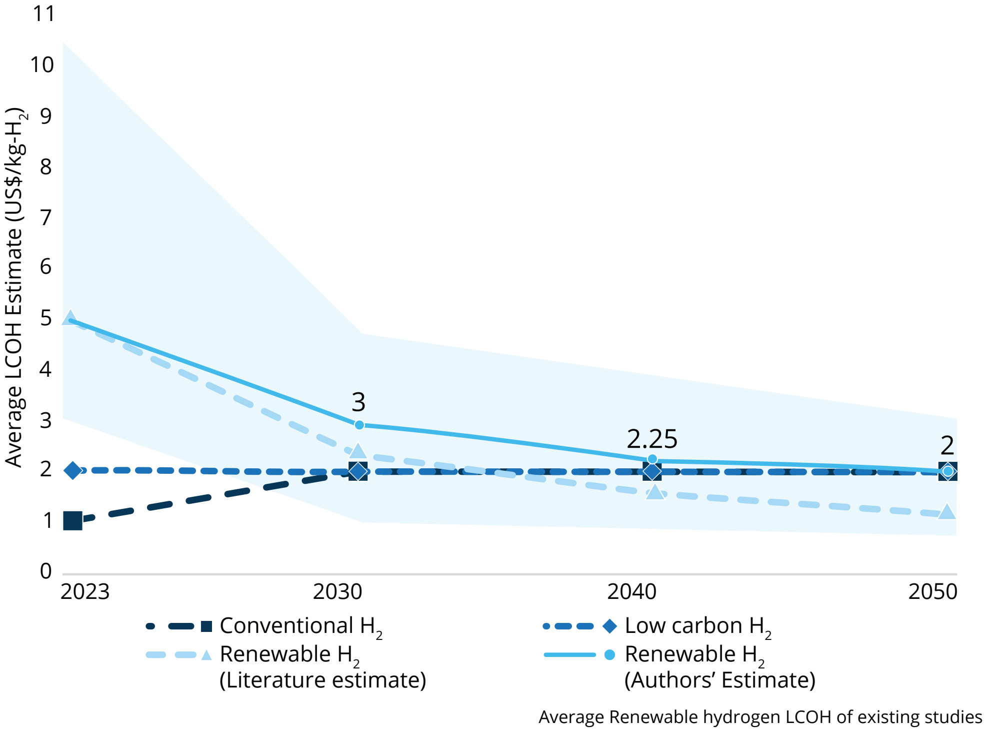
Again, planning financial and policy support for clean hydrogen requires a better understanding of the true cost of producing it. The use of faulty cost assumptions may hamper the effectiveness and efficiency of financing instruments. For this study, the authors complied a comprehensive list of estimates from 26 sources. Figure 2.1 provides a snapshot of renewable hydrogen production estimates, which can be seen to vary widely across regions. As the figure shows, the average LCOH for renewable hydrogen is around \$5/kg today, though the costs of some projects could be more than three times those of best-in-class projects. While international trade could be beneficial, it involves, as already noted, additional costs beyond the LCOH that must be considered when different supply options are compared. Trading costs will also affect the financial support needed for the global hydrogen economy to materialize. Additionally, the presence of carbon markets and accounting for environmental externalities could raise the costs of low carbon and conventional hydrogen, favoring clean hydrogen.

The bottom line is that better cost information is a prerequisite for policymaking, even as innovation continues apace, lowering costs even while good data remain unavailable.

The cost of capital accounts for 30 to 50 percent of the total cost of renewable hydrogen production, reflecting risk perceptions. Thus, a lower cost of financing would significantly reduce overall cost estimates. Renewable hydrogen is presently at least three times more

FIGURE 2.1

Levelized Cost of Hydrogen Estimates for Renewable Hydrogen Production, 2030–2050



Source: Authors' estimates for renewable hydrogen and compiled range of estimates for different types of hydrogen based on 26 global studies published after 2021.

Note: The figure above captures a range of cost information for different project types and sizes across studies. The LCOH of grey and blue hydrogen reflects the best production locations. Further, we assume a carbon price of $100 per tonne taking effect in 2030 and remaining until 2050 for conventional hydrogen production. This translates to an additional $1/kg of H_2 above the conventional LCOH. We ignore the negative externalities of methane emissions.

expensive than conventional hydrogen, but, as noted, the cost gap is projected to shrink in coming years because of learning and reduction in costs. In addition to technical aspects, lead time to procure equipment and longer construction time adds to financing costs. Still, some financing gap will remain between green and conventional or low carbon hydrogen production.

The existence of a financing gap does not imply that governments must fill it via subsidies; other policy interventions are recommended, such as the pricing of CO_2 emissions, accounting for environmental externalities related to non-CO_2 GHG and air pollutant emissions, and mandates for renewable hydrogen consumption in industrial applications and transportation. Such policy initiatives would help to reduce the cost of finance by reducing the perceived risks of hydrogen projects. A detailed discussion of risk-reduction strategies follows in chapter 3.

Compared with renewable power supply, capital, and financing, other factors have a marginal impact on the LCOH (5–15 percent). These include the costs of engineering, procurement, and construction; operation and maintenance; hydrogen purification; cooling and compression of gas; and water supply (including water conditioning and, where relevant, desalination). Figure 2.2 breaks down costs for best-in-class projects with the most optimistic production costs—namely an LCOH of less than $3/kg.

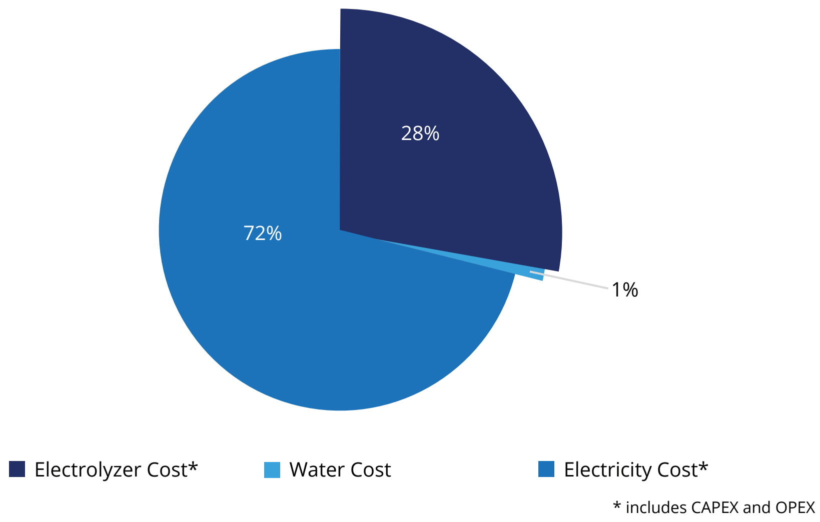
Most studies point to a rapid cost reduction for renewable hydrogen, with cost competitiveness by the 2030s. However, the rate of cost reductions in the medium and long term is uncertain. A lack of historical market experience compounds the challenge, making accurate projections difficult. Yet, the long-term prospects of renewable hydrogen remain promising.

Even so, the accelerated scale-up of renewable hydrogen deployment may increase the need for financial support. In this context, focusing project choice and design solely on the abundance of natural resources would be unwise. A better approach would be to focus on key enabling factors in a holistic manner. The reality today is that less than 2 Mt of clean hydrogen is manufactured each year. To meet the 40 Mt target by 2030—a central assumption of this study—implies a 20-fold increase over the next seven years. Regional and global

FIGURE 2.2

Breakdown of the Best-in-Class Renewable Hydrogen Projects with LCOH of $3/kg, 2023

The percentages have been rounded and therefore the total could be greater than 100.



Source: Authors' calculation.

Note: An LCOH of $3/kg, representative of "best-in-class" projects, is used for the estimation. The breakdown assumes a co-located renewable power plant and electrolyzer. Transmission costs of electricity do not apply. Electrolyzer efficiency is assumed to be 57%; the system requires 15 liters of water per kilogram of hydrogen. Water production requires 2 kWh per cubic meter (m3) and is supplied from a desalination plant with a capital cost of $3/liter/day. Assumed capital costs of equipment are $2,400/kW for offshore wind, $800/kW for onshore wind, $400/kW for solar PV, and $750/kW for electrolyzers with capacity factors of 50%, 40%, 25%. A discount rate of 10 percent and a lifetime of 20 years are assumed, yielding an annuity of 11.4%.

market dynamics can lead to supply chain disruptions and potential scarcity in the market for commodities that are essential for the clean hydrogen transition. Such disruptions can have a cascading effect, where scarcity of resources on the deployment side could push up the cost of clean hydrogen supply. An example is evident in today's market for electrolyzers. If costs do not decrease as foreseen, the financing gap will widen, making it increasingly difficult to meet projected targets by 2030. This problem deserves attention. The cost-reduction potential of electrolyzers through "innovation" and "economies of scale" is generally deemed to be significant, but if costs remain higher than what many forecasts suggest, perhaps because market dynamics fail to provide the required demand, the financing gap for renewable energy could remain high.

Favorable conditions for both wind and solar photovoltaic (PV) power generation, in many cases, can be more advantageous than extremely good conditions for just one of these renewables at any given time. A good supply of such "hybrid" locations leads to higher utilization and a lower need for intermediate hydrogen storage.

Costs of Renewable Power Generation

Renewable electricity costs are key to the cost competitiveness of renewable hydrogen. In principle, to make a renewable hydrogen project viable (assuming other cost factors allow for competitiveness), electricity should be available at less than $0.03/kWh. Many studies assume $0.02/kWh for electricity generation from wind and solar energy. In the past few years, announcements of least-cost solar PV plants with a levelized cost of electricity below $0.02/kWh have come from the Middle East (Abu Dhabi, Qatar, Saudi Arabia), southern Europe (Portugal, Spain), and Latin America (Brazil, Chile). However, today's average global renewable electricity generation costs are substantially higher. Global average utility-scale solar PV generation costs stood at $0.049/kWh in 2022, onshore wind at $0.033/kWh, and offshore wind at $0.081/kWh (International Renewable Energy Agency 2023) the targeted electricity cost.

Whereas most studies assume falling costs of renewable electricity, these costs have been rising in many regions. The COVID-19 pandemic, the global energy crisis, rising inflation, and supply chain congestion have stalled a trend in falling investment costs, pushing up costs (BloombergNEF 2023). It remains to be seen when the downward trend will begin.

Financing costs, too, have risen due to increasing interest rates. The combined effect weighs on electricity prices similar to other sectors of the economy. However, there is some evidence that costs of renewable power will be lower in the second half of 2023 than in 2022—and that this trend will continue in coming years. Yet, a widespread renewable power supply cost of less than $0.02/kWh is not a given today or in the medium term. In the context of hydrogen production, the issue is even more challenging if one considers the need for complementary low-cost solar and wind power supply or the use of offshore wind with a sufficiently high-capacity factor. Therefore, it will be essential to explore which hybrid renewable energy concepts could best provide low-cost renewable power supply and allow for high-capacity utilization factors for electrolyzers. As noted at the end of the previous section, conditions that allow for combined generation of electricity from both wind and PV power are more advantageous than relying on extremely good conditions for just one.

Apart from the levelized cost of electricity, the costs of electricity storage and transmission must be considered in the case of renewable hydrogen production. Typically, it is expected that large-scale hydrogen projects will be co-located with or near a renewable power plant. This is ideal since no transmission is necessary: generated power is immediately supplied to the electrolyzer. Such settings require a well-designed system to ensure that variable renewable power supplies the necessary number of electrolyzer operating hours every year. Ideally, surplus renewable power can be fed into the electricity grid. Alternatively, electricity produced elsewhere will need to be imported, which can also increase supply costs. Storage of hydrogen or electricity may also be needed. Regulatory approaches that require a close coupling of renewable power generation and hydrogen production in time or space can ensure low carbon intensity of electricity supply, but this may come at the expense of higher production costs.

Costs of Electrolyzers and Other Plant Components

The upfront capital cost of electrolyzers is almost as important as a low-cost renewable power supply. Electrolyzers are a key technology that need to be scaled up and improved to make renewable hydrogen cost competitive. Depending on the technology type, the average installed cost of electrolyzers today ranges from $500 to $1,400/kW for the alkaline variety, $1,100 to $1,800 for proton exchange membrane units, and $2,800 to $5,600/kW for a solid oxide electrolysis cell (International Energy Agency 2022). The unit cost depends on the installed capacity of the system, as well as the country of origin. For instance, electrolyzer systems manufactured and installed in China could have capital costs as low as $400/kW, whereas costs in Europe could be at the high end of the noted ranges.

Electrolyzer manufacturing capacity is projected to expand rapidly in the coming years, and this could lower costs thanks to economies of scale and technology evolution. There is a consensus that electrolyzer systems costing $500/kW are likely feasible by 2030 (Fraunhofer ISE 2022). If such cost reductions materialize, the LCOH could be as low as $2/kg for renewable hydrogen when coupled with renewable power priced at $0.02/kWh.

Economies of scale in manufacturing processes are a crucial component of the learning process. Realizing economies of scale through production automation boosts production rates and cost savings. Further cost savings can be had by optimizing stack configurations; increasing plant size; standardizing plant design and system components; and customizing electrolyzer solutions for specific industrial applications. Minimizing or avoiding the use of precious metals in electrolyzer manufacturing would allow dramatically larger deployments. There is significant potential for technology innovation in this area.

Stack degradation, replacement costs, and balance-of-plant costs matter, as well. Upfront electrolyzer capital costs should include stack replacements as essential components.

Stack lifetime depends on the maximum acceptable threshold of performance, thus affecting electrolyzer system costs. Timely replacement of stacks maintains the efficiency of the electrolyzer system and avoids excessive consumption of electricity. Although there is no standard definition of balance-of-plant costs, they include both mechanical and electrical components.[14] These could represent 35 to 45 percent of the total system cost of alkaline systems (International Renewable Energy Agency 2021). The extent to which existing LCOH analyses account for these costs remains unclear.

Electrolyzer efficiency is a critical parameter for hydrogen production costs, as it affects the rate of consumption of renewable electricity. The production of 1 kg of hydrogen needs about 50 to 55 kWh for today's proton exchange membrane and alkaline electrolyzer systems. Electricity consumption may fall below 45 kWh/kg for solid oxide electrolysis cells in certain situations where high-temperature waste heat can be used, as in ammonia production. The theoretical minimum is 33 kWh/kg, the lower heating value of hydrogen. Stack technology development is expected to reduce degradation, and thus limit electricity requirements.

Impact of the cost of capital

In addition to the costs of renewable electricity and electrolyzers, the cost of capital can significantly affect the LCOH. Better data on the weighted average cost of capital (WACC) are critical to inform governments' decisions about financial support. This is illustrated in Figure 2.3. Assuming production cost factors remain the same, a threefold reduction from 15 percent to 5 percent in the cost of capital could reduce the estimated LCOH by up to 45 percent.

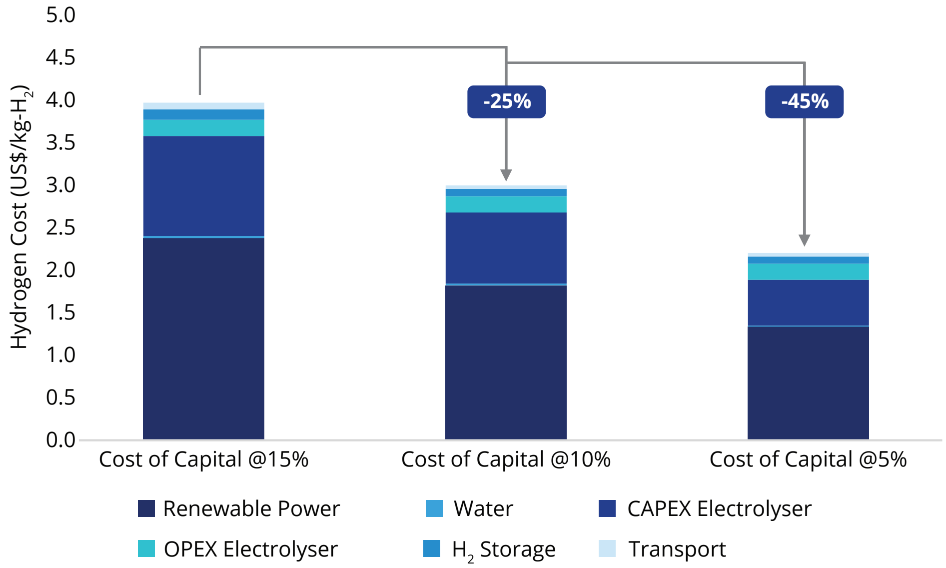
Factors affecting the cost of capital in developing countries must be well understood. The cost of capital (used interchangeably hereafter with WACC) of renewable hydrogen varies depending on a range of factors, including a project's size, type, and financing structure, as well as the region or country in which it is located and the level of risk it presents. Available information on the actual cost of capital is scarce because few projects have reached the final investment decision, let alone operation, and relevant information is often confidential. Additionally, since economies are subject to global inflation, data from previous years has limited value.

Estimates of the cost of capital for clean hydrogen projects can draw on information on renewable power and gas projects as a proxy. Renewable energy projects have greater capital intensity than fossil fuel technologies, as they require substantial upfront investments while having lower operating expenses. The cost of capital is therefore the most important determinant of the levelized cost of electricity generated from renewable energy. For renewable

[14] Mechanical equipment includes piping, valves, and instrumentation. Electrical equipment includes rectifiers and housing, electrical wiring, and electrical infrastructure.

FIGURE 2.3

Impact of Capital Costs on the Production of Renewable Hydrogen



Source: Authors' estimates.

Note: Calculations are based on the same assumptions as indicated in Figure 2.2. The same cost of capital is applied to all assets across the hydrogen value chain. Storage costs are computed on the basis of geological storage with a capacity of 5 percent of annual production. Transport costs are based on short pipelines connecting electrolyzers to industrial onsite use.

energy projects in 2020–21, that cost ranged from 1 percent (onshore wind in Germany) to 10 percent (solar PV in Ukraine) (International Renewable Energy Agency 2023). In mature markets, the cost of capital is lower than in emerging markets. Additionally, overall, financing costs tend to fall as technologies mature. Whereas the regional average cost of capital in mature markets is between 4.4 percent (Europe) and 5.4 percent (North America), it is 5.6 percent in the Asia-Pacific region and 6.9 percent in Latin America. The highest cost of capital for renewable power investments is found in the Middle East and Africa, at 8.2 percent, on average.

Debt and equity ratios matter in computing the WACC. The cost of debt is much lower than the cost of equity (Table 2.1). But for new technologies, more equity is typically needed. Although investors have become comfortable with solar and wind projects, to the point where up to 90 percent of project costs may be financed through debt, this will not be the case for new hydrogen projects, where half of the financing will be from equity. Consequently, the WACC will be considerably higher.

Overall, investors' perception of risk determines the cost of capital for clean hydrogen. The policy environment—and especially expected long-term returns—can affect expectations of equity return. This and other factors influencing investors' risk perceptions as well as how they can be mitigated are discussed in chapter 3.

TABLE 2.1

Cost of Capital for Utilities Powered by Renewable Energy, by Capital Component and Region, 2020–21 (all data in percent)

REGION/COUNTRY	DEBT	EQUITY	DEBT PREMIUM	EQUITY PREMIUM
Europe	4	12–14.5	–0.5 to 0	–4 to –6
United States	4–4.5	8	0	0
China	4.5–5	16.5–18.5	0.5 to 1	0.5 to 3

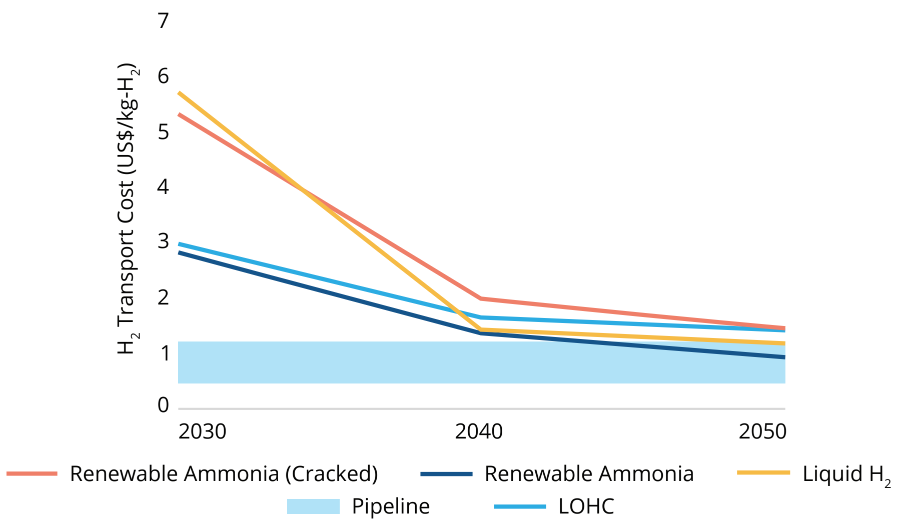
Source: (University of Oxford 2023).

Transport and Storage Costs

Transport and storage costs are important factors to consider for countries that are prioritizing exports of renewable hydrogen. Policymakers must consider them in national strategies; investors must consider them in project planning. As noted, transport and storage costs can affect LCOH significantly, depending on the site, trade route, and mode of trade. The cost of different options for long-distance transportation is presented in Figure 2.4. A typical shipping cost by 2030 might be $2 to $3/kg of hydrogen, but costs are

FIGURE 2.4

The Cost of Transporting Hydrogen, by Various Modes, Based on Distance



Source: Authors' elaboration and projection based on data from Saygin (2023), IRENA (2023), and IEA (2023).

Note: The pipeline transport cost assumes a 2,000 km pipeline with the lower range representing the costs of retrofits and the higher reflecting the end of the pipeline cost showing the costs of installing a new pipeline.

LOHC: liquid organic hydrogen carrier.

considerably higher for today's demonstration projects. Pipeline transport can be much cheaper than shipping for distances up to a few thousand kilometers.

Building new ammonia trade routes for carrying hydrogen can leverage the significant experience with ammonia shipping (IRENA 2022).[15] Hydrogen can be delivered at a cost of $1.5 to $2/kg of hydrogen with renewable ammonia, suggesting that the future prices offered by various exporters could be very similar. It will be important to consider the energy required to convert ammonia to hydrogen—a process known as cracking—and the hydrogen lost in the process (which could be as high as 15 percent).

The costs of hydrogen storage can vary widely and depend on cycling frequency. Underground storage is the lowest cost option for large volumes. Salt caverns have been proven to offer safe and fast cyclic storage at various sites. The investment cost can vary from $38 to $500/kg, depending on the chosen technology. Overall, aquifer and gas field storage options require more research and development before they are ready for commercialization.

Closing the Clean Hydrogen Cost Gap

Cost Reduction through 2030

The hydrogen cost gap depends on the costs of clean alternatives and of conventional production. In the case of low carbon hydrogen, the analysis is relatively simple, as the price of natural gas determines the production costs of both low carbon and conventional hydrogen. (The cost difference is $0.5–$1.0/kg.) However, the cost gap for renewable hydrogen can fluctuate and vary by location; its cost determinants differing from those of conventional hydrogen. The gap can be shrunk—thereby leveling the playing field—by lowering the levelized cost of renewable hydrogen, minimizing market distortions (i.e., by removing fossil fuel subsidies), and rigorously pricing GHG externalities.

Reducing renewable hydrogen's levelized cost will require collective action in multiple areas. Technology innovation, automation of manufacturing processes, and economies of scale will all be needed to reduce the costs of renewable power, electrolyzers, and transport infrastructure. Understanding and reducing risks that increase the cost of capital will be equally important. Finally, enhanced conversion efficiency (notably for electrolyzers, but also in hydrogen shipping) and longer equipment life spans will contribute to lowering costs. The sooner the cost of renewable hydrogen falls, the less financial support will be

[15] It is assumed that a fifth of estimated renewable ammonia production in 2050 will be used as a hydrogen carrier.

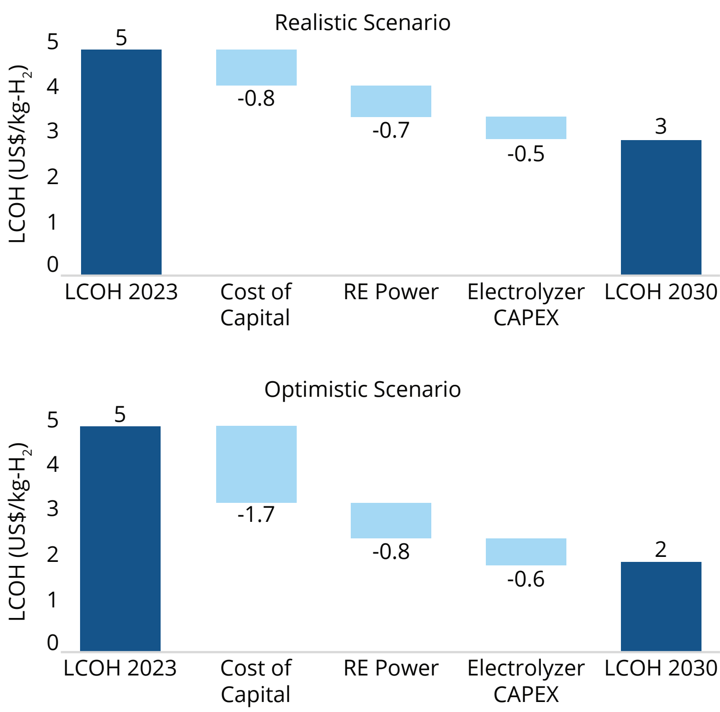
needed for its production, and the earlier governments can withdraw and allow market forces to develop this new economy.

Today's LCOH is \$5/kg H_2 (Figure 2.5), with future reductions depending on two key factors. To attain the initial reduction in costs, the essential focus should be lowering unit capital costs. But to achieve a truly economical hydrogen cost, the emphasis must shift to managing financing expenses. It will be possible to reach an LCOH of \$2/kg H_2 in the best locations by 2030. It should also be possible to reduce shipping costs to \$2/kg in that timeframe. This would mean that renewable hydrogen supplied through international trade could reach \$4/kg (Figure 2.6). In combination with carbon pricing for conventional hydrogen production, the prospect exists for commercial production of renewable hydrogen in the 2030s.

A scenario was analyzed where industrial demand for clean hydrogen expands rapidly through 2030. Clean hydrogen demand for the production of three key commodities—ammonia; iron and steel; and methanol—could account for three-quarters of total projected demand by 2030 (27 of 40 Mt). The analysis for these products is representative

FIGURE 2.5

Reduction in Production Cost of Renewable Hydrogen, 2023–2030

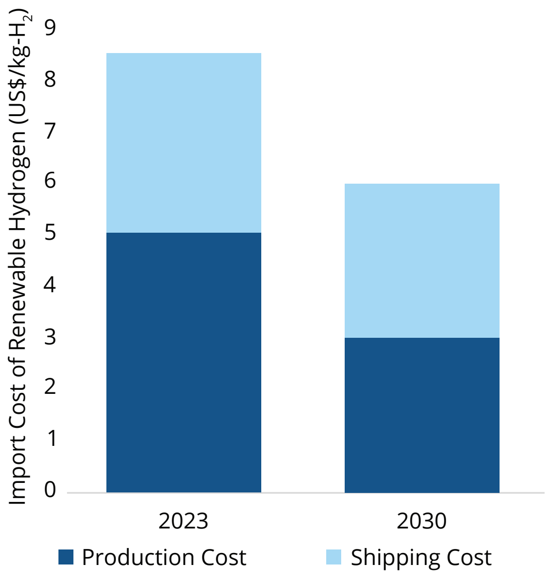


Source: Authors' estimates.

Note: In this figure, we assume two LCOH scenarios—realistic and optimistic—with WACC falling from 15% to 12% and 8%, respectively; the levelized cost of electricity falling from \$0.05/kWh to \$0.35/kWh and \$0.02/kWh respectively, and electrolyzer cost dropping from \$1,100/kW to \$700/kW and \$500/kW, respectively.

FIGURE 2.6

Drop in Import Cost of Renewable Hydrogen, 2023–30



Source: Authors' estimates.

of the global hydrogen economy. The CO_2 reduction potential of clean hydrogen would amount to 307 Mt CO_2 by 2030, nearly 1 percent of today's energy-related CO_2 emissions.

To estimate the marginal abatement cost, we use the conventional commodity cost as a baseline reference and compare the cost differential to its green fueled or low carbon product in that category. By that logic, under current conditions (and assuming high CO_2 capture rates and no methane leakage), the least-cost emission reduction option for steel production—at $55 to 60/t CO_2—is natural gas-based direct reduced iron with carbon capture, use, and storage. Renewable hydrogen-based direct reduced iron would require $125/t CO_2. For ammonia, low carbon ammonia offers a lowercost option for emission reductions ($70/t CO_2) compared with renewable ammonia ($122/t CO_2). Clean alternatives to conventional methanol can be derived at a higher cost: around $115/t CO_2 for low carbon methanol and $210/t CO_2 for renewable methanol.

By 2030, the case for clean hydrogen-based solutions improves greatly, explained largely by learning-driven reductions in renewable power costs and in the capital cost of electrolyzers. Based on these assumptions, analysis shows that renewable ammonia could become cost competitive with conventional ammonia by 2030 under certain enabling conditions in specific countries. These estimates refer to the global average. At the country level, they could differ significantly depending on local conditions that affect the technical characteristics of production facilities, as well as the enabling conditions, financial support, that might raise the cost competitiveness of commodities derived from renewable hydrogen. Box 2.1 provides an example of the benefits and the willingness to pay (WTP) for clean hydrogen in the United States.

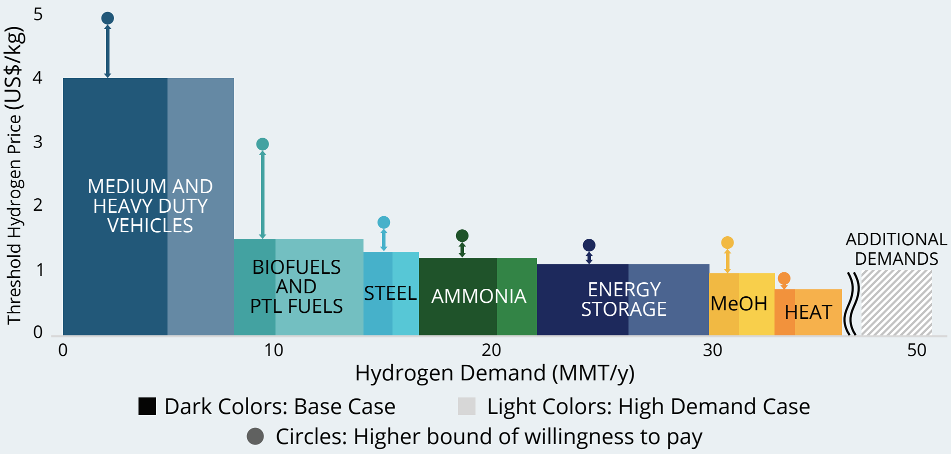
BOX 2.1

COMPARING EXPENSES AND POTENTIAL REVENUES FOR HYDROGEN

While the investment and financing needs for clean hydrogen are significant, there is a certain willingness to pay for clean energy and, in many applications, clean hydrogen use creates efficiency benefits. In the United States, analysis has been conducted regarding the willingness to pay in certain applications. This is illustrated below. The highest willingness to pay exists in the transportation sector, where \$4 to \$5/kg would be acceptable. It should be noted that today's hydrogen cost at the pump varies from \$15/kg in Germany to \$30/kg in California. The gap between prices at the pump and production cost can be attributed to the nascent state of the hydrogen industry and the lacking economies of scale and competition.

While \$4 to \$5/kg means that the payback of investment cost of \$30 billion/Mt annual capacity would be less than 10 years, however, the assessment of costs and benefits is more complex. The key point being that while cost is still high compared to conventional energy use, there is a perspective for viable business cases to emerge. Certain niche markets are willing to pay higher hydrogen product prices, creating the basis for the necessary learning effects that will lower costs. Steel for car making, ammonia for resins, inland nitrogen fertilizer production locations, and container shipping are all examples of applications where consumers are willing to pay a premium and the impact on product price is limited.

Willingness to Pay for Clean Hydrogen in the United States – Clean Hydrogen Demand and Costs for Market Penetration



Source: US Department of Energy (DOE), 2023.

Note: Cost include production, delivery, dispensing to the point of use (e.g., high-pressure fueling for vehicle applications).

Narrowing the Financing Gap and Meeting Requirements for Additional Financial Support

Our analysis estimates that a market of 40 Mt of clean hydrogen, including 27 Mt of renewable hydrogen, will be necessary by 2030 to reduce the cost of renewable hydrogen from \$3/kg H_2 under the best conditions today to \$2/kg H_2 in 2030.

The most optimistic case is characterized by favorable conditions for renewable hydrogen development and a stable cost gap between conventional and renewable hydrogen. Thus the financing gap is calculated assuming that: (1) all renewable hydrogen projects can be produced at the same best-in-class cost, starting from \$3/kg H_2 in 2023; (2) all renewable hydrogen is consumed where it is produced (hence no transport costs); (3) conventional hydrogen is produced at a natural gas cost of \$35/MWh, reflecting the price of liquefied natural gas in the first half of 2023.

The financing gap computed points to the financial support needed to produce 40 Mt of clean hydrogen by 2030. It is based on the estimated average global LCOH, which excludes the effect of any local subsidies or other support schemes. The optimistic financial support needed to achieve the 40 Mt goal is \$174 billion.

The analysis subsequently explores the impacts of a less optimistic reduction in LCOH. In this estimate, the financing support estimate equals a quarter of investment needs through 2030 (\$500 billion).

Upfront grants to lower the high capital cost of clean hydrogen projects, particularly electrolyzer and renewable electricity assets, are a straightforward way of providing financial support. The financial support should be large enough to achieve cost parity between products derived from renewable hydrogen and fossil fuel counterparts. Achieving parity would require a global total financial support of \$174 billion between 2023 and 2030, bringing the LCOH from \$5 to \$2/kg in the optimistic case.

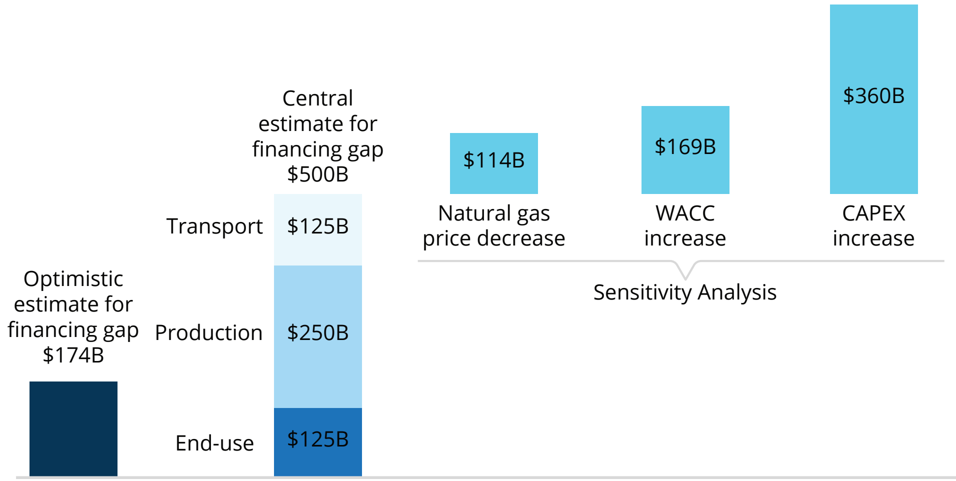
Our central case for estimated financial support is approximately \$500 billion that includes production, transport, and end use and is roughly 25 percent of total investment needs (Figure 2.7). Notably, global production and consumption can evolve differently depending on technical and economic parameters and policy decisions. Sensitivity analysis indicates that the estimates may be higher if capital expenditures, the WACC, and natural gas prices are key variables (Figure 2.7).

Roughly a quarter to half of the total financial support would be needed to support EMDCs (excluding China). This translates into an annual average of \$10 to 40 billion in financial support between now and 2030.

All sources of finance—international and national; public and private—will be needed to provide the necessary support. Private capital will make up the largest share while, scarce public finance from national and international sources will focus on ensuring an enabling investment environment through: (1) credible and predictable national hydrogen strategies and roadmaps; (2) regulatory frameworks; (3) a suite of instruments that can be used by

FIGURE 2.7

Estimation of Financing Gap Under Various Assumptions, 2023–30



Source: Authors' estimates.

Note: The sensitivity analysis estimates are in addition to the optimistic and central estimate for the financing gap.

industry actors and project developers; (4) research and development support; and (5) effective business models.

The central estimate of financial support needs could vary based on several factors. Those factors include country differences in technology progress (and related reductions in the capital cost of technologies), economic performance, and the cost of financing, as well as movements in energy markets, notably the price of natural gas.

The price of natural gas is likely to remain relatively stable in producer countries (below $20/MWh, for example, in the Middle East and North Africa or in Trinidad and Tobago), whereas importing countries and volatile markets (in Asia, for example) have observed peak prices above $100/MWh in recent years. Countries with a well-educated workforce and strong technical skills, such as India, are well positioned to develop domestic manufacturing at low prices, while others will have to rely on expensive equipment imports. The WACC also varies greatly among emerging and developing economies. Trade routes will emerge depending on the landed price for end customers. Therefore, the proximity of potential exporting countries to large demand hubs, and the transportation infrastructure connecting them, will play a key role in shaping the market. Trade can reduce the global financing gap as it makes it possible to obtain supplies at lower costs and open opportunities for EMDCs to develop exported-oriented strategies.

Some of the countries that are planning to import hydrogen on a large scale are already willing to cover some of the additional costs for transporting clean hydrogen. The European Union, Japan, and the Republic of Korea have set import targets that reach nearly 16 Mt by

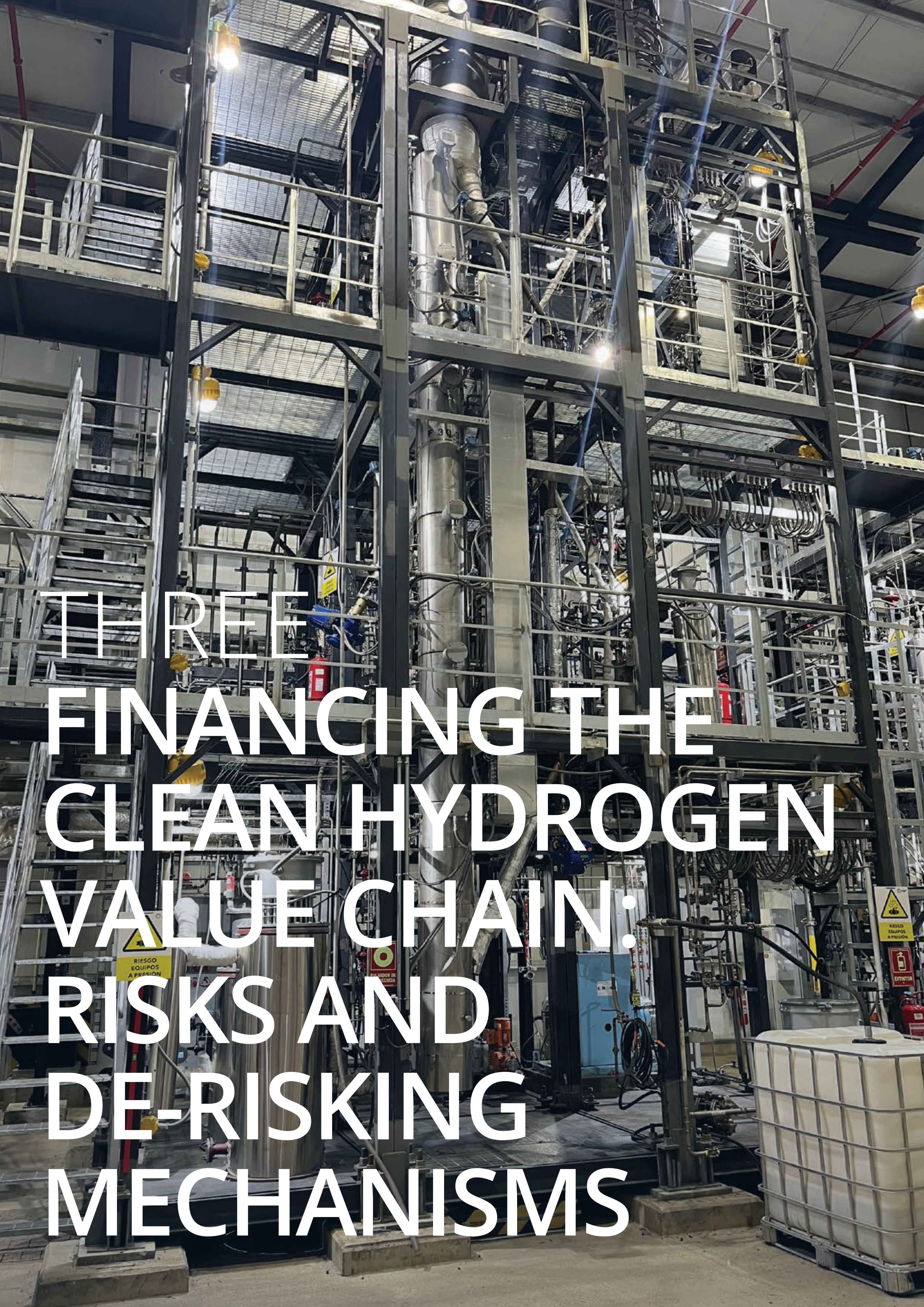
2030 and are putting financial support mechanisms in place to achieve those targets. Production and consumption mandates are equally important ways to induce demand and supply despite the cost gap. India's green hydrogen mission production target is 5 Mt by 2030. China aims to increase hydrogen use to 43 Mt by the same year, with a share to be supplied from clean energy resources. Current policies in the United States could yield 5 Mt of clean hydrogen use by 2030—or even more if new policies are put in place. Together with the import targets of various countries, the realization of countries' production and consumption ambitions would collectively total 40 Mt of clean hydrogen by 2030, a point at which one could plausibly argue that less financial support may be needed.

Smart government policies that create enabling market conditions and mitigate risks can steer the need for financial support to the lower end. These include measures to address offtaker risk; widen access to low-cost renewable power, infrastructure, land, and water; reduce financing costs; and increase the disclosure of transparent cost data on clean hydrogen.

Among these options, it will be essential for producers to be able to secure guaranteed offtake contracts at a set price and to gain access to tax incentives and subsidies linked to announced production levels. The latter can take various forms, such as production and demand support schemes (including investment or production subsidies) carbon contracts for difference,[16] tax rebates, and carbon pricing schemes. In Europe, prices in the Emission Trading System reached €100/tonne of CO_2 in the first quarter of 2023. This translates into additional compliance costs imposed on producers of gray hydrogen, whereas producers of renewable hydrogen would not incur the same costs. In the United States, the Inflation Reduction Act offers up to $3 for each kilogram of low carbon hydrogen produced for a decade. Such incentives close the financing gap and create a viable business case. Policy considerations are examined in greater depth in chapters 3 and 4, focusing on risk mitigation instruments to bridge the cost gap and policy support options.

[16] Carbon contracts for difference are a well-established mechanism in which the government agrees to a fixed price for a product (such as renewable hydrogen) through an auction process, with the difference between the agreed price and the real-world wholesale price topped up by the government.


INGENIERIA
Storage



THREE
FINANCING THE CLEAN HYDROGEN VALUE CHAIN: RISKS AND DE-RISKING MECHANISMS

Key Points

- Large clean hydrogen projects in emerging markets and developing countries (EMDCs) face high financing costs derived from actual and perceived risks, deterring investors to enter in this nascent industry. These risks can be divided into two categories: (A) those common to all large infrastructure projects in EMDCs, which can be subdivided in four subcategories, and (B) those specific to the nascent low carbon hydrogen industry, which can be subdivided in five subcategories. Both categories of risk must be carefully evaluated to avoid unwarranted increases in the cost of clean hydrogen projects.
- Several risks influence the cost of capital for clean hydrogen projects (category B). These specific risks center on engineering, procurement, and construction (EPC) overruns, offtake default, technology nonperformance, withdrawal of regulatory incentives, and exchange rates. Implementing cost-effective and efficient de-risking mechanisms could substantially decrease the weighted average cost of capital, making projects economically viable, which will result in accelerating their deployment and reducing the financing gap.
- The World Bank and OECD performed a robust market sounding among financiers and developers around the world to map the main risks hindering the financing for clean hydrogen projects in EMDCs. The results show the prevalence of six subcategories of risks. In order of priority: offtake risks stand out, followed by equally weighted political and regulatory risks; infrastructure risks; permitting risks; technology risks; and finally macroeconomic risks. The lower sub-categories of risks are: design, construction and completion risks; operational and maintenance risks; and supply risks. In today's nascent clean hydrogen industry, the degree of a particular project's risk largely depends on the actors involved. Evaluating the creditworthiness, experience, and credibility of project sponsors, engineering, procurement, and construction (EPC) contractors, primary technology providers, and offtakers must feature prominently in any risk assessment. As such, it is critical that governments of EMDCs choose reputable partners.
- Risk assessments should be followed by both policy and financial de-risking mechanisms. Policy de-risking mechanisms aim at removing the root causes of risks through policy measures. They include instruments to support institutional capacity building, local skills development, the implementation of relevant laws, and the management of infrastructure assets. Financial de-risking mechanisms deploy financial measures to avoid or reduce project risk. Only through both categories of risk mitigation mechanisms can large-scale clean hydrogen projects in EMDCs achieve financial viability.
- Governments of EMDCs can collaborate with development finance institutions to devise and implement a wide spectrum of financial de-risking instruments for clean hydrogen projects, tailored to the needs and characteristics of each country. Such instruments include partial credit guarantees, partial risk guarantees, political risk insurance, liquidity reserve accounts, and local currency support.

Risks Hindering the Availability of Financing for Clean Hydrogen Projects in EMDCs

In an investment context, risk is the probability that a project will deviate from an expected outcome. To protect against this, investors typically demand what is known as a risk premium. Lenders and investors will demand higher returns from project developers undertaking riskier projects. The risk premium directly affects the weighted average cost of capital (WACC) and the cost of the product or service delivered—in this case the levelized cost of hydrogen (LCOH). Risks that lack a mitigation solution may result in hindering the ability to attract equity, increasing the cost of debt and negatively impacting the debt/equity ratio, which in turn raises the WACC.

De-risking means reallocating, sharing, or reducing the existing or potential risks associated with an investment. Allocating risks in an effective manner decreases the risk premium for equity and debt providers, thus reducing the expectations of equity returns and improving lending terms. Development finance institutions (DFI) play a critical role in de-risking, as they provide capital and debt, as well as deploy mechanisms that lower the exposure of private investors or lenders. When public resources are allocated strategically, a project once considered not bankable can attract and mobilize capital from commercial and institutional investors.

In practice, financiers have developed a wide variety of methods to classify and assess risks when evaluating the bankability of large infrastructure projects.[17] The World Bank and the OECD conducted a global market sounding among financiers, project developers and key stakeholders to identify the risks affecting the availability of financing for large-scale clean hydrogen projects (over 100 MW of electrolysis capacity). The results from the market sounding showed a list of over 40 specific risks affecting the industry.[18] Hence, to facilitate the identification and assessment of risks impacting the development of large-scale clean hydrogen projects, this report divides them into two categories and nine sub-categories (Table 3.1):

Category A. General risks that all potential investors face when considering large infrastructure assets in EMDCs, which can be subdivided in four sub-categories:

1. Macroeconomic risks
2. Political and regulatory risks
3. Infrastructure risks
4. Permitting and compliance risks

[17] See Moody's Generic Project Finance Methodology; S&P Project Finance Transaction Structure Methodology; EXIM USA.
[18] Forthcoming OECD Report.

TABLE 3.1

Risks Affecting the Financing of Clean Hydrogen Projects

CATEGORY A: RISKS RELATED TO INVESTING IN LARGE INFRASTRUCTURE ASSETS IN EMDCS				
1. Macroeconomic Risks	Policy or Financial Risk Mitigation Mechanisms	Prevalence in project lifecycle		Top risks
• Currency depreciation • High inflation • Spike in interest rates	• FX hedging • Build a robust project finance model • Interest rate swaps • Fixed rate loan	Pre-FID ✓	Post-FID ✓	★
2. Political and Regulatory Risks	Policy or inancial Risk Mitigation Mechanisms	Pre-FID	Post-FID	
• Expropriation • Breach of contract • Absence, inconsistency, or modification of legal framework • War or civil unrest • Limitations in currency inconvertibility and transferability • Uncertainty about taxes and incentives	• Political risk insurance • Enhanced rule of law • Sound and predictable regulatory framework	✓	✓	★
3. Infrastructure Risks	Policy or Financial Risk Mitigation Mechanisms	Pre-FID	Post-FID	
• Limited enabling infrastructure • Underestimation of enabling infrastructure • Delay in deployment of infrastructure	• Public-private partnerships • Hydrogen hubs • Development of a feasible infrastructure master plan • Regulation for shared infrastructure	✓		★
4. Permitting and Compliance Risks	Policy or Financial Risk Mitigation Mechanisms	Pre-FID	Post-FID	
• Deficit in stakeholder acceptance • Delay or inability to obtain land rights • Delay or inability to obtain environmental permits • Delay or inability to obtain social permits	• Political risk insurance • One-stop shops • Capacity building for administrative authorities • Early community engagement • Incorporate Environmental, Health and Safety guidelines • E&S frameworks from MDBs • Shared water and power surplus	✓		★
CATEGORY B: RISKS RELATED TO INVESTING IN CLEAN HYDROGEN PROJECTS				
5. Offtake Risks	Policy or Financial Risk Mitigation Mechanisms	Prevalence in project lifecycle		Top risks
• Uncertain hydrogen demand • Limited credible offtakers • Uncertain price of clean hydrogen • Lack of hydrogen trading market • Offtake default	• Partial risk guarantee • Policy based guarantee • Partial credit guarantee • Long-term hydrogen purchase agreements • Credit default swaps • Credit enhancing instruments	Pre-FID ✓	Post-FID ✓	★
6. Technology Risks	Policy or Financial Risk Mitigation Mechanisms	Pre-FID	Post-FID	
• Unforeseen electrolyzer degradation • Defective components • Underperformance • Failing system integration/BoP	• Performance guarantees • Insurance • Liquidity accounts • Select reputable technology provider		✓	★

(*continues*)

TABLE 3.1

Risks Affecting the Financing of Clean Hydrogen Projects (*Continued*)

7. Design, Construction, and Completion Risks	Policy or Financial Risk Mitigation Mechanisms	Pre-FID	Post-FID
• Underestimating costs • Time and cost overruns • Misinterpretation of project scope	• Turnkey EPC contracts • Construction All Risk and Delay Start-Up • Cost overrun guarantee • Completion and construction warranties • Contractors-all-risk insurance • Liquidated damages • Select experienced EPC		✓
8. Operational and Maintenance Risks	**Policy or Financial Risk Mitigation Mechanisms**	**Pre-FID**	**Post-FID**
• Failure to achieve key performance metrics • Failure to provide scheduled and unscheduled maintenance • Limited skilled workers to operate and maintain project	• Reserve accounts • Maintenance coverage • Select reputable O&M company • Upskill and reskill workers		✓
9. Supply Risks	**Policy or Financial Risk Mitigation Mechanisms**	**Pre-FID**	**Post-FID**
• Power unavailability • Noncompliance with renewable power taxonomy from importing country • Water unavailability	• Long term PPA • Expansion of renewable power projects • Select reputable power/water suppliers • Sustainable water management		✓

Source: Authors' analysis based on market sounding.

Note: BOP = Balance of Plant; E&S = environmental and social; EMDC = emerging market and developing country; EPC = engineering, procurement, and construction; FID = Final Investment Decision; FX = foreign exchange; MDBs = Multilateral Development Banks; O&M = operations and maintenance; PPA = Power Purchase Agreement.

Category B. Specific risks to investing in the nascent clean hydrogen industry, which can be subdivided in five sub-categories:

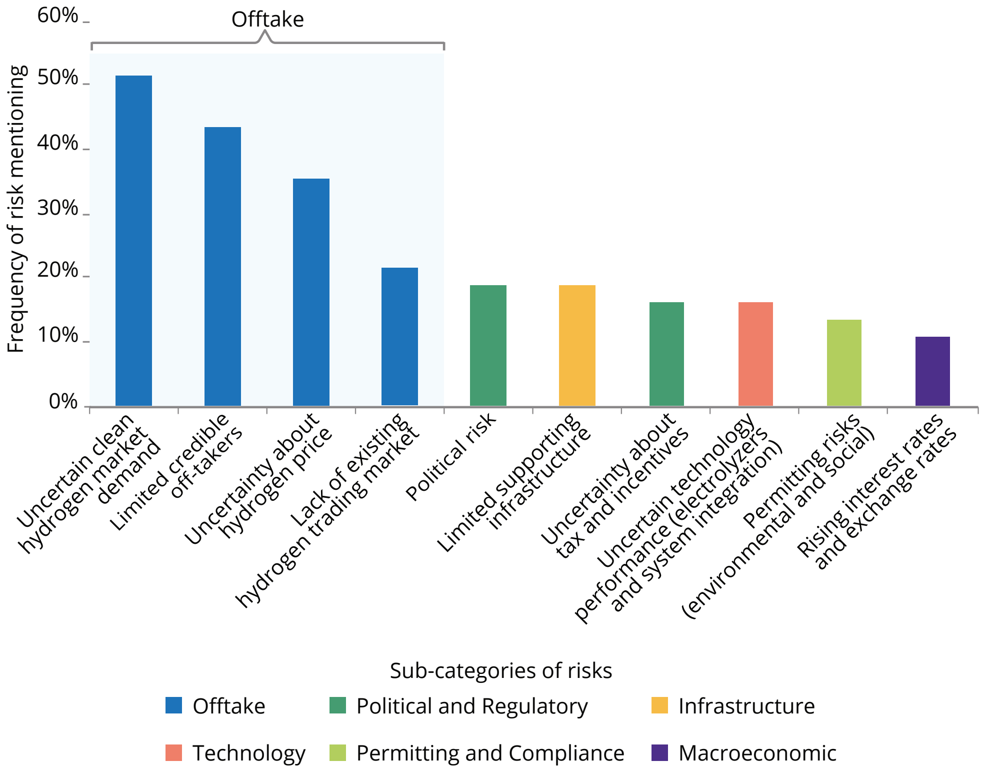
5. Offtake risks
6. Technology risks
7. Design, construction, and completion risks;
8. Operational and maintenance risks
9. Supply risks

Both categories of risks hinder the mobilization of financing and deter entry into the nascent clean hydrogen industry (Figure 3.1). To mitigate them, two groups of de-risking mechanisms are needed:

- **Policy de-risking mechanisms,** which address the root causes of risk through policy measures that support institutional capacity building, local skills development, the implementation of legal and regulatory frameworks, and the management of infrastructure assets.

FIGURE 3.1

Top Risks, if Mitigated, Would Enable Clean Hydrogen Projects to Secure Financing in EMDCs



Source: Authors' analysis.

- **Financial de-risking mechanisms,** which focus on the financial risks associated with infrastructure projects, and include hedging, future contracts, derivatives, insurance coverages, and guarantees, among others. When financial de-risking mechanisms are publicly funded, they transfer the risks that private investors face to public actors, such as development banks or credit export agencies. Examples of publicly funded financial mechanisms include guarantees, political risk insurance, and public equity co-investments.

Only by combining policy and financial risk mitigation mechanisms can large-scale clean hydrogen projects achieve financial viability in the short and medium term.

It is critical to mention that the risks mentioned above must be allocated to the party best placed to manage them in a cost-effective manner—and this is not necessarily the public sector. Also, risk mitigation instruments that use public and concessional funds should only cover risks over which the private sector has no control (i.e., political, regulatory, and new technology risks when the positive spillovers outperform the negative ones) and risks with no, or few, market solutions (i.e., foreign exchange risk in low-income countries).[19]

[19] Source: OECD DAC Blended Finance Principles 4: Focus on Effective Partnering for Blended Finance, OECD, https://www.oecd.org/dac/financing-sustainable-development/blended-finance-principles/principle-4/Principle_4_Guidance_Note_and_Background.pdf.

Category A. General Risks Related to Investing in Large Infrastructure Assets

Financiers of clean hydrogen projects in EMDCs face high financing costs for debt and equity due to actual and perceived risks. This is disadvantageous for capital-intensive technologies, such as clean hydrogen, because equity and debt providers in EMDCs require a higher rate of return or interest to compensate for these risks, than in Europe or the United States.

The risks of investing in EMDCs vary widely across regions and countries but can be divided in four subcategories: (1) macroeconomic, (2) political and regulatory, (3) infrastructure, and (4) related to permitting and compliance.

1. Macroeconomic Risks and Mitigation Mechanisms

The macroeconomic risks affecting the cost of financing for clean hydrogen projects include currency depreciation, high inflation, and spikes in interest rates. Projects are especially exposed to currency depreciation risks if their revenues are denominated in local currency while (all or part of) their debt is denominated in a foreign currency, typically dollars or euros. This currency depreciation is a latent risk as most electrolyzers used in clean hydrogen projects will be imported from high-income economies, such as European countries and the United States, with repayments to technology providers in hard foreign currencies. If private financiers anticipate high inflation and spikes in interest rates in the short and medium term, their perceived risk will grow, pushing up financing costs and making it more difficult for clean hydrogen projects to achieve bankability and economic viability. The market sounding held by the World Bank and the OECD shows that perceptions of macroeconomic risks differ significantly between high-income countries and EMDCs. For example, 33 percent of respondents considered that clean hydrogen projects located in Egypt would face macroeconomic risks, compared with only 3 percent in Germany.

To mitigate macroeconomic risks, private lenders and equity providers construct comprehensive financial models using a variety of assumptions about interest rates, inflation rates, and foreign exchange rates to test the economic robustness of a project and seek financial coverage. In running these sensitivity analyses, financiers will identify the circumstances under which the financial “coverage ratios”—a metric intended to measure a company’s ability to service its debt and meet its financial obligations, such as interest payments or dividends—will not be met. If those circumstances were to materialize, the ratio of debt to equity in the project (leverage ratio) or some other aspect of its economics would have to be adjusted to meet the coverage ratios; alternatively, additional security or support from a third party would have to be obtained.

The ideal way to tackle spiking interest rates is to secure a fixed rate loan that carries a predetermined interest rate with a typical term of 15 to 20 years. If this sort of contract is not available, there are securities (also known as derivatives) offered by third parties to mitigate macroeconomic risks (World Bank 2020). For example, interest rate swaps serve to protect projects against spikes that affect interest rates by converting variable to fixed debt rates. To mitigate currency depreciation and foreign exchange (FX) risks, hedging against FX variability by contracting swaps is an option. However, interests and FX hedging instruments are expensive, and commercial financial institutions do not offer long-term hedging options for many of the currencies in EMDCs. Export credit agencies (ECAs) can play an important role in mitigating interest rate risks, as they can offer interest rate support, compensating commercial banks for any difference that may arise between the interest rate under the loan agreement and the commercial rate.

2. Political and Regulatory Risks and Mitigation Mechanisms

Political risks are changes in the legal, regulatory, or political order that may jeopardize a project's financial viability. Such risks include inconsistency, or modification of the legal and regulatory framework, expropriation, war or civil unrest, limitations to currency convertibility and transferability, and breach of contract. While all energy projects face risks related to and derived from legal and regulatory uncertainty, unscheduled changes in laws or regulations that reduce the level of public financial support for clean hydrogen projects may jeopardize a projects' financial viability. This risk is particularly relevant to clean hydrogen projects because they depend on explicit regulatory schemes that aim to underpin market demand or enable supply of hydrogen—mostly tax incentives, premium prices, subsidies, mandatory quotas, and purchase guarantees. In addition, the absence of a consistent legal definition for clean hydrogen poses a risk to export projects, as they may fail to comply with the regulatory requirements for clean hydrogen or derivatives in the country of destination. For example, producers in EMDCs that plan to sell hydrogen to the European Union (EU) will need to comply with relevant EU criteria.

Clean hydrogen projects designed for domestic consumption, which would likely earn their revenues in local currency, are at risk of legal or political events impeding the conversion of local currency into hard currency, or the transfer of hard currency outside EMDCs. If project developers are international consortiums, and host governments restrict access to foreign currency or the transfer of profits abroad, clean hydrogen projects will be subject to convertibility and transferability risks. The market sounding conducted by the World Bank and the OECD shows that the perception of political risks greatly varies between high-income countries and EMDCs. For example, 65 percent of respondents consider clean hydrogen projects to be completely free from political risks in Germany, compared with only 5 percent in India.

Clean hydrogen projects have a long-life cycle, typically for more than two decades. As financiers expect to obtain financial returns over a long term—minimum 10 years—countries with poor governance and rule of law or with prior cases of expropriation, nationalization, war or civil unrest may not attract investors, despite having excellent renewable energy resources and overall good conditions to produce clean hydrogen.

TABLE 3.2

Financial De-risking Instrument Offered by Multilateral Development Banks and Export Credit Agencies to Mitigate Political and Regulatory Risks

INSTRUMENT	DESCRIPTION
Political Risk Insurance	This de-risking instrument includes four forms of coverage for equity holders: (1) expropriation, (2) war or civil unrest, (3) currency restrictions, and (4) breach of contract. MIGA, for example, proposes an instrument in which the cost is assumed by the private company, which will pay a risk-based premium typically in the range of 1 to 1.5 percent per annum of the investment amount being covered. Ninety percent of equity value can typically be covered, and 95 percent of debt (principal + interests).

Source: Authors' analysis.

The main policy measure to mitigate this risk is to uphold the rule of law. Where that may not be entirely possible, political risk insurance can protect against country-specific governance and legal actions that could disrupt projects across their life cycle. Multilateral development banks and export credit agencies can provide political risk insurance that may not be available from the insurance market, or available only at a cost that makes the project nonbankable (Table 3.2). Export credit agencies and the Multilateral Investment Guarantee Agency (MIGA), for example, insure against the risks of currency transfer restriction and inconvertibility, breach of contract, expropriation, and war and civil disturbance. Moreover, these entities use their government relations to resolve disputes when they occur, rather than simply paying claims after a project has failed.

3. Infrastructure Risks

The scarcity or inexistence of enabling infrastructure in EMDCs for clean hydrogen (or its derivatives, such as ammonia, methanol, and SAF) production, storage, and transport poses a critical risk to financiers and developers, as some of them might deter from entering this new industry due to high level of capital expenditures (CAPEX) to build this new infrastructure. A dearth of up-, mid-, and downstream infrastructure threatens the timely deployment of clean hydrogen projects, many of which are to be located in zones with high solar and wind capacity factors but without sufficient or adequate ancillary infrastructure (i.e., electricity transmission, pipelines, storage, water supply, ports, etc.). The limited availability of hydrogen infrastructure will constrain scaling in cases where co-location is not feasible and for projects aiming to export.

To decrease the risk posed by limited enabling infrastructure, MDBs, and governments of EMDCs may need to evaluate financing the construction or retrofitting of key infrastructure. Governments may also assess the possibility of developing public-private partnerships to facilitate the creation of ancilliary infrastructure, such as ports or roads. It is also essential to define the state's role in managing shared infrastructure. This calls for a comprehensive regulatory framework, particularly with respect to third-party access, property rights, tariff remuneration, competitive market participation, and collaboration for interconnections. Governments should also evaluate the creation of hubs, clusters, or valleys that offer connective infrastructure to accelerate the use of clean hydrogen. Special Economic Zones can play a relevant role as prospective hydrogen hubs, as some of them have robust industrial infrastructure in place.

4. Permitting and Compliance Risks and Mitigation Mechanisms

Sponsors of large-scale clean hydrogen projects must obtain a series of permits to achieve a final investment decision (FID). Permits are of many types, including land tenure, environmental permits, social licenses, and construction permits. The risk of delays in obtaining permitting approval may increase the initial cost of clean hydrogen projects and cause projects to miss early-entry market opportunities. Delays may be expected where host countries lack the institutional capacities and technical knowledge to handle licenses and permits in an efficient, legal, and transparent manner.

It is relevant to note that for EMDCs to grant licenses and permits in a timely manner does not require them to relax their environmental, social, and governance policies. Clean hydrogen production must proceed hand in hand with robust community consultations and sound management of water, land, and biodiversity. In some EMDCs, government officials and enforcement agencies in charge of providing land rights, environmental permits, and social licenses may be unfamiliar with the processes for producing, transporting, and consuming clean hydrogen and its derivatives. Also, some countries still regulate hydrogen as a hazardous substance rather than as an energy vector. Lack of familiarity with the technology and, in particular, the treatment of hydrogen as a dangerous element, may lead government actors to overestimate the negative environmental impacts of projects.

In some countries, the best renewable energy resources are located on lands not previously used for productive purposes. Developers would need to conduct environmental impact assessments for clean hydrogen production and transport facilities to be constructed in pristine ecosystems, for which environmental baseline data are not available. Projects may also face the risk of community opposition. Related risks include poor local community engagement from the initial stages of a project, limited project benefit sharing, limited confidence in the safety of the technology, or perceptions of adverse impacts on social well-being.

To mitigate the risk of delayed permits, it is necessary to coordinate multilevel government agencies to clearly define responsibilities when handling and evaluating permits. National, regional, and local authorities from EMDCs must make efforts to understand the technology and evaluate projects objectively. An additional solution is to set up one-stop shops that simplify, streamline, and centralize the different approval processes. Most importantly, companies, governments of EMDCs, and MDBs developing clean hydrogen projects should comply with international and national environmental, social and governance frameworks.

National, regional, and local authorities from EMDCs must make efforts to understand the technology and evaluate projects objectively. In addition, MDBs should prioritize supporting projects that secure the highest socioeconomic benefits. Developers should secure an acceptable social license from local communities, which may be obtained by raising awareness of projects' value and demonstrating benefits for both local communities and the host country in general, such as jobs created, increased access to desalinated water and renewable electricity with local communities, decrease in the levels of pollutions.

At the project level, MDBs must continue prescreening environmental and social risks, and ensuring compliance with their stringent environmental, social and governance frameworks. Moreover, MDBs must continue to ensure that project developers adhere to environmental and social management plans throughout the project life cycle, protecting people and the environment from adverse impacts.

Category B. Risks Specific to Investing in Clean Hydrogen Projects

5. Offtake Risks and Mitigation Mechanisms

Offtake risk is perceived as the most critical risk in the nascent clean hydrogen industry because it affects the speed of deploying projects. Sponsors that fail to secure long-term hydrogen purchase agreements with a fixed price from a creditworthy purchasers are unlikely to achieve final investment decisions (FID).

Offtake risk also includes the danger that the buyer of the hydrogen or its derivatives (ammonia, methanol, or SAF) may fail to meet its financial obligations under the purchase agreement and that there is no substitute buyer. As such, a disruption in the offtake agreement will jeopardize revenues, possibly driving them below the level needed to service the debt and pay the project's expenses, putting the whole project at risk of default.

Offtake risk is exacerbated by uncertain long-term demand and the fact that clean hydrogen's cost is higher than that of fossil fuel alternatives. Uncertainty regarding demand prevents companies from determining long-term offtake volumes and prices. Moreover, the availability of finance is affected by the lack of historic pricing benchmarks or a wholesale market reference to which pricing can be tied , as lenders are less keen to participate when they are unable to use the offtake contract as security.

The limited pool of creditworthy offtakers also affects the bankability of clean hydrogen projects. Financiers will participate only in projects where they are certain that the offtaker is financially sound and operationally able to fulfill its purchase obligations over the contract term. Lenders will require the offtaker to have a minimum credit rating from an appropriate rating agency. Financiers may also require letters of credit to support the offtakers' payment obligation or request guarantees, which will affect the cost of financing.

Offtake risks may be mitigated by selecting a reputable purchaser and signing long-term offtake agreements under which clean hydrogen or its derivatives are acquired through a take-or-pay model - preferably with liquidated damages. The take-and-pay and take-or-pay clauses afford predictability to the projects revenue stream and counterbalance the issue that there are no trading markets for clean hydrogen where companies can sell their product(s) in case of default. Once clean hydrogen markets are more advanced and commoditized, the offtake risk may be counterbalanced through hedging contracts or by requiring purchasers to set aside cash in secured accounts, which may entitle the project company to collect a payment from a third party under certain default conditions. Additionally, the development of trading markets will also mitigate offtake risks by offering spot markets for clean hydrogen and its derivatives.

An example of a successful instrument that tackles offtake and price risks is H2Global. It provides investment security to producers and offtakers of clean hydrogen and its derivatives, by making the products available through auctions. It operates by covering the cost gap between a selling price and a buying price, which are established through a double-auction model by using a market intermediary aggregator, HINTCO. This mechanism conducts auctions to purchase hydrogen from suppliers outside the European Union through fixed-price 10-year contracts. A separate auction is then held to sell the hydrogen to buyers using 1-year contracts. H2Global launched first tenders with a budget of €900 million for ammonia, synthetic methanol, and synthetic kerosene produced from renewable hydrogen at the end of 2022, with deliveries planned to begin in 2024 (H2Global 2023).

The World Bank and other MDBs can offer EMDCs two financial mitigation mechanisms against offtake risk (Table 3.3). The first is a partial risk guarantee, typically used in

TABLE 3.3

Financial and Policy De-risking Instruments Offered by Multilateral Development Banks to Mitigate Offtake Risks

INSTRUMENT	DESCRIPTION
Guarantees 	**Partial credit guarantees** support the public sector borrowing from commercial creditors to finance public investment projects. They cover commercial lenders against all risks during a specific period of the financing term of a loan for a public investment. **Partial risk guarantees** are used in limited-recourse private projects. They cover commercial lenders to a private sector investment project against default on a loan arising from a government-owned entity failing to perform its obligations with respect to the private investment project. **Policy-based guarantees** a portion of debt service on government borrowing (through loans or bonds) from commercial creditors but are not associated with specific public investment projects. Instead, they cover borrowings undertaken with the assurance that certain structural, institutional, and social policies and reforms will be carried out.

Source: Authors' analysis.

limited-recourse private projects. This guarantee covers the risk of the nonperformance of sovereign contractual obligations, as when a state-owned enterprise or government entity has agreed to purchase clean hydrogen by entering into a purchase agreement with a production company. The second is a policy-based guarantee, which applies to funds borrowed with the assurance that the government will undertake certain structural, institutional, and economic policies and reforms—such as a policy mandating clean hydrogen quotas that is triggered if the government does not comply with its commitment.

6. Technology Risks and Mitigation Mechanisms

Electrolysis is at the core of clean hydrogen production. Electrolysis technology has only been tested in clean hydrogen projects of an installed capacity of 100 MW; projects at gigawatt scale raise questions about the technology's performance, durability, and asset lifetime. The absence of information on technology performance at scales over 200 MW increase the cost of finance. In addition, the asset lifetime of electrolyzers—between 60,000 to 90,000 hours depending on the hours of operation and consistency of the energy input—will raise risks related to the interplay of electrolyzer degradation and the replacement cycle. Appropriate contractual measures with original equipment manufacturers will need to be put in place to ensure one major maintenance cycle over the life of a 15 to 25-year project finance contract (Fitch Ratings 2023; IRENA 2020).

The electrolysis technology must function in a way that secures the planned output and earns the expected return on investment. Currently, manufacturers offer contracts that include replacing defective components at their expense. Some primary technology providers fund a warranty reserve at the time of sale. The risk is that actual warranty costs will exceed the reserve. If the manufacturer cannot honor the warranty because of insolvency, the excessive repair costs directly affect the developer's cash flow and the ability to repay its debt obligations. This situation puts stress on the balance sheet of the project and endangers its liquidity, solvency, and financial closure (Fitch Ratings 2023).

A straightforward way to mitigate the technology risk is by carefully selecting a reputable primary technology provider and assessing the technology options, providing costs/benefits for the project outputs. Performance, product, and availability guarantees for electrolysis technologies are also available, but the high cost of the coverage deters manufacturers and developers from acquiring them. If, for example, the repair and maintenance cost is $800,000 and the warranty insurance includes a deductible of $300,000 and a co-payment of 10 percent, the manufacturer would pay $450,000 in premiums—almost half the value of the coverage.

Private companies may offer innovative insurance risk transfer solutions that provide protection for electrolyzer manufacturers, particularly coverage for the high costs of warranties for repair or replacement. For example, insurance companies, such as Munich Re or Swiss Re, may offer coverage for product, performance, and availability guarantees (Table 3.4). However, this type of insurance is fairly new and has not been used in large-scale clean hydrogen projects.

TABLE 3.4

Commercial Insurance Covering Specific Technology Risks

PRODUCT GUARANTEE	PERFORMANCE GUARANTEE	AVAILABILITY GUARANTEE
• Protection against part breakdown • Coverage of maintenance and replacements • Cost overrun operations and maintenance plan	• Protection against underperformance • Hydrogen production rate	• Protection against under availability • Covers downtime • Project-specific spare parts

Source: MunichRe. 2022. Securing the power of Green Hydrogen. https://www.munichre.com/content/dam/munichre/contentlounge/website-pieces/documents/MunichRe-Factsheet-Hydrogen.pdf/_jcr_content/renditions/original./MunichRe-Factsheet-Hydrogen.pdf.

7. Design, Construction, and Completion Risks and Mitigation Mechanisms

Clean hydrogen projects are complex undertakings that bring together multiple stakeholders along an intricate supply chain. For example, a production project has critical engineering interfaces, namely between intermittent renewable power generation, the hydrogen electrolysis unit, the water desalination plant, and the compression and storage mechanisms.[20] The complex nature of clean hydrogen projects makes it easy to underestimate initial costs during the design phase. The risk of underestimating the costs of construction work and equipment (capital expenses) may reflect:[21] (1) the limited experience of sponsors and financiers with clean hydrogen, as an emerging industry, or (2) the misinterpretation of project scope and configurations, as clean hydrogen production needs both renewable power to operate the electrolyzers and ancillary infrastructure to support mid- and downstream activities.

Construction and completion risks refer to the possibility of a project not being completed within the expected budget and by the expected date. These cost and time overrun risks are higher for clean hydrogen projects than for other energy assets (such as offshore wind or gas projects), because of the participation of multiple contractors and the deployment of multiple technologies. For example, in a greenfield investment to produce green ammonia from renewable hydrogen, intertwined project elements—renewable power, electrolyzers, Haber Bosch plant, water desalination, among others—require thorough system integration. Failure to build all the parts of the project to technical specifications and on schedule will result in cost overruns and delays, ultimately affecting returns on investment. For this reason, financiers will look at the track record of the engineering, procurement, and construction (EPC) contractor, as it will normally be the single point of responsibility in building infrastructure assets.

[20] Financing a world scale hydrogen export project. Oxford Energy Studies. Oxford, https://www.oxfordenergy.org/publications/financing-a-world-scale-hydrogen-export-project/.

[21] https://assets.kpmg.com/content/dam/kpmg/be/pdf/2022/hydrogen-industry-1.pdf.

Choosing an experienced EPC company mitigates the risks of cost and time overruns. Signing a fixed-price, turnkey EPC contract with a creditworthy company is also a de-risking mechanism. In the absence of such a contract, completion and construction warranties are the best course of action. A definition of completion will need to be agreed to; it will usually be a requirement of the lenders that completion be verified by an independent engineer acting for the lenders.

A cost overrun guarantee, another de-risking mechanism, is a commitment by a third party that, should the costs of completing the project exceed the agreed budget, the cost overrun guarantor will meet the shortfall. In both completion and cost guarantees, lenders take a credit risk on the guarantors. As the clean hydrogen industry is nascent, the experience and creditworthiness of the EPC company will be critical to computing the losses the company is likely to incur in the event of late completion, an estimate that will figure in the contract as liquidated damages. Insurance companies may also offer solutions to mitigate risks related to design, construction, and completion. For example, "contractors' all-risk insurance" generally covers risks related to physical loss or damage to works during construction, and "coverage for delays" during start-up provides protection against delays caused by physical damage.

8. Operational and Maintenance Risks and Mitigation Mechanisms

Risks related to operations and maintenance (O&M) include failure to achieve the key performance metrics forecasted for the project, failure to provide scheduled or unscheduled maintenance, limited availability of skilled technicians to operate and maintain plants, and lack of an enabling infrastructure.

The risk of falling short on operational key performance metrics is intrinsically related to the balance of plant for electrolyzers and the overall plant design. Metrics, such as production quantity and quality of hydrogen or its derivatives, are essential to determine the cash flow available for debt service. Financiers will look to whether the performance specified in the hydrogen purchase agreement can be achieved and maintained over the life of the project. For example, metrics on hydrogen production (in kilowatt hours per kilogram) and the efficiency of conversion into ammonia (in kilograms per hour) will be critical to project success. It is relevant to say that the O&M risks are deeply intertwined with technology risks, as there is a lack of track record of how the electrolyzers will operate in large scale projects (over 100 MW of electrolysis capacity).

The risk of not performing scheduled or unscheduled maintenance may reduce the hydrogen output and constrain project cash flows. Another O&M risk is a lack of local technicians with the skills required to operate and maintain facilities. If technicians must be brought in from abroad, investors will demand a higher return on investment. A lack of skilled workers is not exclusive to EMDCs. An example of high-income countries with limited skilled labor is Australia, where 70 percent of companies participating in the hydrogen economy requested training programs focused on O&M of electrolyzers, fuel cells, hydrogen storage, and refueling stations (Beasy, Emery, Pryor, and Vo 2023).

TABLE 3.5

Financial De-risking Instruments Offered by MDBs to Mitigate Operational Risks

INSTRUMENT	DESCRIPTION
Liquidity Accounts	This innovative risk-mitigation instrument is applicable where a concessional loan by a MDB is made to a public authority. The MDB constitutes a reserve account to guard against disruptions to the payment of the commercial lenders derived from the non-achievement of operational key performance from unforeseen technology disruptions caused by the electrolyzers.

Source: Authors' analysis.

Note: Concessional loans from MDBs offer interest rates below market value, with longer terms and grace periods than loans from commercial banks.

Careful consideration should be given to selecting an O&M contractor and drafting the O&M contract to optimize the performance of the clean hydrogen project. To mitigate O&M risks, financiers will require a comprehensive O&M contract using either a fixed-price, cost-plus structure, or an incentive/penalty structure. Financiers prefer the incentive/penalty structure, because it insulates the project company from operating risks and offers the best chance of the project staying within budget.

Another way that MDBs could help mitgate the failure to comply with key performance metrics derived from technology underperformance or non-foreseen failure is by setting up liquidity reserve accounts to cover downtime, underperformance, maintenance, and repairs in case of technology disruptions (Table 3.5).

Where local skilled workers are limited, EMDCs can implement programs to develop and improve local technicians' relevant competences. In addition, companies should collaborate with employment and educational authorities from host countries to create programs that support the upskilling and retraining of workers.

9. Supply Risks and Mitigation Mechanisms

Supply risks relate to a disruption in the availability and price of the two main inputs for renewable hydrogen production: water and renewable power. The provision of water and power is a central feature of renewable hydrogen projects, one that creates complexities for project configuration, construction, and operation. Supply of both water and power may well be separate from the project company and sold to it by utilities or other third parties, thereby raising risks related to price, volume, and duration of the contracts for these inputs.

Given that electricity costs represent one-third of the levelized cost of renewable hydrogen, reducing power price volatility and ensuring reliability of supply are of central concern for investors. In addition, that the renewable electricity complies with the characteristics of importing countries—that is, additionality, temporality, and geographical correlation—will be assessed during the due diligence performed by financiers. In the current market structure, most projects are internalizing electricity production to avoid this risk—at a greater project cost.

If renewable power is supplied by a third party, the credit profile of the electricity-producing company will be a key consideration, along with the terms of the power purchase agreement and the hydrogen purchase agreement. The price will be benchmarked to the reference market. Renewable hydrogen projects in which electrolyzers are powered through grid connections will depend on regulatory requirements and qualifications related to direct use of renewable electricity, which may raise regulatory risks and, possibly, operational risks due to grid constraints. In countries where the power plant is connected to the grid and electricity markets are sophisticated, competitive pricing may be achieved. Many EMDCs lack financial instruments to cover volatility in electricity prices; this may constrain the use of short-term power market contracts and pricing to feed renewable hydrogen projects. This means that the risks associated with an ill-designed electricity market and potential risks associated with market design reforms will be transferred to clean hydrogen projects.

Limited water availability is a key risk for renewable hydrogen projects, particularly in locations where solar and wind energy are abundant but water is scarce. To decrease the water supply risk, projects can be located near the coast and equipped with a desalination facility. Should water be supplied through a desalination facility, risks related to construction and operation of the asset would also apply. When water is supplied by a third party, financiers will look at the pricing, duration, and technical requirements of water contracts to reduce price volatility and volume risks. Essential to a project's long-term financial sustainability is an assessment of its water source(s) to avoid competition with other possible uses.

To de-risk the supply of water and power, companies providing both inputs must have a positive reputation and be financially sound. Particularly for power supply, securing cost-competitive renewable electricity contracts is key to achieving financial closure; projects that do not include their own power production from renewable energy sources will require long-term power purchase agreements that specify the quantity, origin, and price of the electricity used. Clean hydrogen projects must ensure that their operation does not aggravate water shortages but helps reduce water stress through investments and efficient management. If desalination plants are built in EMDCs, they should also help improve the provision of water to local communities.

Top 10 Risks Affecting the Availability of Financing for Large-Scale Clean Hydrogen Projects

The World Bank and the OECD conducted a robust global market sounding to identify the top risks affecting the availability of financing for clean hydrogen projects in EMDCs. In a comprehensive survey, project developers, private financiers, and development finance institutions were required to identify the top 10 risks that, if mitigated, would improve financing availability for large-scale clean hydrogen projects (Figure 3.1). Results shows that the top 10 specific risks are part of six subcategories mentioned previously: offtake; political and regulatory; infrastructure; technology; permitting and compliance; and macroeconomic risks.

The results from the market sounding demonstrate that the top four risks affecting the availability of finance pertain to the subcategory "offtake risks." The prevalence of these risks reflects the incipient stage of the clean hydrogen market and the extremely limited availability of mechanisms to secure a long-term hydrogen purchase agreement with a fixed price by a creditworthy offtaker. They also demonstrate that actors participating in the clean hydrogen industry do not have solutions to overcome the uncertainty around demand and prices.

Another risk selected among the top 10 is the uncertainty around technology performance, related to the industry's nascency. The rest of the top risks selected by respondents are related to the specific location to develop a clean hydrogen project. They encompass political, infrastructure, regulatory, and macroeconomic considerations—around which financiers may perceive high risk in EMDCs. Yet effective, relevant de-risking mechanisms, such as political risk insurance or public-private partnerships, have been available for decades (Table 3.6).

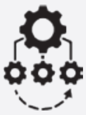
Tailoring Financing De-Risking Measures to the Relevant Phase of the Clean Hydrogen Project Life Cycle

It is worth mentioning that the funding structure used to finance clean hydrogen projects affects the allocation and pricing of risks. The two structures most often used to fund clean hydrogen projects are (1) corporate finance and (2) project finance. Corporate financing involves getting finance for a clean hydrogen project based on the balance sheet of the private company rather than the project itself. This is normally only possible when the developer is so large that it chooses to fund the project with its own funds. Project finance takes the form of limited or nonrecourse financing to a special purpose vehicle, which will depend on revenue streams from the developed clean hydrogen project. In the case of project finance, the only collateral a commercial lender can have recourse to is the underlying assets of the investment. In this case, the lender is likely to perform a detailed due diligence on the investment itself and set a lending cost that reflects the various investment risks.

When a clean hydrogen project uses project finance, the debt-to-equity ratio is the result of a compromise between the project shareholders (equity providers) and the lenders (debt providers) based on the overall risk to be borne by the lenders, the project's overall degree of risk, the creditworthiness of the sponsors, the industrial sector offtaker, the technology used, the total project cost, and the country where the project is being developed. For example, debt-to-equity ratios for power projects in developing countries tend to be in the order of 80:20 to 70:30 (World Bank 2022); but for clean hydrogen projects in EMDCs the debt-to-equity ratio can be 60:40. Therefore, it is essential to optimize the level of debt throughout the life cycle of a project by securing the largest possible share of debt and minimizing its cost.

TABLE 3.6

Top 10 Risks and Proposed Financial and Policy De-risking Mechanisms

	RISKS	FINANCIAL & POLICY DE-RISKING MECHANISMS
	Uncertain clean hydrogen market demand	Purchase obligations; public procurement; quotas; long-term hydrogen purchase agreement
	Limited credible off-takers	Partial risk/credit guarantees by MDBs; export credit agencies guarantees; credit defaults swaps; credit enhancing instruments
	Uncertainty about hydrogen price	Contracts for Difference; long-term hydrogen purchase agreement, demand aggregators as H2Global
	Lack of existing hydrogen trading market	Development of spot markets
	Political risk (expropriation, breach of contracts, war, currency inconvertibility and transfer restriction)	Political risk insurance; public equity investment
	Limited supporting infrastructure	Hydrogen hubs; public private partnerships
	Uncertainty about tax and incentives	Carbon tax; political risk insurance; policy-based guarantee; rule of law
	Uncertain technology performance	Performance warranty, guarantees, technology insurance
	Permitting risks	Political risk insurance, capacity building, one-stop-shops, digitalization
	Rising interest and exchange rates	Foreign exchange swaps, interest rate hedging, derivatives

Source: Authors' analysis.

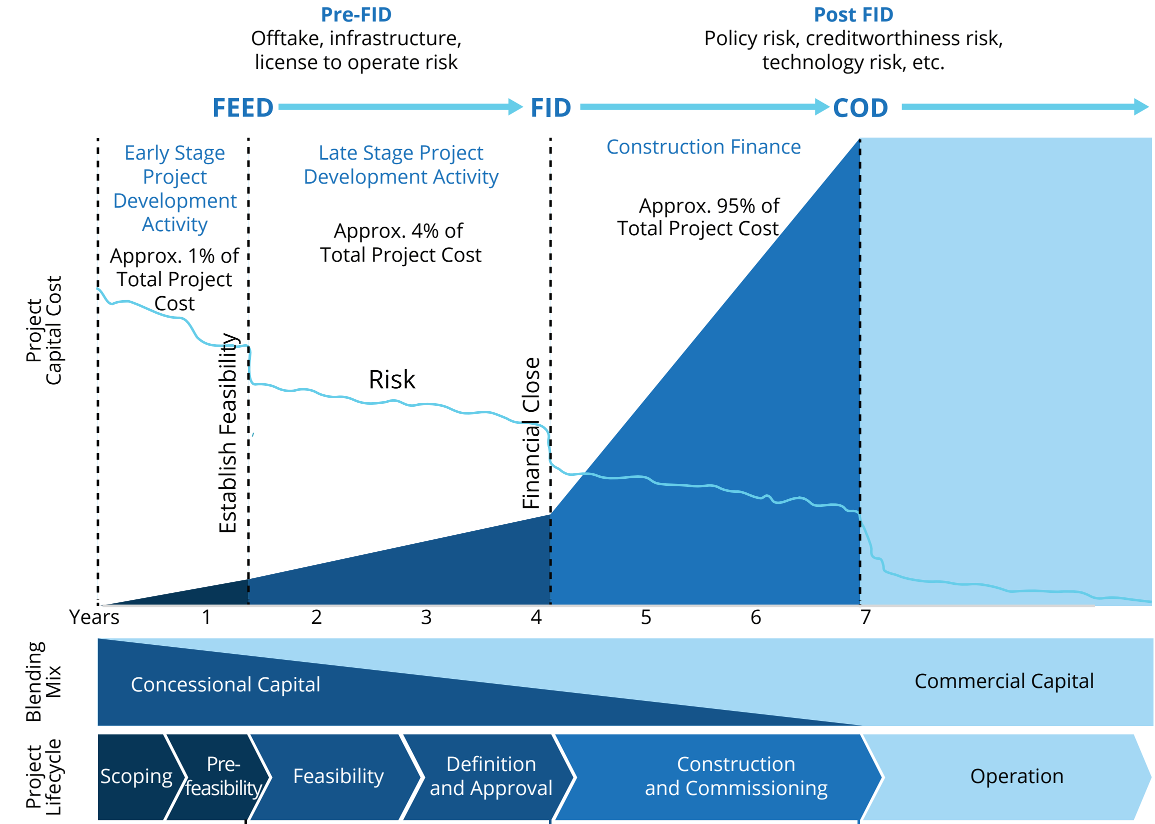
Risks change over the project life cycle, calling for different mitigation instruments at each stage. MDBs' involvement in the early stages of project preparation (prefeasibility, feasibility, front-end engineering design) can help make projects an investible asset for equity investors (project developers, donors, angel investors, venture capitalists, high-yield investors, institutional investors, pension funds) while also attracting debt investors (commercial banks, bond investors). Although projects are perceived as less risky after achieving the FID, clean hydrogen projects keep critical post-FID risks centered on EPC overruns, offtake default, technology nonperformance, withdrawal of regulatory incentives, and exchange risks. Furthermore, the construction, commissioning, and operation phases of clean hydrogen projects absorb 95 percent of total project costs. MDBs could participate by providing risk mitigation instruments, such as liquidity accounts to mitigate technology risks (Figure 3.2).

To decrease the current clean hydrogen production cost from $5 to $3 per kilo, as established in chapter 2, it is critical to bring the cost of capital down. This is possible through a mix of financial and policy de-risking mechanisms that offset the most prevalent risks perceived by lenders and equity providers in the clean hydrogen industry. For instance, tackling the six sub-categories of risks that hinder the availability of finance with the following de-risking mechanisms—(1) long-term hydrogen purchase agreements, (2) partial risk and credit guarantees, (3) contracts for difference, (4) development of spot markets, (5) political risk insurance, and (6) development of hydrogen hubs—can substantially decrease the cost of financing and help achieve a levelized cost of $3/kg for clean hydrogen (Figure 3.3). As such, if all risks have the same severity affecting the risk premium, their effect in increasing the cost of capital should be counterbalanced by deploying the appropriate risk mitigation instruments or direct policy interventions.

The analysis in chapter 3 demonstrates that financiers will give better terms of financing to projects that have available risk mitigation instruments, which will translate into a lower cost of capital. Those clean hydrogen projects that have the lowest exposure to perceived and actual risks will be the ones achieving FID in the short and medium term. Therefore, government authorities from EMDCs, MDBs, sponsors, and financiers must assess their appetite for risk and select the most efficient and cost-competitive risk mitigation instruments to make clean hydrogen projects a reality.

FIGURE 3.2

Risks, Costs, Financing Over the Life Cycle of a Clean Hydrogen Project



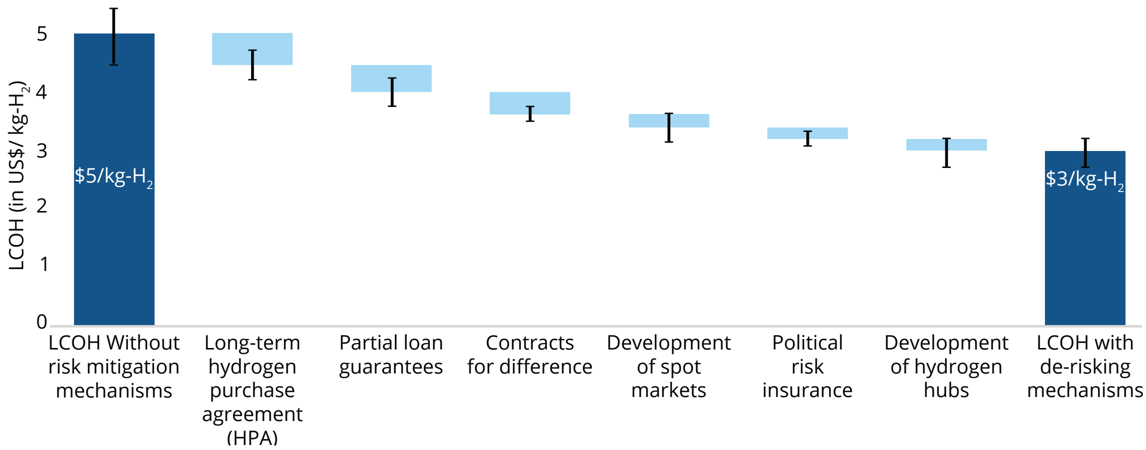
	Scoping / Pre-feasibility	Feasibility / Definition and Approval	Construction and Commissioning	Operation
Equity Investors	• Donors • Governments • Project developers • Angel investors	• Donors • Governments • Project developers • Venture capitalists • High yield investors	• Project developers • Institutional investors	• Corporations • Institutional investors
Debt Investors	• DFIs	• MDBs • DFIs	• MDBs • DFIs • ECA • Commercial banks	• MDBs • Commercial banks • Bond investors
Sample Blended Finance Structure	• Grants	• Grants • Concessional finance	• Blended finance • Commercial debt • Equity investment • Risk mitigation instruments	• N/A - Exit to a commercial buyer of the asses

Source: Authors' analysis based on H2Global Stiftung (2022) and Worley (n.d.).

Note: COD = construction, operation, and decommissioning; DIFs = development finance institutions; ECAs = Export Credit Agencies; FEED = front-end engineering design; FID = final investment decision; H_2 = hydrogen; MDBs = Multilateral Development Banks.

FIGURE 3.3

Financial and Policy De-risking Mechanisms Lowering the Cost of Producing Hydrogen from $5 to $3/kg



Source: Authors' analysis. Approach for determining the cost of each risk factor from OECD's forthcoming working paper (Lee and Saygin Forthcoming).

Note: The error bars represent 95% confidence intervals based on a standard normal distribution. H_2 = hydrogen; LCOH = levelized cost of hydrogen.

FOUR

GROWING THE MARKET: FUNDS, POLICIES, AND THE ROLE OF MULTILATERAL DEVELOPMENT BANKS

Key Points

- There is no functioning market for clean hydrogen at present. To leverage private investment, policies need to look beyond fixing today's market and begin to build the market of the future. Clean hydrogen faces a substantial cost gap, as estimated in chapter 2. Even the most promising projects face high risks. As shown in the preceding chapters, proposed projects have yet to reach the final investment decision stage despite an announced $100 to $300 billion in subsidies worldwide. If policymakers aim to achieve net-zero emissions by 2050, they must explicitly design policies to engage the private sector in developing a workable clean hydrogen market, on both the supply and demand sides. Such policies would consider the entire energy system, and all decarbonization pathways, rather than separating power and gas infrastructure from end uses.
- Policies promoting clean hydrogen in a few first-mover countries can spur development elsewhere and begin to shrink costs. Governments' willingness to share and absorb risks is critical to accelerate investment. Yet, financial instruments in emerging markets and developing countries (EMDCs) are insufficient to mitigate the risks of a nascent clean hydrogen industry.
- Not all countries need to be among the first movers in clean hydrogen, but benefits await the competitive EMDCs that choose to participate in this process. Promoting clean hydrogen production in EMDCs supports climate mitigation now and in the future, as relevant resources—in particular renewable electricity—become increasingly available. Moreover, including EMDCs among first movers strengthens an international clean hydrogen value chain that may yield substantial socioeconomic development benefits. Aligning climate mitigation and development benefits is an opportunity to advance climate justice.
- An appropriate clean hydrogen policy package would mitigate perceived risks and thus leverage private investment. Countries' choice of strategy determines the necessary level of intervention, as well as the appropriate policy design and pattern of public resource allocation. First movers may choose to focus on: (1) the entire value chain; (2) limited exports from pilot projects to industrial countries; or (3) substantial exports from large plants, appropriate where natural resources are readily available at competitive rates. Where exports are planned to be substantial, it will be important to internalize segments of the upstream and downstream value chain to optimize socioeconomic benefits. In all cases, decision-makers must act today to strengthen regulatory frameworks for hydrogen. Predictable policy and streamlined regulation are two essential factors whose lack in a number of jurisdictions is stalling progress.
- Multilateral development banks (MDBs) and development finance institutions have a strategic role to play in supporting EMDCs willing to become first movers. They can support governments to attract private sector investment by improving enabling conditions, de-risking both clean hydrogen industry and individual projects, reducing costs, and promoting adequate financing instruments. Moreover, they can support countries in defining policy frameworks that catalyze local socioeconomic benefits and climate mitigation to align with national development agendas.

- MDBs must cooperate with one another to develop the clean hydrogen industry. Clean hydrogen is an especially interesting area in which to take a single-platform approach because the volume of resources, knowledge, and assistance needed far exceeds what any MDB alone can provide, even for a single country or a small-scale but big-picture "lighthouse" project. Cooperation is the only way to lower transaction costs, distribute the cost of risk mitigation, share existing knowledge, spur innovation, and attract private sector participation.

Addressing Clean Hydrogen's Financing Needs, Given Global Finance Metrics

Clean hydrogen projects face a bankability gap, pose particular risks, and require investments that approximate those made in the entire energy transition to date. Developing large-scale projects before 2030 will require closing the project cost gap (identified in chapter 2) and mitigating overall risks (identified in chapter 3) through policy interventions to leverage private investment. This section considers the main financing choices of EMDCs looking to be first movers.

In the scenarios outlined in chapter 1, EMDCs will produce 25 to 50 percent of the world's hydrogen by 2050. This implies an annual average investment of $250 to $500 billion between now and then, translating to unprecedented volumes of greenfield foreign direct investment in a single industry. About 33 percent of the projects planned until 2030 are in EMDCs, implying an investment of about $106 billion through that year. This equals about 25 percent of all investments in renewables in EMDCs between 2013 and 2020 (International Renewable Energy Agency 2023). The Middle East and China lead committed investments, at $5 billion each, which is significant but much lower than the annual requirement. Other regions, such as Latin America, which lead in announced projects, have no significant committed investments, yet (Hydrogen Council & McKinsey 2023).

EMDCs should be able to leverage international funding and a broad range of public finance instruments. Funding for development ($186 billion per year) and climate change mitigation ($49 billion per year) could be channeled into clean hydrogen. Doing so would need to be a strategic decision, as it would mean prioritizing hydrogen investment over other development and climate change priorities. Moreover, even if other international funds can be considered (e.g., pension funds, sovereign wealth funds), national public funds would also be required. A summary of EMDCs' finance options include the following:

Multilateral development finance. Development funds are stretched across an ever-expanding list of priorities—from humanitarian crisis response to the provision of global and regional public goods. Despite tightening budget constraints, 2020 saw contributions from official providers reach an all-time high of $76.4 billion, as multilateral organizations deftly tapped alternative sources to raise exceptional amounts of finance.

Decision-makers must strategize to ensure the efficient allocation of development funds (to produce the most competitive clean hydrogen projects) while maximizing developmental impact. As of 2023, funds for clean hydrogen projects at the final implementation decision stage in EMDCs amounted to $10 billion (Hydrogen Council & McKinsey 2023). Development funds through MDBs and the International Monetary Fund could enable other projects to reach this decision point. Promoting $10 billion of EMDC projects yearly would require subsidies worth $5 billion, or 5 percent of official development assistance.[22] This would double the total energy development aid allocated to energy supply, which was $16.3 billion in 2019. The necessary increment could be channeled through MDBs as part of noncore contribution funds (Organisation for Economic Co-operation and Development 2021).

The decision to allocate clean hydrogen development funds depends on the beneficiaries' competitive advantage, which determines the optimal development path for hydrogen. It is also depends on donors' strategic interests, and the degree to which their outlook is global, since the funds to be shared with developing countries could be allocated to donors' own domestic hydrogen industry.

International climate finance. There will be no energy transition by 2050 unless climate funds reach EMDCs. Climate funds reached $83 billion in 2020, of which $68 billion was allocated to public financing and $15 billion to private[23] (United Nations 2023). Combined with development funds, the wise channeling of climate finance can help close the cost gap for EMDCs. Using climate finance for clean hydrogen projects has been criticized for absorbing funds that could otherwise be used to meet the relatively high cost of mitigating greenhouse gas emissions. However, clean hydrogen will ultimately be needed to achieve net-zero emissions by 2050. Investing solely in inexpensive greenhouse gas mitigation tools now may delay the innovation required to reach the Paris Agreement goals. It is an intertemporal choice and requires balancing the benefits realized from previous clean technology investment cycles (such as solar and wind generation) with fostering new technologies (such as hydrogen). The general interest in allocating climate funds to clean hydrogen projects is not recent, though it has gained momentum. It should be noted that most of the contributions to date have focused on technical assistance, knowledge, and pilots.

Other international funding sources. In 2021, sovereign wealth funds and public pension funds invested $9.77 billion directly in clean energy with a view to promoting mature technologies (SWFI 2021). The relatively high risks associated with a now-nascent clean

[22] The estimate of $5 billion is just to illustrate the investment necessary to double the effort, which aims to bring about equilibrium between global investment needs and available resources. There is no publicly available model calculating the volume of economically efficient subsidies for clean hydrogen in EMDCs.

[23] Public climate financing can again be split into $32 billion in bilateral financing and $36 billion in multilateral financing. Private financing includes $3 billion in export credits and $12 billion in mobilized private financing.

hydrogen industry, and its need for long-term funding, do not fit the usual profiles of such funds. But because they have substantial capital volumes, they can contribute alongside private investors to financing bankable hydrogen projects. Moreover, initiatives such as the OnePlanet platform can coordinate efforts and share risks otherwise too high for a sovereign wealth fund.

Public financing instruments. Alongside international funding, public finance will be crucial in helping EMDCs move large projects forward (Organisation for Economic Co-operation and Development 2015). Public funds supporting clean hydrogen should follow general best practices for transparency and financial sustainability, and the principles of green budgeting and fiscal reforms. They should ensure coherence between the economics of clean hydrogen and the entire transition process. Public financing instruments necessarily involve the coordination of decision-makers across levels, including subnational governments, state-owned enterprises, and national development banks.

To date, public funds have been used by first movers, directly or indirectly, to fund clean hydrogen subsidies. In the United States, the Inflation Reduction Act and hydrogen hub subsidies have been announced, as well as various other research, development, and demonstration subsidies totaling more than $25 billion (some estimates are much higher). In Europe, the Important Projects of Common European Interest (IPCEI) account for more than $20 billion, along with programs in individual countries such as Germany, France, Italy, the Netherlands, and Denmark that add up to more than $50 billion. China has announced $22 billion in subsidies. Japan is considering setting aside $113 billion in public and private sector funding. Existing and planned subsidies worldwide exceed $100 billion.[24] Given an investment need of about $30 billion for 1 Mt of hydrogen, this is sufficient funding for more than 3 Mt of hydrogen production per year. If private sector funding matches government funding, the announced subsidies worldwide may be enough to fund 6 Mt hydrogen of manufacturing capacity.[25]

The appropriate mechanism to allocate public funds will depend on a country's institutional framework and experience developing new industries, such as renewables. National development banks, oil and gas companies, and state-owned enterprises may play a key role in this process. Such providers can facilitate equity instruments and complement governmental budget funds, which are typically limited.

[24] This is a conservative estimate based on public information. In a fast-changing environment characterized by frequent announcements of public support and often unclear operationalization, some subsidy announcements and plans cover a large range of clean technologies and solutions, including clean hydrogen.
[25] World Bank analysis outlined in chapter 2 suggests $25–$200 billion will be needed for learning investments to "buy down" the cost of electrolyzer technology. This wide range reflects substantial uncertainty.

Enhancing Credibility with a Clean Hydrogen Strategy

Decision-makers have several choices when fostering good conditions for clean hydrogen. A credible and consensus-based strategy must be set before making investment choices. This step is essential to reduce uncertainty and political risk. Setting a strategy allows a government to explore possibilities, evaluate costs and benefits, map and coordinate stakeholders, and choose its own path. To ensure long-term credibility and resilience across political cycles, a strategy requires broad consensus among stakeholders. The process ushers policies, documents, and regulatory reforms toward a high-level goal (zero emissions) amid broader economic transformation.

In countries where national oil companies provide significant socioeconomic benefits, clean hydrogen strategy needs to be aligned with their decarbonization plans. The hydrogen industry could offer these companies a strategic opportunity to transition toward long-term sustainability. It can also prudently counterbalance and mitigate oil and gas price volatility risks. Moreover, national oil companies possess resources—financial, human, technological, and organizational—that can be redirected to fill the clean hydrogen cost gap.

Mitigating Institutional and Political Risks

Defining a coherent and credible institutional framework for clean hydrogen is the first step toward narrowing the cost gap and de-risking operations, while reducing administrative costs. An institutional framework encompasses rules, regulations, policies, and governance structure. As clean hydrogen development requires a cross-industry perspective, the governance structure in first movers should define a champion agency responsible to lead the development of the sector and coordinate all stakeholders. The responsible agency should have the required resources and capacity to lead the task.

Developing the clean hydrogen industry requires regulations and standards on safety, environmental, and social safeguards; technical and network codes; permitting and licensing; certification; and market mechanisms.

Particular attention should be paid to devising safety regulations, codes, standards, and protocols for any hydrogen project, even for research and development (R&D) projects and pilots. All fuels pose some degree of danger; hydrogen has technical characteristics that call for special safety awareness. Safety management programs should consider the technical aspects of risk avoidance, organizational competencies, and the strength of management systems, even for small inventories (AIChE 2023; United States Department of Energy 2023).

Clean hydrogen certification is essential to defining the product's economic value. Uncertainty regarding certification is a significant source of risk, as noted by stakeholders. This is particularly relevant for those projects that export clean hydrogen, chemicals, or industrial products, such as clean ammonia or clean steel, to countries with relatively strict environmental targets (as in the European Union). In the niche market for clean hydrogen and derivative products, value is associated with certification requirements. Even where private institutions provide certification, policymakers and regulators must promote international harmonization of related definitions and standards (International Energy Agency 2023; Vazquez and Hallack 2022). Certification can become a mechanism for the qualitative comparison of power systems across regions. This will advance international dialogue and coordination efforts (Vazquez and Hallack 2022).

While network codes and market mechanisms are not necessary in a nascent industry that is largely vertically integrated, common transport infrastructure offers a better model than having every project developer building its own infrastructure. Market development may support the financing process as it increases the number of players and the possibility of risk sharing, and decreases the volume of financing required per project. This, however, requires a market model, regulations, and an infrastructure operator.

Besides hydrogen-specific regulations, the design of electricity and water markets, property rights, and related laws can influence the costs and risks associated with developing a hydrogen project.

In particular, the regulation and design of electricity and water markets are necessary elements of a regulatory framework to decrease hydrogen risks and avoid projects' need for full vertical integration. As identified in chapter 3, mitigating supply risk requires that policies and regulations ensure the predictability of prices and continuity of services. Renewable hydrogen production depends on the development of renewable industry; thus, it depends on the regulatory framework and incentives for renewables.

Factors such as public and private ownership, foreign land ownership, and land lease terms are crucial to consider. Addressing them decreases the political risks perceived in some EMDCs. For instance, access to land is a precondition for project development, and land ownership laws and practices need to give investors confidence, while discouraging speculation. In short, policies should not incentivize early developers to claim locations and later speculate on land prices.

A credible regulatory framework strengthens the governance structure, which, in turn, mitigates political and regulatory risks. Organizational responsibilities need not overlap. Multiple sectors converge in the clean hydrogen industry, and regulatory agencies and institutions must act in coordination. The lack of a clear governance structure often brings uncertainty, risks, delays, and unnecessary costs for projects and the overall process. An adequate governance structure would promote a transparent and credible adaptation process, keeping in mind the industry's evolution over the coming decades.

Policy Options to Decrease Costs and Mitigate Risks

Narrowing the cost gap calls for private sector investment, which requires clear steps to mitigate risk. Policy options should tackle those risks that financial instruments cannot (at least not cost effectively).

Carbon Pricing to Increase Competitive Fuel Costs

Inadequate carbon pricing poses a significant macro financial constraint on mobilizing private capital for transition-related technologies, including clean hydrogen. Credible carbon pricing (World Bank 2019) would highlight the value of low carbon projects and promote a more transparent market, thus informing investment decisions[26] (World Bank 2019). The global average price of carbon dioxide (CO_2) is about $6 per tonne; this needs to rise to $75 by 2030 (International Monetary Fund 2023; 2022). The increase would translate into $0.75 per kg of hydrogen from natural gas, an important step toward closing the gap in 2030. Prices in the European Emissions Trading System, one of the most mature carbon markets, recently reached €100/tonne of CO_2. At 10 kg of CO_2 per kg of gray hydrogen, this translates into $1/kg of clean hydrogen.

The Carbon Border Adjustment Mechanism (CBAM) is a trade policy that aims to prevent carbon-intensive industries from transitioning to jurisdictions with low (or no) carbon prices. Such a policy could boost the international production and adoption of clean hydrogen. The CBAM will ensure equivalence of the carbon price of imports and domestic production by confirming that a price has been paid for the carbon emitted during the production of certain goods imported into the European Union. It will apply to hydrogen, ammonia, cement, iron and steel, aluminum, fertilizers, and electricity. The CBAM may drive up clean hydrogen demand by incentivizing the direct price differentiation of

[26] In addition to climate-related benefits, fiscal reforms in EMDCs have a pivotal role to play in aligning decarbonization efforts with sustainable development objectives by raising economic activity and generating development co-benefits such as cleaner water, safer roads, and improvements in human health.

hydrogen and promoting industries that can decrease their carbon footprint by using it. The mechanism opens the possibility of exporting clean hydrogen through products with higher added value and lower transport costs (such as steel and fertilizers) (Marcu et al. 2023; European Commission 2023).[27]

Tax Incentives

Governments can impose taxes and implement custom incentives to promote clean technologies and benefit the clean hydrogen industry. Options may be categorized into four groups: (1) fuel excise taxes, (2) energy subsidy reforms, (3) clean technology tax rebates, and (4) reduction of import taxes for clean technologies (Roaf et al. 2022).

Governments can efficiently incentivize clean fuels using fuel excise taxes and energy subsidy reforms. This decreases the clean hydrogen cost gap by raising the cost of competitive fuels with higher emissions. These policies are efficient, technologically neutral, and expand a government's fiscal space. Energy taxes, subsidies, and price reforms are politically sensitive and must be carefully designed and communicated to society.

Tax rebates for clean technologies effectively incentivize investments. Rebates tend to be simple, transparent, flexible, and market competitive, and have low administrative costs and a sustained impact. However, they constitute a long-term cost, and, depending on the design, could become a fiscal burden for countries with limited fiscal space.

A tax credit is the primary mechanism adopted by the United States through the Inflation Reduction Act, which is expected to benefit clean hydrogen enormously, by reducing the difference in price between clean hydrogen and carbon-intensive alternatives by up to $3/kg.[27] Hydrogen producers can either receive a credit (equal to a specified dollar value per kilogram of hydrogen produced) as a production tax credit or as a tax credit equal to a specified fraction of their capital expenses—an investment tax credit. A production tax credit is received over the 10 years after a facility becomes operational. The Inflation Reduction Act also allows taxpayers to receive payments in place of tax credits for the first five years.

[27] The current regulation, however, poses certain challenges. For example, when hydrogen needs to be transported over longer distances, it is likely to be in the form of hydrogen derivatives and carriers to overcome some of the inherent limitations in transporting this element in gaseous and liquid forms. Additionally, ammonia, other derivatives and carriers (e.g., liquid organic hydrogen carriers), methanol, and synthetic gases and e-fuels (including e-kerosene, e-diesel, or e-methane) are not included in the regulation's scope. This could create a regulatory loophole, even though it is equally clear that the provision it contains to address circumvention—Article 27—is largely limited to reviewing trade patterns and flows, deferring any actual solutions to future legislative and regulatory action.)

Reducing import tariffs on environmental goods can lessen the clean hydrogen cost gap along several dimensions, especially in countries that rely heavily on imported technologies. Such a policy can also reduce renewable generation costs (central to clean hydrogen), even in countries seeking to develop a clean hydrogen value chain. For instance, exclusive economic zone areas or tax-free ports may reduce costs for an export-oriented clean hydrogen hub. The socioeconomic benefits of a tax-free arrangement of this type must be carefully considered.

EMDCs tend to have reduced fiscal space. Smart government policies that create enabling market conditions and mitigate risk can decrease the amount of financial support required. Where a fiscal impact is projected, it is important to assess the degree to which it will affect the government budget and for how long. For instance, the U.S. Inflation Reduction Act—a landmark United States federal law which aims to curb inflation by investing into domestic energy production (among other things) while promoting clean energy—defers fiscal impacts since it is based on tax exemption instruments: $738 billion of offsets fund roughly $499 billion of new spending and tax breaks. It would reduce deficits by $238 billion over a decade, and by more than $61 billion in 2031 before interest (United States Congressional Budget Office 2022). It is not expected that policies with comparable magnitude are feasible in EMDCs.

Other, nonfiscal, policies need to be considered. For instance, subsidies can be provided through public utilities, national oil companies, and national development banks. Any such mechanisms need to be carefully planned to guarantee the efficient use of public resources and the sustainability of public-owned institutions.

It is worth mentioning mechanisms not based on subsidies, such as portfolio obligations. These transfer costs to the industry and, potentially, to final consumers. It is important to consider the impact that this would have on final industry costs and competitiveness. For instance, clean steel for the automobile industry may have a small impact on final prices to the consumer and a large impact on creating clean hydrogen demand.

Past experience with renewable policies offers lessons for hydrogen. A large part of renewable costs, based on auctions and feed-in mechanisms, were passed to consumers through regulated tariffs. The final users of clean hydrogen are less regulated than those of electricity, so the implementation of a similar mechanism would be more limited. However, some uses of hydrogen—to enhance a power system's flexibility or to blend in regulated natural gas pipelines, for instance—could follow the same principles.

Mitigating the Price Risk with Targets and Premiums

Price targets can be established as policy goals. For example, the U.S. government has an ambitious aim to reduce the cost of renewable hydrogen production to $1/kg in one decade (United States Department of Energy 2023). This price goal establishes a framework for renewable hydrogen strategy, road maps, and specific policies for promoting cost reductions and scaling up the country's clean hydrogen industry. It is expected to lead the nation's effort to achieve competitiveness in clean hydrogen while indicating when policies could be phased out.

A price premium is a policy to decrease price risk, identified as one of the highest perceived risks in the industry. The European Hydrogen Bank recently chose fixed premiums to design its first €800 million pilot auction for clean hydrogen in the European Union. Funds are drawn from the Innovation Fund, which is fed by the bloc's carbon market. The auction aims to efficiently allocate funds to scale up Europe's industry and reduce costs by rewarding renewable hydrogen production with a fixed premium per kilogram produced over 10 years. The design choice was based on stakeholders' preferences, ease of implementation within the European Commission's regulatory environment, and the absence of a hydrogen reference market.

Contracts for differences offer another way to mitigate price risk. They have been used to promote electricity, and recently applied to clean hydrogen in United Kingdom. In the electricity market, the generator is paid the difference between the "strike price"—an electricity price that reflects the cost of investing in a low carbon technology—and the "reference price"—a cost measure for the average market price for electricity. Contracts for differences guarantee investors greater certainty and stability of revenues by insulating them from volatile wholesale prices. At the same time, they protect consumers from paying higher support costs when wholesale prices are high. In the absence of a liquid hydrogen market, the challenge of applying this principle is to define the reference price.

Policies to Mitigate Demand and Offtake Risk: Portfolio Obligations and Adoption Targets

Quantitative policies, such as portfolio obligations, create a niche market. This could be a protected market solely for clean hydrogen or a market for clean technologies, where clean hydrogen competes with other clean options, such as batteries, direct electrification, and biogas. In this context, the price gap between gray and clean hydrogen does not apply directly to the investment decision. Although these policies are effective, they can be risky as they do not limit prices and could be costly to society. They may become economically or politically unsustainable if poorly calibrated.

Portfolio obligations for clean technologies and clean hydrogen can be broadly defined through CO_2 emission restrictions, fossil fuel bans (with phase-out periods), and quotas for green industrial products, such as green steel or clean ammonia. These policies are not specific to clean hydrogen but can be game changers for the industry because they protect the market.

The European Union's clean energy policies include targets that affect the clean hydrogen industry. For instance, it sets a binding combined sub-target of 5.5 percent for advanced biofuels (typically derived from non-food-based feedstocks) and renewable fuels of a nonbiological origin (mostly renewable hydrogen and hydrogen-based synthetic fuels) in the share of renewable energy supplied to the transport sector by 2030. Nonbiological renewable fuels have a minimum 1 percent share. Moreover, the European Union sets a target for an increase in renewable energy use in industry by 1.6 percent annually and requires that 42 percent of hydrogen used in industry be renewable by 2030, and 60 percent by 2035 (European Parliamentary Research Service 2023). This target establishes a market both within the European Union and in countries with export-oriented strategies.

Adoption targets for clean hydrogen (or clean technologies) are a soft regulatory tool, indicating a direction but allowing adjustments based on cost information revealed during adoption. As an example of an adoption target, the European Union has proposed to import 10 Mt of renewable hydrogen by 2030, in addition to the 10 Mt of renewable hydrogen it expects to produce within the region (European Parliament 2023).

Double Auctions: Combining Offtaker and Price De-Risking

Procurements through auctions can tackle the risks associated with hydrogen prices, market demand, credible offtakers, and the lack of a liquid trading market. Revealing prices through auctions favors efficient resource allocation while mitigating risks. To this end, auctions must be designed so as to set the right incentives, preventing manipulation through strategic behaviors, and avoiding unnecessary entanglements that could be barriers, especially in a highly complex nascent industry. European countries have gone far in exploring this mechanism. For instance, Germany developed H2Global, a double-auction-based mechanism for long-term purchase contracts on the supply side and short-term sales contracts on the demand side. The mechanism aims to compensate for the difference between supply prices (production and transport) and demand prices by using grant funding from the German government. H2Global received €0.9 billion (approved in 2022) for round 1 and another €3.5 billion for round 2 (expected to be approved by 2023) (BMWK 2022). The Netherlands joined H2Global with €0.3 billion (announced in 2023) (Government of the Netherlands 2023).

Double auctions may be the most efficient mechanism for promoting clean hydrogen production at the industry's present stage of maturity.[28] They create a niche market with enough modularity and adjustment instruments to match demand and supply in light of different levels of price or availability of subsidy funds. However, double auctions also come with challenges, notably their complexity, the risks associated with preparing projects to compete in auctions, the length of the contract duration, and how to accommodate uncertainties related to competitive fuel prices (such as natural gas prices).

[28] In double auctions, buyers and sellers interact to arrange trade. The result defines the contracted prices and volume. For more on double auctions in the electricity sector. Refer to World Bank (2011).

Setting Up Enabling Infrastructure and Hubs

Enabling infrastructure—hydrogen pipelines, transmission grids, water supply, and hydrogen storage—is essential to encourage investments. To decrease project risks and costs, government planners must coordinate and share information on infrastructure needs. Institutional credibility is central to this process.

CO_2—capture, transport, and storage—infrastructure and export ports are essential for countries pursuing an export strategy. Industry scale-up will require transport infrastructure to allow producers to reach disparate users and locations, and access to such infrastructure may determine a project's viability. As repeatedly noted in this report, developing the clean hydrogen market requires an underlying set of infrastructure (for transport and storage). Considering lessons learned from electricity and natural gas markets, a policy framework for investment and open access will be essential. The European Hydrogen Backbone initiative is an advanced example of such a framework.[29]

Clean hydrogen hubs are key to the creation of adequate infrastructure and enabling conditions in some regions. They can simplify the requirements for coordination and infrastructure investment. Policies promoting hub development should focus on regions that can host competitive, large-scale clean hydrogen production and that feature high-priority hydrogen users. This will allow the sharing of a critical mass of infrastructure. Hubs can facilitate offtake agreements to drive synergies; scale production, distribution, and storage; and boost market takeoff. Joint regional efforts will reduce the financing needs of each player and facilitate risk sharing.

A steady supply of renewables-based electricity is an essential condition for most clean hydrogen projects, and the main variable in efforts to reduce costs. Renewables require enabling infrastructure at several levels. For example, power systems need to be strengthened to accommodate dispersed power generation, and roads improved to allow the construction of wind power plants. This is especially important in EMDCs, where renewables' integration in the power system may still face decisive infrastructure barriers. Advancing the viability of renewables is essential to de-risking clean hydrogen.

Innovation

Closing the clean hydrogen cost gap requires worldwide investment in innovation. The development of the industry depends on a steep cost decline in the coming years. Policy makers must decide whether and how much to invest in R&D and pilots—and where in the value chain that investment should focus.

[29] The European Hydrogen Backbone initiative includes 31 European network operators with infrastructure in 25 EU member states, including Norway, the United Kingdom, and Switzerland. The initiative seeks to repurpose natural gas pipelines for hydrogen, and proposed five new supply corridors by 2030. This is a massive initiative; smaller-scale efforts can be made through the development of clean hydrogen hubs and then corridors to connect these hubs.

The cost of electrolysis-based renewable hydrogen production already fell by 60 percent over the past decade amid declines in electricity prices. Also, the capital expenditure for electrolysis declined (Hydrogen Council & McKinsey 2021). Countries of the Organisation for Economic Co-operation and Development have historically accounted for the bulk of global R&D spending on hydrogen, although China is quickly catching up, as seen in government expenditure on hydrogen R&D in 2019 (International Renewable Energy Agency 2022; Organisation for Economic Co-operation and Development 2022).

Public R&D spending has grown significantly since 2016. This has been driven by hydrogen research, which grew from €152 million to €371 million in 2016–19. The topics of hydrogen and fuel cells represent 3.3 percent of all energy-related R&D spending across countries of the Organisation for Economic Co-operation and Development (down from 5.8 percent in 2008). Yet hydrogen deployment accounts for 6 percent of cumulative emissions reductions over 2021–50 under the International Energy Agency's Net Zero Emissions by 2050 Scenario (IEA Global Hydrogen Review 2021). This suggests that even with the recent substantial increase in public R&D support for clean hydrogen, support is far from matching hydrogen's potential contribution to climate neutrality. It is especially important to consider the maturity of hydrogen compared with other technologies, such as renewable energy or carbon capture and storage (Organisation for Economic Co-operation and Development 2022).

In this context, policy makers, especially in EMDCs, must evaluate hydrogen's competitive advantage to decide how much to focus on it, how to design supporting policy, and which part of the value chain to support.[30] A study of the clean hydrogen hub in Ceara, Brazil, shows that internalizing part of the value chain associated with local capabilities in renewables (in the case of wind generation) can increase the development impact compared with a pure export-oriented strategy or with investment in other local value chains that are nascent (such as solar panels) (Caiafa et al. 2023).

The Role of Multilateral Development Banks

MDBs are at an early stage of formulating and implementing their support for clean hydrogen. Funding is available for technical assistance projects and prefeasibility studies, although total approved lending for hydrogen remains below $5 billion per year. As announcements indicate, funding will likely ramp up in the coming years. Given the growing demand for technical assistance, pilot projects, and associated financial operations in developing countries, it is imperative that MDBs and development finance institutions coordinate. A single-platform approach would reduce transaction costs, foster complementarity, prevent duplication and misalignment of resource allocation, and facilitate joint operations.

[30] India, for example, has established a public-private partnership framework for R&D and allocated Rs 18.66 billion to R&D and pilots.

At clean hydrogen's current phase of development, spillovers associated with innovation—sharing knowledge and promoting market transactions—need to be promoted by decreasing transaction costs. The activities of MDBs can focus on public good services that will benefit all countries. These include knowledge sharing, capacity building, and promotion of international cooperation through standards, mutual recognition of certification schemes, and evolution of market models for hydrogen. The World Bank's Hydrogen for Development (H4D) Partnership has advanced in this direction.

The United Nations Industrial Development Organization (UNIDO) Global Program for Hydrogen in Industry (GPHI), in collaboration with the Breakthrough Agenda, the World Bank, and IRENA, recently conducted a comprehensive survey to map the landscape of both financial and technical initiatives related to clean hydrogen in developing countries. The objective of this exercise was to provide a comprehensive overview of (a) financial and (b) technical support initiatives currently being implemented or in development by development finance institutions, governments, and international development agencies.

Initial findings indicate a significant focus on financial instruments, such as risk guarantees and bonds, primarily targeting downstream aspects of the value chain, especially in the chemicals and fuels sectors.

Likewise, the exercise categorizes the type of technical assistance provided along the value chain and in creating an enabling environment. Technical assistance categories include awareness raising and information dissemination, assessments and studies, capacity building, and equipment and infrastructure development. The most commonly offered form of technical assistance to developing countries is awareness building, followed by the development of assessments and studies related to strategy and policy.

MDBs can support countries in designing and implementing policies that will indirectly promote the clean hydrogen industry, such as carbon pricing. Technical assistance and development policy financing are instruments to consider. Support that aligns incentives to the economic transition in the direction of net-zero emissions should be made available to EMDCs, regardless of their clean hydrogen strategy. Eventually, these policies can decrease the clean hydrogen cost gap or mitigate clean hydrogen industry risks.

First-mover policies imply some cost and risk allocation to the public sector to leverage private sector investment. MDBs can support countries through the process, from understanding risks to setting strategies to designing, implementing, and financing policies and enabling infrastructure.

To scale up the clean hydrogen industry in a timely way, developing international lighthouse projects is urgent. MDBs can also play a central role in this process by supporting project development (an expensive and risky part of the process), pooling international funds, decreasing capital costs through blended finance, raising trust, offering risk mitigation instruments (as discussed in chapter 3), and guaranteeing that these projects align with both climate change and broader socioeconomic development goals.

MDBs are well placed to provide financing instruments and channel international funds, especially because their extended timelines are compatible with clean hydrogen industry requirements (projects can last decades). In recent years, multilateral development finance has also supported middle-income countries, some of which can access private debt markets. In contrast, others have difficulty accessing affordable, long-term commercial finance, underscoring the importance of MDB lending. Loans can also be long term (30–50 years), with more significant grace periods to allow time for Sustainable Development Goal-related investments to yield results.

Figure 4.1 outlines MDB support activities by their scope, from virtually all countries (first and second group of activities) to only first movers (third and specially fourth group of activities). The boxes provide examples of activities, instruments and highlighting relevant targeted audience. The **first group** of clean hydrogen support activities include all economies seeking to decarbonize, independently its competitive advantage and interest on clean hydrogen. The **second group** include activities from which every country involved in the clean hydrogen industry will benefit, as they focus on the international public good. The **third group** lists domestic activities necessary to define and implement a clean hydrogen strategy. These support activities will be necessary for all market entrants, but most important for first movers. The **fourth group** of activities requires a detailed strategy that considers competitive advantages, renewable resources at hand, and potential end users.

The MDBs has already started to promote clean hydrogen, especially considering actions regarding the groups 1 to 3 identified above. To illustrate some of these actions, see the summary of recent approved operations in India (Box 4.1) and Chile (Box 4.2).

Even though the MDBs have already taken actions to support first-mover clean hydrogen projects through the promotion of knowledge, strategies, and enabling conditions, it is just the beginning when considering the demand from EMDCs. Meeting this demand requires the efficient allocation of resources, coordination among stakeholders, and capacity building. Furthermore, the role of MDBs in providing financing instruments and channeling international funds to leverage private capital in specific lighthouse projects needs to be further operationalized. The coordination among stakeholders necessitates the development of an implementable action plan and the definition of roles and responsibilities within the clean hydrogen ecosystem. International coordination is challenging but necessary to achieve investment in energy transition, and clean hydrogen serves as a clear example.

FIGURE 4.1

Multilateral Development Bank Support Options to Accelerate Clean Hydrogen Projects

1. Supporting policies, market reforms, and regulatory adaptation to level the playing field for clean technologies

Activities

- Supporting green budgeting and fiscal reforms
- Designing carbon pricing and taxes
- Facilitating carbon emission tracking and emission policies
- Capturing international carbon pricing revenues
- Facilitating fossil fuel subsidy reforms
- Adapting market design to high shares of variable renewable energy

Main supporting instruments

Knowledge products, technical assistance, development policy financing and results-based finance – not specific to clean hydrogen instruments but with high impact in the industry development.

Targeted audience

Every country that requires MDBs support for the energy transition independently of the development of clean H2 strategy.

2. Promoting knowledge sharing and coordination to reduce transaction costs: international public goods

Activities

- Promoting consistent global standards for international offtake agreements
- Establishing a common procurement framework and a standard set of bidding documents for DFI-financed public sector projects to help reduce the administrative burden for client countries
- Establishing good practices and standards for environmental and social procedures, in order to provide clarity to project developers and client countries
- Supporting, globally applicable, low-carbon and renewable hydrogen standards and definitions with clear emission thresholds and sustainable development requirements
- Facilitating knowledge platform about projects, technical cooperations, and stakeholders' perceptions
- Enabling matchmaking platform

Main supporting instruments

Global or regional technical assistance and knowledge products.

Targeted audience

Involving all first movers' countries and stakeholders interested at the international clean hydrogen market development independent of each national strategy.

3. Supporting policy makers in strategic decisions and policy package implementation

Activities

- Providing independent advice, knowledge, and capacity building
- Supporting project preparation and financing strategy
- Ensuring a systematic approach to the development of the clean hydrogen industry
- Supporting countries in designing a mechanism for efficient fund allocation
- Promoting and measuring socioeconomic benefits and progress of the operationalization of clean hydrogen toward the Sustainable Development Goals
- Support governments in developing a common infrastructure investment and use for hydrogen

Main supporting instruments

Technical assistance, development policy financing, investment project financing, results-based finance and guarantees – based on country strategies (or sub-region-specific strategy).

Targeted audience

Countries (at national or sub-national levels) developing and operationalizing the clean hydrogen strategy.

4. Providing financing instruments and channeling international funds

Activities

- Providing concessional financing and grants to lighthouse projects that are not yet competitive
- Developing confidence in first-mover projects, in turn reducing financing costs. MDBs' and DFIs' have an anchor effect.
- Crowding in private sector financing
- Promoting efficient allocation of incentive mechanisms globally, such as the "auction-as-a-service" concept promoted by the European Hydrogen Bank
- Supporting the alignment between clean hydrogen projects and international stakeholders interested in meeting climate finance targets through international cooperation mechanisms, such as the Just Energy Transition Partnership

Main supporting instruments

Technical assistance, investment project financing, guarantees and results-based finance for specific first-mover hydrogen project or hub's infrastructure.

Targeted audience

First-mover stakeholders developing solid projects aligned with the clean hydrogen strategy.

Note: DFI = development finance institution; H_2 = hydrogen; MDB = multilateral development bank.

BOX 4.1

THE WORLD BANK'S $3 BILLION DEVELOPMENT POLICY SUPPORT TO INDIA'S GREEN HYDROGEN PROGRAM

The Government of India (GoI) has adopted a bold low carbon long-term development strategy. In this context, it intends to promote renewable hydrogen[31] to unlock new sources of growth, reduce India's dependence on imported fossil fuels, and support its energy transition journey. Thanks to successful investments in renewable energy (RE), India now enjoys low-cost renewable energy that positions it well to become a leading renewable hydrogen producer among emerging market economies.

In January 2023, India launched National Green Hydrogen Mission (NGHM) that targets to achieve the following results by 2030: (1) Green Hydrogen production capacity of 5 million metric tonnes (MMT); (2) an addition of 125 GW of RE; (3) total investments of US$100 billion; (4) the creation of more than 600,000 jobs; (5) a reduction in fossil fuel imports of US$12.5 billion; and (6) abatement of 50 MMT of annual GHG emissions.

The World Bank has been supporting India's green hydrogen agenda through analytical studies that focused on: (1) sequencing green hydrogen development (which confirmed the short-term potential of replace existing grey hydrogen produced from natural gas in the fertilizer and refinery sectors); (2) identifying suitable locations for green hydrogen hubs; and (3) supporting selected states in developing their own green hydrogen adoption roadmaps.

(*continues*)

[31] The language used in the documents in India refers to Green Hydrogen, as those produced from renewable electricity. This is equivalent to the discussion of renewable hydrogen as discussed in this document.

BOX 4.1 (*Continued*)

This analytical engagement provided the launching pad for the Low Carbon Energy Programmatic Development Policy Program with the Development Objective to accelerate the development of low carbon energy in India. The operation supports three interconnected reform areas:

1. Promoting green hydrogen, through strengthened enabling policies and regulations to reduce costs and increase market demand
2. Scaling up renewable energy by reducing costs and improving grid integration, while also incentivizing storage solutions
3. Enhancing climate finance to meet the large investment needs of green hydrogen and renewable energy through the development of carbon markets and of a stronger framework for green finance instruments

The outcomes of these policy actions will be monitored through 2026. Meeting them will put India on the path to meet its objectives, as set forth in the National Green Hydrogen Mission.

BOX 4.2

FINANCING CHILE'S GREEN HYDROGEN INDUSTRY: A CASE STUDY ON INNOVATIVE FINANCING TO SPUR THE NASCENT INDUSTRY

In 2020, Chile launched its ambitious National Green Hydrogen Strategy (NGHS) to become a global leader in green hydrogen production and leverage its abundant and low-cost renewable energy potential. Chile expects to produce the lowest-cost hydrogen in the world by 2030 and to be among the world's top three hydrogen exporters by 2040. According to estimates by Chile's National Green Hydrogen Strategy, this industry could generate up to US$ 330 billion in private investment opportunities and some US$ 30 billion in exports by 2050.

(*continues*)

BOX 4.2 (*Continued*)

To accomplish the goals set in the NGHS, the Government of Chile, through its Chilean Economic Development Corporation (CORFO), worked with the World Bank to develop a Green Hydrogen Facility that provides an innovative financing mechanism and capacity building to help build the nascent industry. The Project aims at reducing the production costs of green hydrogen while supporting the enabling environment through the provision:

- Blending finance for CAPEX of renewable hydrogen production projects
- Risk mitigation instruments such as debt service reserve account to mitigate payment risk and liquidity reserve account to mitigate technology performance risks
- Capacity building and fostering demand to support the enabling environment

Under CORFO's leadership, the World Bank has convened several international partners, such as the European Investment Bank (EIB), Inter-American Development Bank (IADB), and Kreditanstalt für Wiederaufbau (KfW) to contribute to the Green Hydrogen Facility (for a total c. US$1bn), thereby further multiplying the Project's impact on private capital mobilization, estimated at three times multilateral financing. CORFO is currently working with the World Bank on developing a one-stop-shop to facilitate the provision of financial instruments offered by the different multilateral development banks within the Green Hydrogen Facility, which is expected to be operational by mid-2024.

The World Bank's Project will kick-start a new industry that will create local green jobs and value chains. It will also help decarbonize hard-to-abate sectors and increase the competitiveness of local industries (e.g., mining, freight and heavy transport, and agriculture); create new export opportunities (of green hydrogen derivates, such as green ammonia and e-fuels); and will support Chile's vision of producing the world's cheapest green hydrogen by 2030.

Chile's Green Hydrogen Facility can be considered a global public good by testing an innovative financing mechanism that supports creating a clean hydrogen industry that can be replicated in other developing economies. Several lessons learned can derive from this first-of-its-kind Project, including the possibility of decreasing transaction costs by providing blended finance and risk mitigation instruments to reduce risks perceived by financiers and decrease the financing gap to mobilize private capital to scale up the nascent green hydrogen industry.

FIVE

ACTIONS TO ACCELERATE CLEAN HYDROGEN FOR INTERNATIONAL DEVELOPMENT

Key Points

- A four-point action plan is proposed to accelerate clean hydrogen deployment in emerging markets and developing countries (EMDCs).
- The 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) will be an occasion to discuss this plan, which centers on a series of renewable hydrogen lighthouse projects designed to increase investor confidence.
- Given its urgency, the effort should begin with promising projects from the existing pipeline, keeping in mind aspects such as diversity, replicability, and cost effectiveness.
- Better coordination among participating international institutions will reduce transaction costs and speed up approvals—for example, through harmonization of approval and due diligence procedures.
- In the longer term, more transparent price information should be elicited through the development of hydrogen markets.
- A general capacity-building and knowledge-sharing effort is needed to bring governments up to speed with the clean hydrogen opportunity and its challenges.

Action is needed now to scale up clean hydrogen investment for the broader purpose of decarbonizing the energy sector. Developing the hydrogen economy must consider all aspects of hydrogen production, transportation, and use. This implies the need to coordinate a large array of resources and expertise under conditions of uncertainty. Prominent among the uncertainties is the absence of a functioning hydrogen market, whereas hydrogen will certainly be traded internationally on a large scale in the near future. For this reason alone, clean hydrogen energy production calls for strong international cooperation.

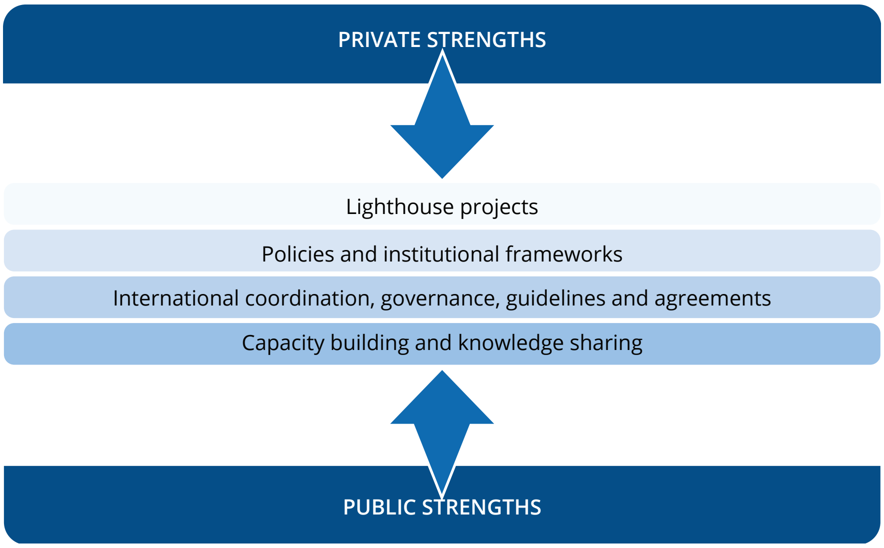
It is time to reach an agreement on the role that international institutions and other stakeholders should play in shaping hydrogen's future. The four-point action plan was built in parallel to the MDBs support options (see chapter 4), however it has a broader perspective of multiple stakeholders' actions. The action plan presented below includes: (1) capacity building and knowledge sharing in the areas of project development and financing; (2) international coordination on certification schemes, market price formation, and other policies relevant along the supply chain; (3) policies and institutional frameworks to promote project development; and (4) the development of a program of lighthouse projects (including mid-size and large projects in EMDCs).

The proposed plan, schematized in Figure 5.1, is designed to marshal support from governments, multilateral development banks (MDBs), and other international organizations to facilitate private sector financing for clean hydrogen projects in EMDCs.

Clean hydrogen is ideally suited for international collaboration. The magnitude of resources, knowledge, and assistance needed far exceeds what any one MDB can provide, even for a single country or lighthouse project. Also, the industry is still in an early phase of development, while continuing to evolve rapidly. This creates particular challenges—but also opportunities—for investment and financing.

FIGURE 5.1

Four-Part International Action Plan to Facilitate Private Investment in Clean Hydrogen



Better cooperation can lower transaction costs, distribute the cost of risk mitigation, share existing knowledge, spur knowledge, and attract private sector participation. Moreover, a cooperative platform can account for the diversity of countries' strategies and the variety of types of support needed for clean hydrogen—ranging from the sharing of knowledge as a public good to the establishment of lighthouse projects in cooperation with the private sector.

The ultimate focus of the action plan is to scale up private investment in EMDCs. General actions to promote the international public good, such as the sharing of knowledge, will benefit all be independent of countries' individual strategies.

Deliberate action is essential. Unless projects are developed on a sufficient scale, the cost reductions needed to allow clean hydrogen to enter a market-driven phase will not occur in time to meet the requirements of the Paris Agreement.

Capacity Building and Knowledge Sharing

Major initiatives are advancing the deployment of clean hydrogen, both in EMDCs and in the high-income countries of the OECD.[32] The knowledge generated by those initiatives should be integrated into the ongoing dialogue on hydrogen to ensure a timely exchange

[32] The Breakthrough Agenda has published a comprehensive overview of these initiatives. The Breakthrough Agenda was launched at the UN Climate Change Conference (COP26) in November 2021. The Breakthrough Agenda currently covers more than two-thirds of the global economy, with endorsement from 45 world leaders, including those of the G7, China, and India.

of information and lessons learned—for the particular benefit of the Global South's nascent clean hydrogen industry.

The financing of clean hydrogen projects, which so far has received limited attention, is a particularly rich area of knowledge sharing. The Hydrogen for Development (H4D) initiative through ESMAP was launched for that purpose. H4D was created by the World Bank and its partners during COP27. Its goal is to bring together the leading international and regional actors providing technical assistance and funding to developing countries and emerging markets. Though just one year old, it has already become an important platform for knowledge sharing, with 36 partners. The platform's early accomplishments fall into four work streams: (1) hydrogen technologies, infrastructure, and systems integration; (2) enabling frameworks (policy and regulation); (3) investment and financing models and procurement; and (4) socioeconomic issues and sustainability.

Actions to Take

- Enhance the access of EMDCs to international hydrogen support initiatives through a matchmaking platform
- Promote a worldwide digital hub of regional initiatives to perform the following tasks:
  - Map the hydrogen support landscape
  - Explore and highlight possible solutions to financing projects
  - Improve stakeholders' understanding of clean hydrogen's risk
  - Publicize risk-mitigation mechanisms
  - Map project development and improve visibility and transparency of best practices, especially with respect to projects co-financed by development and climate funds
  - Expand the hub's network and formal participants' engagement
- Encourage those responsible for climate and development funds to participate in joint knowledge-sharing and cooperation through H4D

International Coordination

International coordination and consensus go beyond knowledge sharing; they must support the development of international standards and markets. International cooperation will play a decisive role in the future of clean hydrogen by mitigating risks and decreasing the costs of transactions with international offtakers of clean hydrogen.

Actions to Take

- Short-term plan. Identify actions that international institutions might take to benefit hydrogen development in regions and countries.
  - **Standards and certification.** Support ongoing international cooperation on hydrogen certification coordinated by International Partnership for Hydrogen and

Fuel Cells in the Economy (IPHE) with support from IEA H2 TCP Task 47 and other actors under the Breakthrough Agenda's Hydrogen Breakthrough priority action H.1 "Standards and certification." It is critical that governments commit resources to capacity building on certification and delegate representatives to these relevant global platforms enabling international dialogue and technical cooperation on this subject matter. The focus should be on advancing mutual recognition of certification schemes for hydrogen and derivatives, in line with the conclusions of G7 and G20 Energy Ministerial meetings.[33,34,35] In addition, continued work on global International Organization for Standardization (ISO) standards will remain critical, in particular the development of the suite of standards on GHG emission assessment of hydrogen production conditioning and transport following the launch of ISO DTS 19870. (International Organization for Standardization 2023)
    - **International end-user policies.** Identify, map, and promote dialogue among organizations driving the decarbonization of international transportation and clean trade policy tools. Here, the International Maritime Organization's strategy for reducing greenhouse gases from global shipping and the Carbon Border Adjustment Mechanism (CBAM) are good examples. The goal is to assess the impact of those policies on the clean hydrogen industry in EMDCs, to identify opportunities and challenges—and to raise awareness.
- Mid-term plan. It is important to act now, with a longer time horizon in view:
    - **Develop a transparent hydrogen pricing system.** Better price information is critical to facilitate investments and financing. The hydrogen market will develop gradually. Lessons can be drawn from experience with liquefied natural gas and the electricity market. Early trade will determined by bilateral agreements, followed by over-the-counter trading. Eventually, these will give way to more sophisticated market designs that include spot markets. Such transitions take time. Pricing systems require both soft and hard infrastructure, including an information hub (virtual or physical). Some level of flexibility will be necessary to enable adaptation to players' responses to price variations.
    - **Ensure that EMDCs can compete fairly in international clean hydrogen bidding mechanisms.** Considering the announced volume of subsidies for clean hydrogen within the Organisation for Economic Co-operation and Development (OECD), it is important that international procurement policies, such as H2Global, consider the impact of national subsidies when comparing projects to avoid bias against EMDCs and promote the most efficient projects.
    - **Ensure open access to the infrastructure necessary to participate in hydrogen hubs.** One of the insights from the history of price formation in the natural gas and electricity sectors is the need for open access to essential facilities. A transparent mechanism to allocate (regulated) infrastructure services is needed.

[33] G7 Climate, Energy and Environment Ministers' Communique', 16 April 2023.
[34] G20 Presidency Leaders Declaration, 9–10 September 2023.
[35] IEA Global Hydrogen Review, 2023.

Policies and Institutional Frameworks to Accelerate Project Development

Several institutions already offer technical assistance to developing countries in the clean hydrogen industry. What has changed is the growth in demand for assistance to build the industry into a competitive market in time to meet the requirements of the Paris Agreement. Coordinated planning allows countries to define their long-term strategies (beyond political cycles) to mitigate risks and avoid inefficient use of resources. For countries willing to be among the first movers, an enabling policy framework mitigates investment risks and nudges the private sector to buy clean fuels, specifically clean hydrogen, in the most feasible industries.

Procurement quotas should be considered for industries where the quotas will have the least effect on competitiveness and may have a considerable impact on demand, especially if demand is localized. For instance, imposing obligations to purchase green steel in the automobile industry could make a big difference with a small impact on the final price (and low distributive effects). Public procurement of energy and materials offers another option for creating demand.

Actions to Take

- **Promote a global digital platform for exchange of information on technical assistance.** The platform should have four parts: (1) an organized list of funds, institutions, and facilities that can provide resources for clean hydrogen assistance and the requirements for gaining access to funds; (2) a list of assistance received and available results, by beneficiary country; (3) the development of a tool to facilitate access to best practice information from previous projects; and (4) creation of a dynamic toolkit built on lessons learned and identifying enabling conditions in light of country characteristics and goals. The platform should be designed to facilitate the allocation of development and climate funds by avoiding duplication, increasing accountability, demonstrating consistency in the development of policy and project frameworks, sharing information, and contributing to credibility in the eyes of private investors.
- **Expand financial resources for technical assistance to promote the production and use of clean hydrogen.** The need is especially great for assistance focused on risk mitigation and policies to induce demand for clean hydrogen from the private sector (such as procurement quotas).
- **Support countries in implementing signed memorandums of understanding with companies.**
- **Compile lessons learned and guidelines on interinstitutional coordination.** Chile could be used as an example of cooperation to improve enabling frameworks (see Box 4.2).

A Proposal for Lighthouse Projects

Lighthouse projects are necessary to accelerate the scaling up of the clean hydrogen market. As clean hydrogen projects tend to be large and involve multiple stakeholders and financing sources, coordination can be essential to mobilize private capital.

Actions to Take

- **Strengthen the hydrogen dialogue among MDBs and other development finance institutions.** A regular exchange among financing institutions could be organized as an H4D workstream. Institutions could support an annual matchmaking event by region to allow project developers to sell their projects to financiers and potential offtakers. Pre-identified offtakers interested in buying clean hydrogen could present their goals and contracting models.
- **Expand technical assistance and coordination in project development through scale-up funding for existing project preparation facilities.** Lighthouse projects require substantial high-risk capital (estimated at $100 million in front-end engineering and design expenses for a large project). MDBs and other international financial institutions have a central role to play in this phase of project development.
- **Lower transaction costs by coordinating the project information requirements of financial stakeholders.** The transaction costs of hydrogen projects are too high during the preparation phase, especially for small and mid-size companies. A single due-diligence approach for development finance institutions would remove this barrier.
- **Promote lighthouse projects in EMDCs (exclusive of China) before 2030.** The projects should be of mid- to large size (100 MW to 1 GW) and have a total electrolyzer volume of 10 GW or more. Additional aspects of the lighthouse project include the following:
    - Develop a guideline or checklist of factors across the supply chain that need to be considered when developing a clean hydrogen project
    - Promote tools for prioritizing and assessing projects, drawing initially from the pipeline of existing projects
    - Identify and remove bottlenecks
    - Enhance project quality to improve bankability
    - Promote joint mechanisms (funds and donors such as MDBs) to allocate financial support to the projects
    - Follow the principles of the World Bank Group’s International Finance Corporation (IFC or similar environmental, social, and governance guidelines) to define a set of actions to guarantee sustainable, socioeconomically equitable, and beneficial project development

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