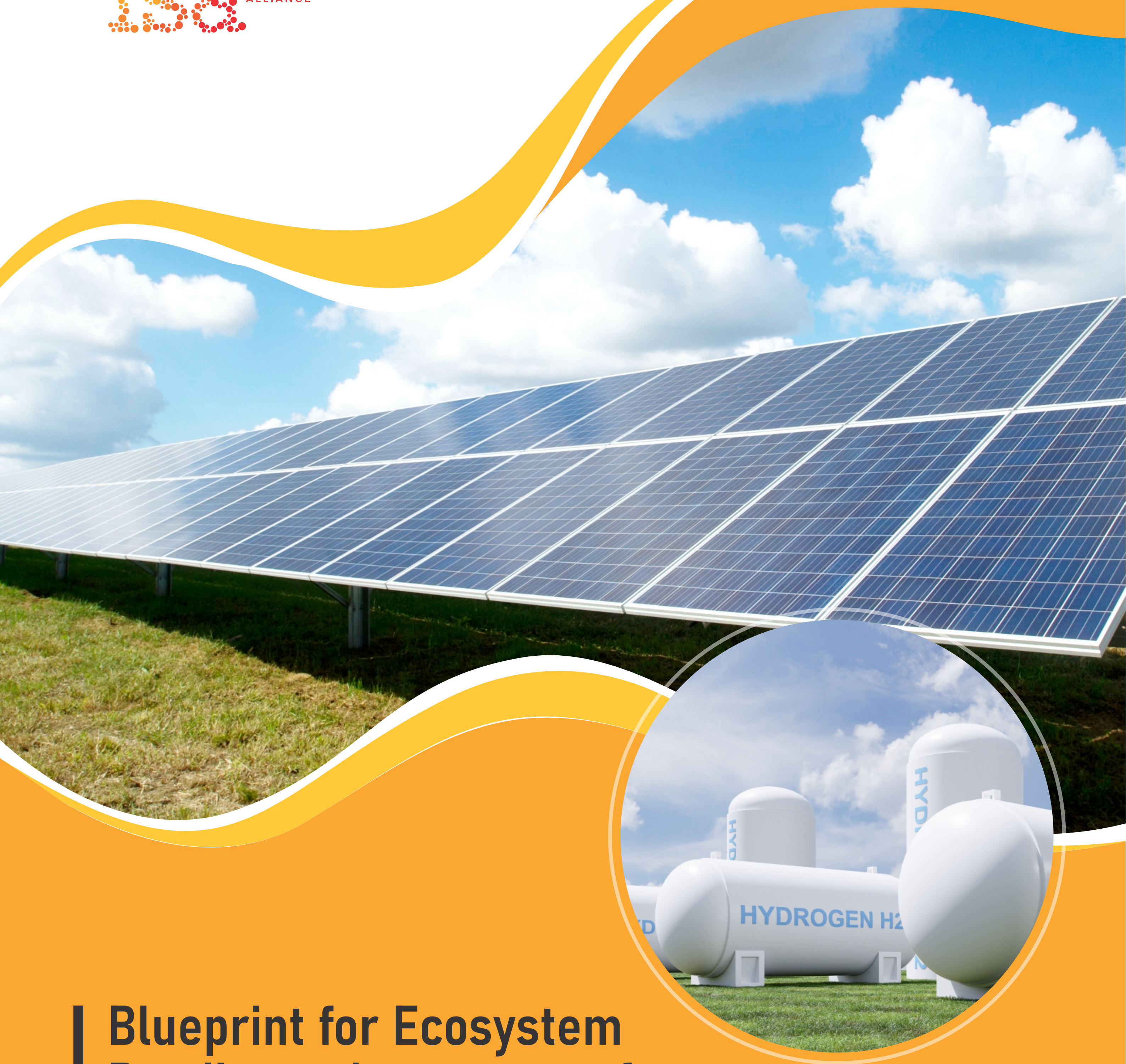

Blueprint for Ecosystem Readiness Assessment for GREEN HYDROGEN

A Consultation Draft

International Solar Alliance

November 2022

This report was prepared under Asian Development Bank 's Knowledge and Support Technical Assistance to the International Solar Alliance in implementing the Solar for Hydrogen programme.

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AWE	Alkaline Water Electrolyser
NH3	Ammonia
AEM	Anion Exchange Membrane
APS	Announced Pledges Scenario
ADB	Asian Development Bank
CAPEX	Capital Expenditure
CCUS	Carbon Capture, Utilization, and Storage
CO2	Carbon Dioxide
CEFC	Clean Energy Finance Corporation
DRI	Direct Reduced Iron
EV	Electric Vehicles
EUF	Electrolyser Utilisation Factor
ETS	Emissions Trading Scheme
EU	European Union
EEZ	Exclusive Economic Zones
FCEV	Fuel Cell Electric Vehicle
FC	Fuel Cells
GW	Gigawatt
GH	Green Hydrogen
GHG	Greenhouse Gases
HDV	Heavy Duty Vehicle
HRS	Hours
H2	Hydrogen
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
IFI	International Financial Institutions
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
Kg	Kilogram
Kt	Kiloton
kW	Kilowatt
kWh	Kilowatt Hour
LCOE	Levelised Cost of Energy
LCOH	Levelised Cost of Hydrogen
LDV	Light Duty Vehicle
LNG	Liquified Natural Gas
MW	Megawatt
Mt	Million tonnes
MTPA	Million Tonnes Per Annum
MFI	Multilateral Financial Institutions
PPM	Parts Per Million
PV	Photovoltaic
PVOUT	Photovoltaic Power Output

PLF	Plant Load Factor
PEM	Proton Exchange Membrane
PPP	Public-Private Partnerships
RE	Renewable Energy
REN	Renewable Energy Policy Network
R&D	Research and Development
RoW	Rest of World
SOEC	Solid Oxide Electrolysis Cell
STEPS	Stated Policies Scenario
TFEC	Total Final Energy Consumption
USD	United States Dollar
VRE	Variable Renewable Energy
W	Watt

EXECUTIVE SUMMARY

Green Hydrogen (GH), today, accounts for less than one percent of global hydrogen production. However, the declining costs of renewable electricity and electrolysers indicate the investment readiness of GH sector. Although this emerging technology is gaining traction across industries, it faces certain challenges including, but not limited to, shortage of specialized manpower, high operational costs, lack of knowledge, underdeveloped infrastructure, absence of dedicated policy for GH and limited access to affordable financing. Interventions such as increased investment, government support, engineering development and skilled workforce development, are some of the critical levers for accelerating a smooth transition to GH economy.

The International Solar Alliance (ISA) supports its membership in accelerating this energy transition through solar energy and its derivative applications. Against the backdrop of global momentum for GH as a viable energy transition vector, the ISA has launched a dedicated Programme - Solar for Green Hydrogen – to support its membership with analytics on potential for GH deployment across various end-use sectors. ISA is being supported by the Asian Development Bank (ADB), under ADB's Knowledge and Support Technical Assistance, in implementing the programme.

The programme will also assess and support ecosystem readiness, including appropriate standards and certifications, to channelize investments in the sector, and build capacity to create/strengthen domestic as well as cross-border hydrogen value chain.

The GH value chain is in its infancy and is being driven by disjointed efforts that are yet to achieve the scale needed for the expected demand under net-zero scenario. At each stage of the GH value chain, intervention in areas such as policy, technology, infrastructure, financing, project development and offtake are needed to create a robust value chain and effect a rapid scale up (Refer to Figure 1). Governments need to stimulate demand and induce scale through strategic collaborations and partnerships, create stable and predictable regulatory framework and fiscal incentive regime, and develop infrastructure for storage and transport for ease of trade. The technology developers, on the other hand, need to leverage the opportunities that the global GH market will provide to develop innovative business models, thread together partnerships to push rapid scaling. The financial institutions need to align their lending practices/guidelines and create innovative financial products, particularly carbon finance, suited to a nascent GH sector, much the same way these institutions did for the solar energy sector after the turn of the millenium.

This document presents a consultation draft of ISA's Blueprint for Ecosystem Readiness Assessment for Green Hydrogen and incorporates a high-level roadmap for development of a hydrogen ecosystem in select ISA member countries. The draft provides, in addition to recommendations for various stakeholders, a synopsis of methodology to assess ecosystem readiness in a country to adopt GH as an energy vector – on the basis of potential to produce and cost of production of GH, ability to consume GH, and the infrastructure needed to produce GH viably. The consultation draft is aimed at an audience comprising of policy makers, regulators, and private sector stakeholders.

Figure 1: Green hydrogen value chain and key elements of project development

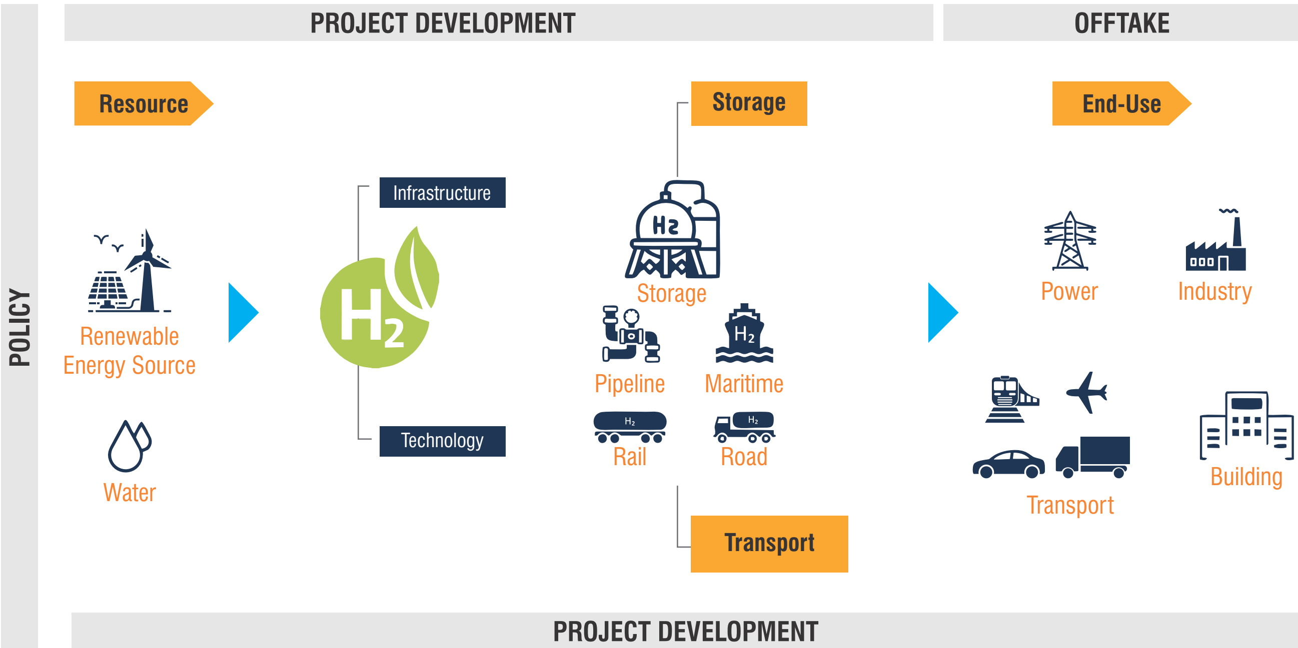


Table 1: Key interventions recommended for stakeholders across GH value chain

SI NO.	Interventions	Stakeholder	
1	**Policy**	Government	• Create an overarching national **strategy and roadmap** for the development of a robust hydrogen economy • Frame policies that **stimulate demand** • Implement measures to maintain **global cost competitiveness** • Formulate **certifications and standards at par with global levels**
2	**Technology**	Government	• Establish **open collaboration initiatives, working groups** and **expert panels** to promote sector collaboration around key projects and **public–private partnerships** • Introduce **relaxing tax schemes** for electrolysers. • Promote **R&D and innovation**
		Technology Provider	• **Leverage technology collaboration programmes** to facilitate international R&D and information exchange
		Developers	• **Showcase pilots** with technology providers

SI NO.	Interventions	Stakeholder	
3	**Infrastructure**	Government	• Form **trade networks** to promote hydrogen / ammonia trade • Ease out **site allocation** requirements for RE and hydrogen • Increase transmission networks for increased **RE evacuation** • **Develop** RE and hydrogen **storage** hubs • Upgrade **ports to facilitate hydrogen/ammonia trade and bunkering** • **Establish hydrogen pipeline**
		Developer	• **Encourage PPP** in infrastructure development
4	**Finance**	Government	• Introduce **volume-and price-based incentive** mechanisms to bridge the economic gap • Provide **loans, grants and dedicated funds** • **Introduce multilateral borrowing**
		IFIs/MFIs	• **Propose low cost long tenor concessional financin**g • **Establish innovative** financing mechanisms including carbon financing • **Credit** Guarantees • **Hedging** instruments
5	**Project Development**	Government	• **Map resource rich-sites** and support in **project readiness** through initial infrastructure investments
		Technology suppliers	• **Streamline supply chains**
6	**Offtake**	Government	• Implement **risk-sharing mechanisms** to allow for the absorption of offtake risks (volume, price, duration), technology scale-up risks and operational risks • Set up **global demand aggregation** programmes • **Attract capital** through tax exemptions/resource mobilization and availability
		Technology provider	• Support government on **innovation programmes** • **Establish international collaboration and technology partnerships** • **Co-locate RE, hydrogen production and demand, wherever possible**

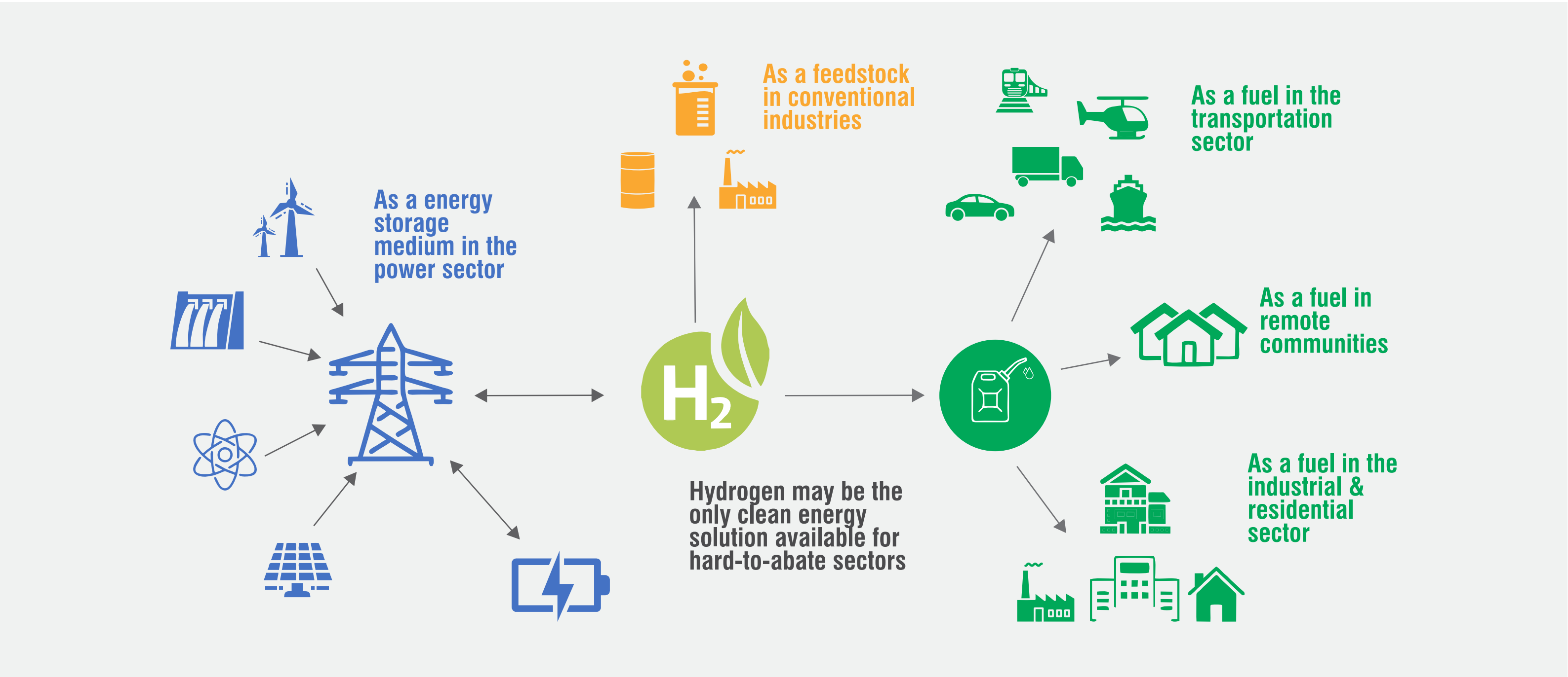
01
INTRODUCTION

The Paris Agreement under the UNFCCC has renewed the global commitment to limit temperature rise to 1.5°C and atmospheric carbon dioxide (CO_2) concentrations to 450 parts per million (ppm). The Agreement calls for concerted global efforts for rapid economy-wide decarbonization. If the Paris goal is to be fulfilled, actions that are immediate and tangible need to be taken globally. Growing number of countries are pledging Net Zero emissions by mid-century, which is a positive development for climate change mitigation.

Energy transformation in electricity generation has accelerated significantly since the turn of the century, and growth in renewable energy, particularly solar PV, in the electricity sector is consistently displacing traditional fossil fuels in nearly all the mature electricity markets. The International Energy Agency (IEA) estimates that renewable energy is set to account for almos t 95 percent of the increase in global power capacity through 2026. The amount of renewable capacity added over the period of 2021 to 2026 is expected to be 50 percent higher than from 2015 to 2020, driven by stronger support from government policies and more ambitious clean energy goals.[1] Rapid scale of renewable energy deployment has been a critical enabler for economies of scale and consequent precipitous drop in the levelized cost of electricity of the associate technologies. Solar PV, without energy storage, is now amongst the cheapest source of electricity in large markets where government policy and regulatory frameworks support renewable energy development in general, and solar in particular (e.g., India).

In 2021, however, the share of electricity in global final consumption of energy was only 20.4 percent.[2] It is expected to increase to around 50 percent by 2050[3]. Thus, there is clearly a need to decarbonize other forms of energy usage in hard-to-abate sectors to keep the goal of 1.5°C alive, which was reiterated at COP 26. Hard-to-abate sectors encompass steel, cement, chemicals (including Fertilizer), long-haul road transport, maritime shipping, and aviation (see Figure 2).

Figure 2: Green hydrogen in hard-to-abate sectors



[1] IEA 2021 - Renewable Energy Growth
[2] Enerdata - World Energy & Climate Statistics
[3] IEA 2021 - Net Zero by 2050 - A Roadmap for the Global Energy Sector

GH will play a key role in decarbonization of the hard-to-abate sectors. Global hydrogen demand reached 94Mt in 2021, mainly for petroleum refining, and production of chemicals and fertilizer. The existing demand for hydrogen in these sectors indicates that the molecule is not entirely novel. GH currently accounts for less than one per cent of the total amount of hydrogen produced,[4] however, the global demand for GH and its applications is expected to increase exponentially over the next 20 years as the pressure to decarbonize continues to mount. It is expected that in the Net Zero scenario (IEA) the demand will likely be around 180 Mt by 2030.

Deployment of GH comes with significant challenges, such as cost and supply chain issues. The global electrolyser manufacturing capacity is miniscule compared to the total expected demand. However, with increasing capacity the cost of electrolyser is expected to reduce sharply due to inherent manufacturing economies of scale. As per IRENA 2020 report on GH cost reductions, the electrolyser investment cost in 2020 was USD 650-1000/kW. Electrolyser costs can reach USD 130-307/kW with 1-5 TW of capacity deployed by 2050.[5] Renewable energy costs are also expected to fall further going forward. Many countries have already shown commitment towards accelerating GH solutions and have already declared electrolyser targets as well as taken other supply side and demand side measures. The traction is only going to increase with falling cost curves.

Other barriers exist to scaling up GH such as lack of robust carbon pricing mechanism which makes it hard to capture negative externality of grey hydrogen/other fossil-fuel based energy vectors; lack of proper monitoring and reporting framework for GHG accounting; regulatory gaps/barriers vis-à-vis blending (lack of standards across end-use applications/geographies) for market creation; lack of global standards (carbon accounting, origin, classification of Hydrogen as an energy carrier, end-use equipment standards); and finally policy barriers such as lack of adequate incentives. Overcoming these barriers and transitioning to GH will require dedicated support and policy action in each of the stages of technology readiness, market penetration and market growth.

This draft report provides a synopsis of GH demand, current technical and economic viability of GH, the geographical landscape and financing, as well as the challenges faced by the sector. The final 'Blueprint' will incorporate inputs to this consultation draft from various stakeholders and be launched at the ISA Assembly in October 2023. Based on an assessment of global GH space from multiple perspectives, the Blueprint would aim to provide a framework for a global hydrogen economy in leading ISA member countries. The Blueprint will focus on holistic interventions needed from various stakeholders and develop a readiness assessment framework to identify and map high-potential countries and regions, their end-use sectors and trade opportunities, and recommend policy mechanisms and strategies, that could help guide country-level interventions and investments in the GH space.

[4] IRENA 2021 - Coalition Green Hydrogen
[5] Assuming average (USD 65/MWh) and low (USD 20/MWh) electricity prices, constant over the period 2020-2050
IRENA 2021 - Green Hydrogen Policies and Technologies Cost

02

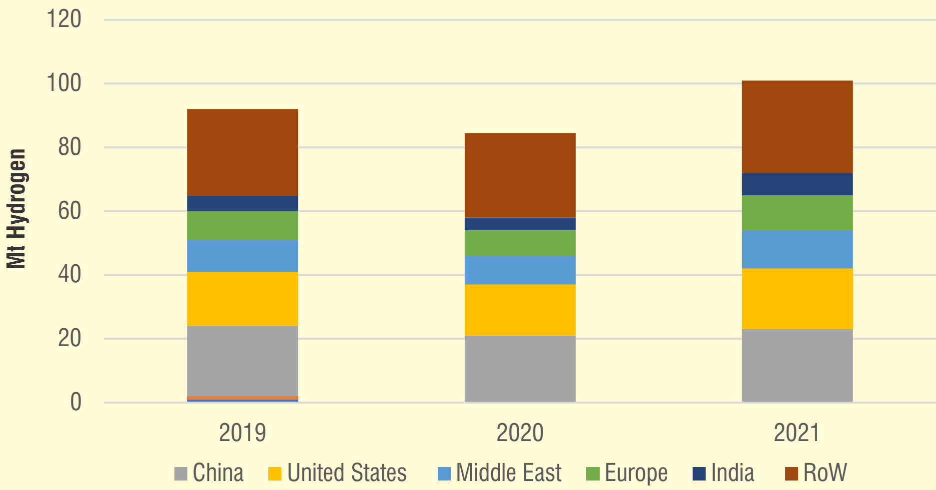
GLOBAL HYDROGEN ASSESSMENT DEMAND AND SUPPLY

2.1 H_2 global demand

Global demand for hydrogen has increased since the 1980s, and as of 2021, demand is more than **94 MTPA and is growing currently at ~five percent**.[6] Most of the hydrogen currently being consumed is produced from fossil fuels (more than 90 percent) and the cost of production is based on local market costs of coal and natural gas.

China is the world's largest consumer of hydrogen, with demand of around 28 Mt in 2021, followed by t**he United States and the Middle East,** both at **12 Mt** of hydrogen demand in 2021. **Europe** and **India** trail with a demand close to **8 Mt each** (see Figure 3).

Figure 3: Global hydrogen demand projections, 2019-2021

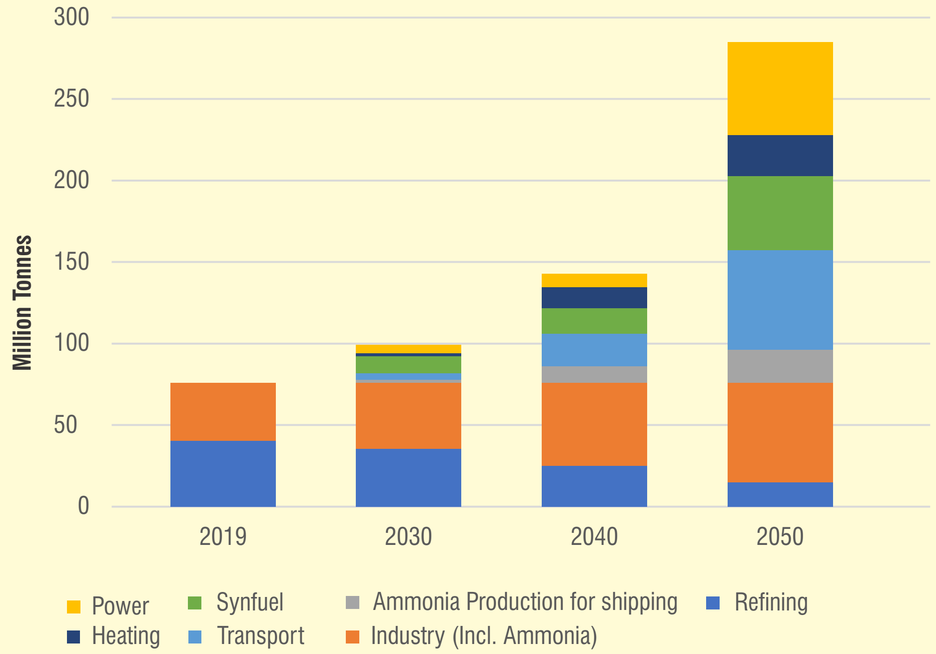


(Source: IEA 2022- Global Hydrogen Review)

The future growth of GH is expected to be led by the increased usage in current as well as emerging applications. Global hydrogen demand has potential to grow more than threefold by 2050. (See Figure 4).

[6] IEA 2022- Global Hydrogen Review

Figure 4: Global Hydrogen Demand Outlook



(Source: IEA 2022- Global Hydrogen Review)

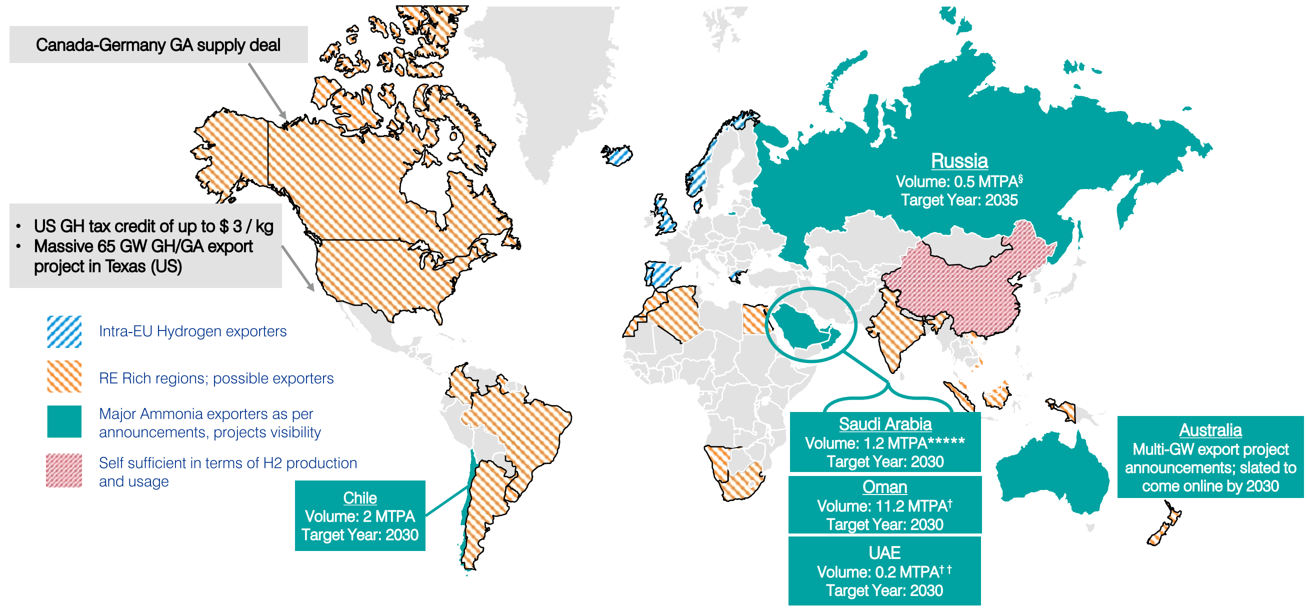
Many countries have taken the first step for establishing GH strategies, policies, roadmaps, initiatives, and pilot projects to meet their Net Zero commitments. Currently, at least **43 countries are setting up strategies or roadmaps for a GH economy. China** is expected to lead the GH market by 2050, with around 200 Mt demand. **Europe** and **North America** are expected to follow, accounting for 95 Mt of GH each. **Japan and Korea will require about 35 Mt of GH** in 2050, the majority of which will be imported.

Regions like **South-East Asia, Oceania, Middle East, and Latin America are expected to account for about 235 Mt hydrogen demand in 2050.**

Russia, Australia, Saudi Arabia, Oman and Chile are the top green ammonia exporters.

Northern & Southern Africa, US, Canada, Brazil may become emerging exporters of green ammonia in the future (see Figure 5).

Figure 5: Global hydrogen hotspots and distribution corridors



*Note: *** Recharge | * Ammonia Energy | ***** NEOM Project | †: Based on projects of Geo & Acme | †: Based on Kizad Ammonia project*

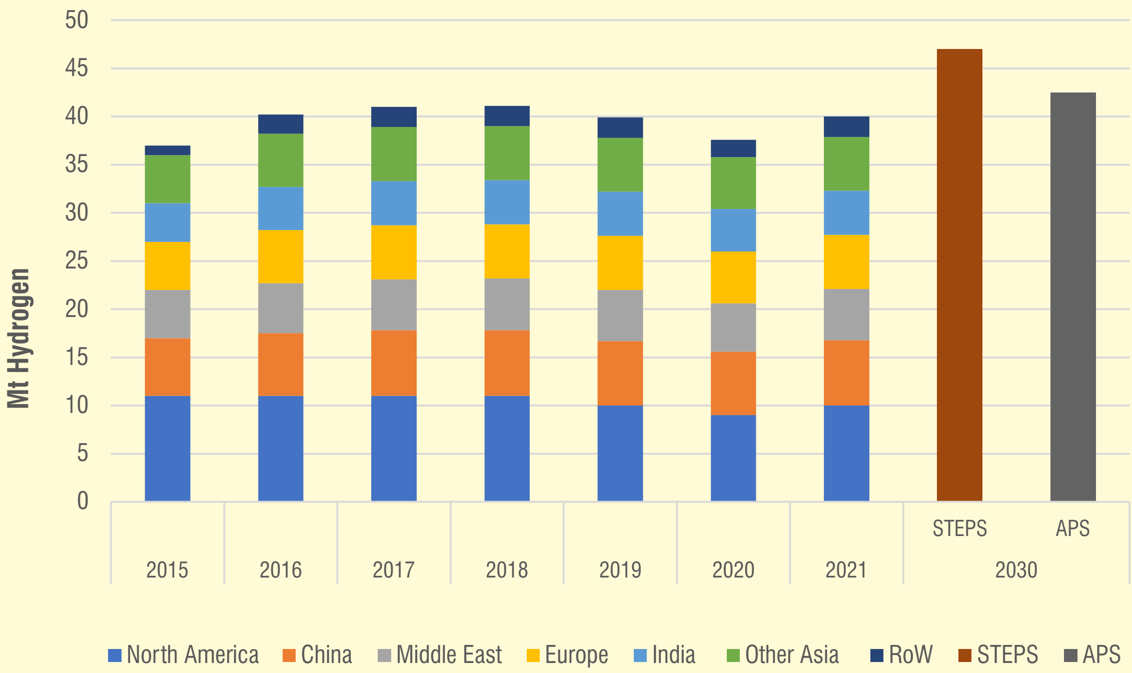
(Source: KPMG Analysis)

The following sections examine the significance and role of hydrogen in key end use sectors like refining, industry, transport, buildings and power generation sectors and provide an overview of hydrogen demand by 2030.

a) Petroleum refining

In 2021 hydrogen demand for refining was **40 Mt.** Almost half of global hydrogen demand for refining in 2021 was observed in two regions **- North America at 10 Mt and China at over 9 Mt** (see Figure 6).

Figure 6: Global hydrogen demand in refineries, 2015-2030

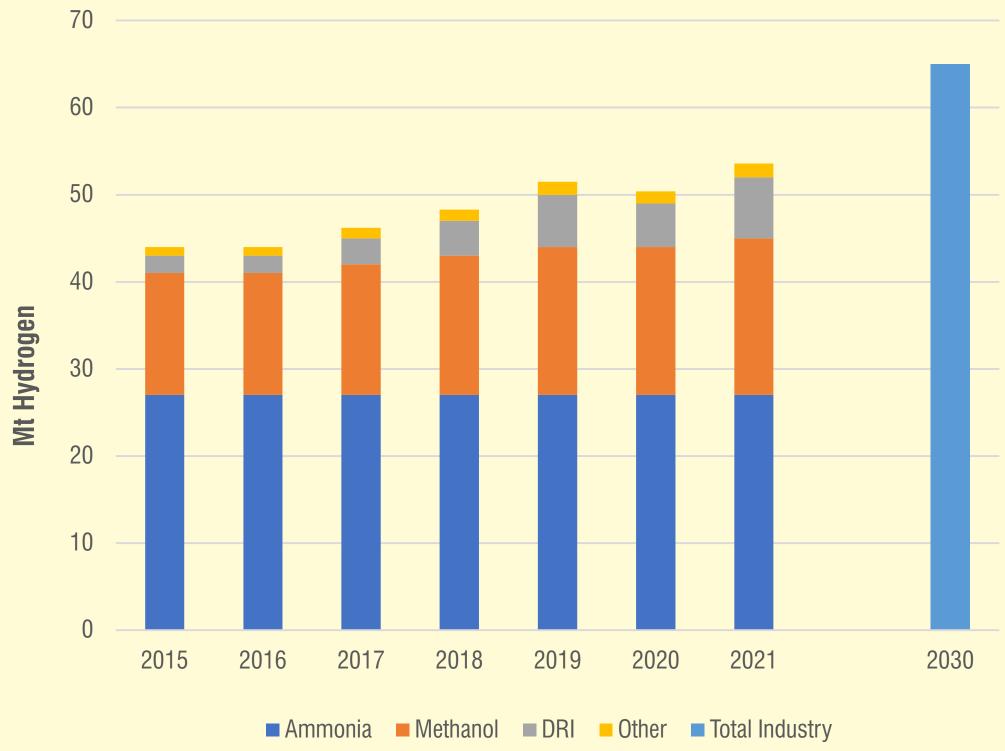


(Source: IEA 2022- Global Hydrogen Review)

b) Industries

In 2021, hydrogen demand for **ammonia production** was **~34 Mt**, for **methanol was ~15 Mt and for DRI in the steel industry, demand was ~5 Mt**. Considering current trends and announced policies, global hydrogen demand in these segments is expected t**o increase by 11 Mt by 2030** (see Figure 7).

Figure 7: Global hydrogen demand in industries, 2015-2030



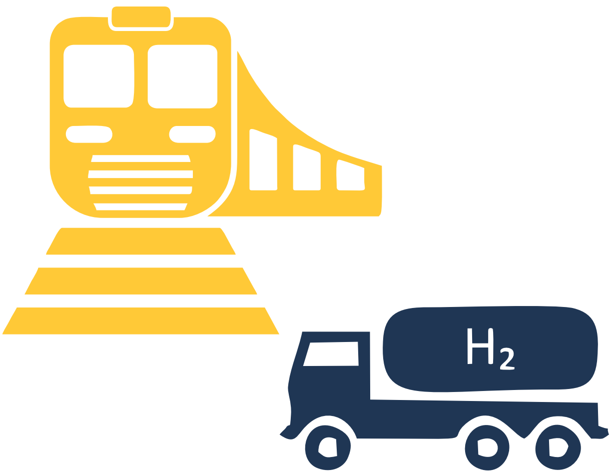
(Source: IEA 2022- Global Hydrogen Review)

The demand for green ammonia primarily stems from fertilizer segment and there are some other uses such as power generation and shipping. Ammonia (NH_3) is also considered as a good medium for storing GH. NH_3 is a highly versatile fuel for transition to a carbon free economy.

c) Transport

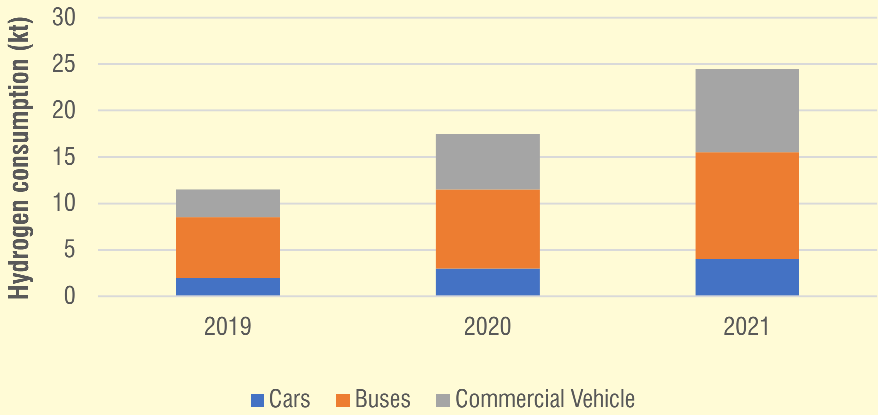
The transport sector observed slight but growing hydrogen demand at approx. 30 kt in 2021. Most of the hydrogen demand came from the bus segment, making up for 45 percent of the total hydrogen demand in the transport sector (see Figure 8). 2021 also saw over 51,000 fuel cell electric vehicles (FCEVs), nearly double that from 2020. As per IEA, hydrogen demand in transport in the Stated Policies Scenario (STEPS)[7] can reach up to 0.7 Mt by 2030. Most of this demand will come from road transport.

Interest is also increasing in the use of hydrogen and hydrogen derived synthetic fuels in the maritime and aviation sectors. However, application in these sectors is at a nascent stage and is less mature than those for road and rail.



[7] The IEA Stated Policies Scenario (STEPS) reflects current policy settings based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.

Figure 8: Hydrogen consumption in road transport by vehicle segment, 2019-2021



(Source: IEA 2022- Global Hydrogen Review)

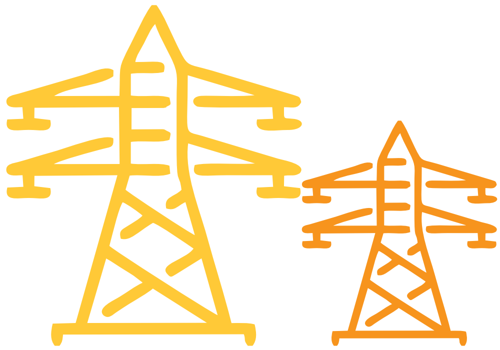
d) Buildings

Due to the insistent need to achieve Net Zero, many countries have or are reducing fossil fuel use in new buildings. There may be opportunities for hydrogen applications in buildings where natural gas infrastructure is already in place and where energy use is hard to decarbonize.

e) Power

For **generating electricity**, hydrogen has little role to play at present, with just over 0.2 percent share of global electricity generation. However, with an urgency to reduce emissions, interest in the use of hydrogen and ammonia in power sector is also rapidly increasing. Several projects have or will be announced that represent around 3500 MW of hydrogen and ammonia power capacity worldwide, by 2030.[8]

The use of hydrogen in fuel cells and ammonia in coal power plants account for around 10 percent and six percent, respectively, of the capacity of the project pipeline by 2030. These projects appear to be mainly concentrated in the **Asia Pacific region (40 percent), Europe (33 percent) and North America (26 percent)**



[8] IEA 2022- Global Hydrogen Review

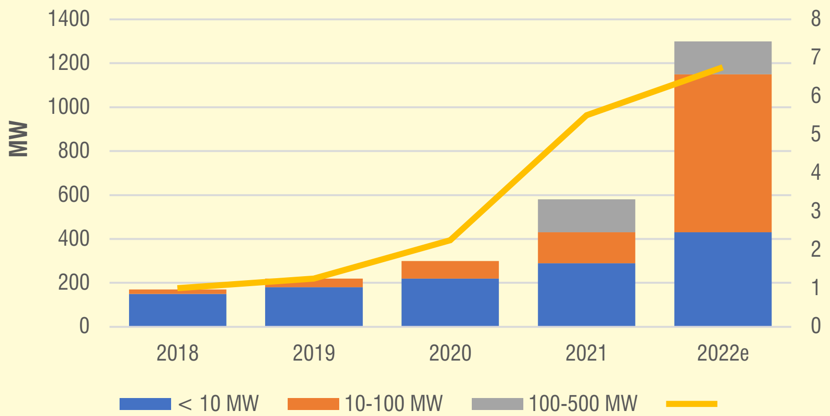
2.2 H_2 global supply

Europe and **Australia** are first movers in GH production. Based on the current project pipeline, GH production in Europe could reach close to **5 Mt by 2030**.[9] Australia is expected to become a global hub of GH production, with production quantity of **3 Mt by 2030**,[10] based on the project pipeline.

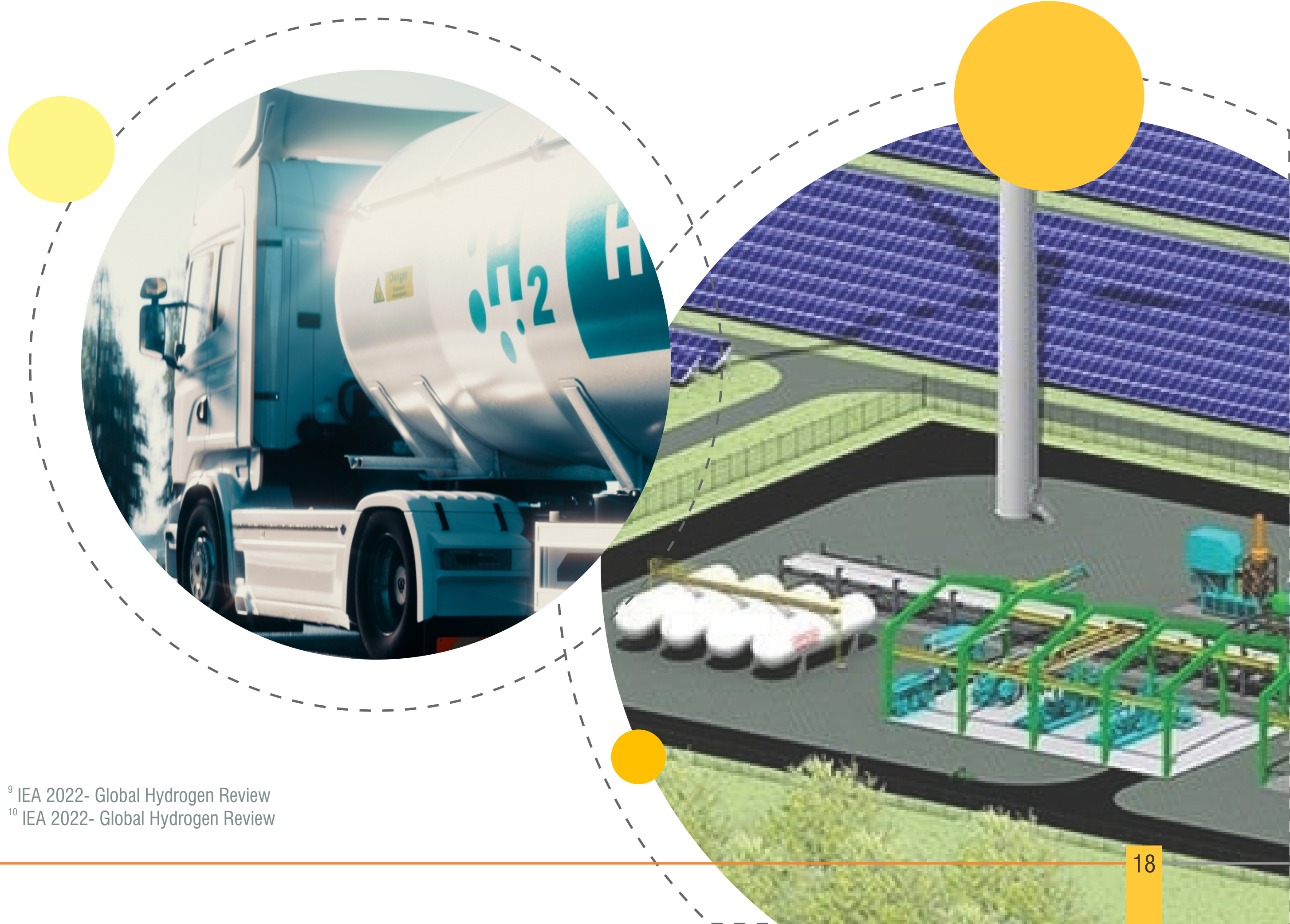
GH hubs are also being created in Latin America, North America, Middle East and Africa, projecting these regions as major export hubs for markets like EU and East Asia.

Electrolyser capacity has been growing at an accelerated pace for the past couple of years. 2021 saw a significant growth with over 200 MW of capacity in the operational stage. The **total installed capacity stood at 0.5 GW and is expected to reach around 1.4 GW by the end of 2022** (see Figure 9). As depicted in the previous section, electrolysers are a critical technology for producing GH. In terms of technology, electrolysers are continuously evolving with several technologies under development.

Figure 9: Global electrolyser capacity by size based on project pipeline 2018-2022



(Source: IEA 2022- Global Hydrogen Review)



[9] IEA 2022- Global Hydrogen Review
[10] IEA 2022- Global Hydrogen Review

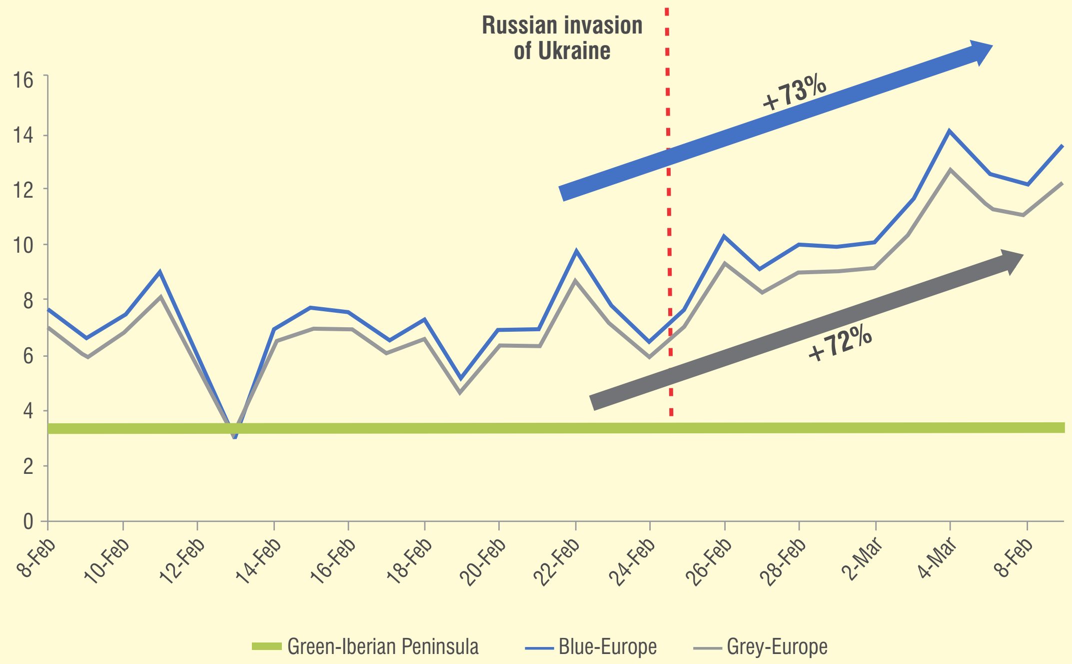
At present, technologies that are prevalent in the market include **Alkaline, Proton Exchange Membrane (PEM), Solid Oxide Electrolysis Cell (SOEC)** and **Anion Exchange Membrane (AEM)**. Some are in pre-commercial phase and some have already commercialized. **Almost two-thirds of production capacity today is for alkaline electrolysers and a fifth for PEM electrolysers.** IEA estimates that under Net-Zero emissions scenario, 850 GW of total electrolyser capacity needs to be deployed by 2050.

Alkaline electrolysers are a more mature technology than PEM, with a long history of deployment in the chlor-alkali industry. However, for hydrogen production, both technologies are at the same readiness level, both being commercially available. At the same time, both technologies require policy support and improvements to stay competitive. SOEC is a technology under demonstration. AEM electrolyser is in very earlier stages of development. A brief description of the technologies is provided in Annexure 2.

2.3 Projections of green hydrogen

Hydrogen production from fossil fuels was generally more cost-competitive than from renewables until the recent surge in natural gas prices. However, post the current geopolitical conflict, GH procurement has started witnessing traction and investments have already started flowing into the segment. Based on the current circumstances, the surging cost of blue and grey hydrogen in line with fossil fuel price hikes have amplified the growing viability of GH as an affordable and secure source of RE in European region. The cost of blue and grey hydrogen in Europe is already at USD 8/kg to USD 14/kg, considering the inflation in natural gas prices. GH is already projected to be as low as USD 3.5/kg today (see Figure 10).[11]

Figure 10: Levelised cost of hydrogen in Europe (USD/kg hydrogen)



(Source: PV Magazine 2022)

[11] PV Magazine 2022-Invasion of Ukraine an inadvertent boost for green hydrogen

Natural gas price volatility is expected to continue due to the ongoing conflict in Europe, but price decreases will directly translate to reduced costs for blue and grey hydrogen. There is substantial opportunity to reduce production costs for GH further through technology innovation and increased deployment, and in any case, the GH has characteristic cost certainty which has some inherent value with respect to gaining immunity from fossil fuel price volatility. GH production costs will fall as long as electrolysers and renewables costs decline, and costs as low as USD 1.3/kg by 2030 can be expected in regions with excellent renewable energy resources.[12] In the longer term, GH costs can reduce further to USD 1/kg.

$LCOH_{green}$ is driven primarily by three factors:

a. Levelised cost of Electricity (LCOE),

b. Capital Expenditure (CAPEX), and

c. Electrolyser Utilisation factor (UF).

IRENA estimates that electrolyser cost of USD 200/KW at an LCOE of about USD 20/MWHr (some geographies have or are at the verge of breach this $LCOE_{Solar PV}$ – Chile, Middle East and North Africa etc.) and a UF of about 48 % would result in $LCOH_{green}$ of USD 1.38/Kg[2]. Figure 12[13] provides an analysis by the Hydrogen Council that brings out the impact of the three primary drivers of $LCOH_{green}$.

Figure 11: Variation in LCOH green with CAPEX and LCOE

Cost of renewable hydrogen with varying LOCE and load factors
USD/kg H_2

< USD 2/kg | USD 2-3/kg | USD 3-4/kg | > USD 4/kg | Viable medium-term (<2030)

LCOE / Capex electrolyser	USD 750/kW					USD 500/kW					USD 250/kW				
UDD 0/MWh	5.7	2.8	1.9	1.4	1.1	4.2	2.1	1.4	1.1	0.9	2.8	1.4	0.9	0.7	0.6
USD 10/MWh	6.1	3.3	2.4	1.9	1.6	4.7	2.6	1.9	1.5	1.3	3.2	1.9	1.4	1.2	1.0
USD 20/MWh	6.6	3.8	2.8	2.4	2.1	5.2	3.0	2.3	2.0	1.8	3.7	2.3	1.9	1.6	1.5
USD 30/MWh	7.1	4.2	3.3	2.8	2.5	5.6	3.5	2.8	2.5	2.2	4.2	2.8	2.3	2.1	2.0
USD 40/MWh	7.5	4.7	3.8	3.3	3.0	6.1	4.0	3.3	2.9	2.7	4.6	3.2	2.8	2.6	2.4
USD 50/MWh	8.0	5.2	4.2	3.7	3.5	6.5	4.4	3.7	3.4	3.2	5.1	3.7	3.2	3.0	2.9
USD 100/MWh	10.3	7.5	6.5	6.1	5.8	8.9	6.7	6.0	5.7	5.5	7.4	6.0	5.6	5.3	5.2
Load factor	10%	20%	30%	40%	50%	10%	20%	30%	40%	50%	10%	20%	30%	40%	50%

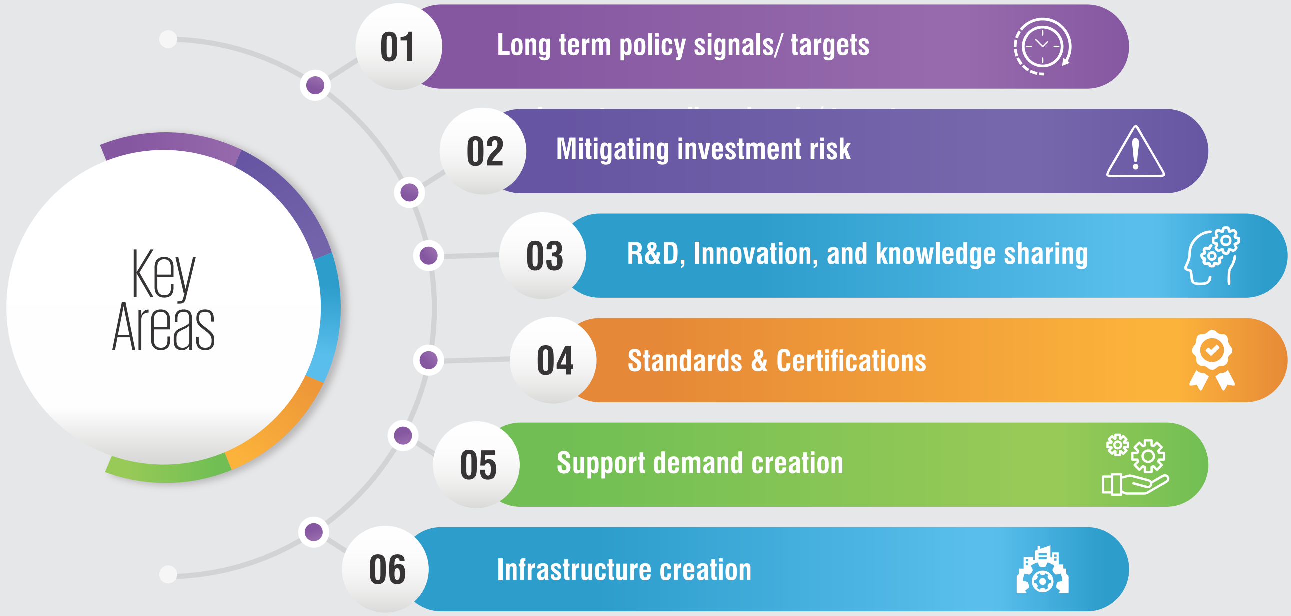
(Source: Hydrogen Council 2022)

[12] IEA 2021- Net zero by 2050
[13] Hydrogen Council 2022- Path to Hydrogen Competitiveness

03

HYDROGEN POLICY ASSESSMENT

Government intervention is expected to play a pivotal role in integrating hydrogen into energy systems across the country. The needs and priorities of policies and strategies are different for different countries. Some of the key areas that the governments are focusing on to accelerate the adoption of hydrogen across energy systems include:



1. **Setting long term policy signals/ targets:** In the overall energy policy framework, production and consumption targets will play a vital role in creating a roadmap for the development of a hydrogen market.
2. **Mitigating investment risk:** Introducing policies to mitigate risk in projects facilitates easy and **smooth access to finance and in turn, accelerates deployment of more hydrogen projects.**
3. **R&D, innovation, and knowledge sharing:** R&D and technical innovations will be crucial drivers in bringing down the costs, thereby helping increase competitiveness.
4. **Standards, certification systems and regulatory framework:** In a GH market, standards, certification systems and frameworks will be helpful to boost investor and customer confidence, facilitate trade, assure robust practices, and mitigate risks, especially the ones related to safety.
5. **Support demand creation:** To stimulate the adoption of GH as a clean energy option, creating mandates will boost demand of hydrogen in the energy sector.
6. **Infrastructure creation:** For successful hydrogen projects deployment, it is important to locate renewable energy production and hydrogen production facilities together so they can be better integrated. Thus, the development of hydrogen infrastructures for producing and delivering hydrogen is a basic necessity to achieve a smooth transition to a hydrogen economy.

To anchor long-term targets, most of the governments across the world are adopting a phased approach for hydrogen integration, focusing on scaling up, adoption and implementation.

Table 2 below highlights some of the hydrogen strategies and policies adopted in a few countries[14]:

Table 2: Overview of hydrogen strategies and policies worldwide

Countries	Year	Targets	Production	Uses	Public investment committed
Australia	2019	None specified	Blue H2 Green H2		~USD 0.9 billion
Canada	2020	Total use: 4 Mt H2/y 6.2 percent TFEC	Green H2 Blue H2		~USD 19 million
Chile	2020	25GW electrolysis	Green H2		USD 50 million
Czech Republic	2021	GH demand: 97 kt H2/yr.	Green H2		NA
European Union	2020	40GW electrolysis	Green H2 Transitional role of Blue H2		~USD 4.3 billion
France	2020	6.5 GW electrolysis 20-40 percent industrial H2 decarbonized 20000-50000 FC LDVs 800-2 000 FC HDVs 400-1000 HRS	Green H2		~USD 8.2 billion
Germany	2020	5 GW electrolysis	Green H2		~USD 10.3 billion
Hungary	2021	Production: 20 kt/yr. of clean H2 16 kt/yr. of carbon-free H2 240 MW electrolysis Use: 34 kt/yr. of clean H2 4 800 FCEVs 20 HRSs	Green H2 Blue H2		NA
Japan	2019, 20,21	Total use: 3 Mt H2/yr. Supply: 420 kt clean H2 800 000 FCEVs 1 200 FC buses 10 000 FC forklifts 900 HRSs 3 Mt NH3 fuel demand	Green H2 Blue H2		~USD 6.5 billion
Netherlands	2019, 20	3-4 GW electrolysis 300 000 FC cars 3 000 FC HDVs	Green H2 Blue H2		~USD 80 million/yr.
Norway	2020, 21	NA	Green H2 Blue H2		~USD 21 million
Portugal	2020	2-2.5 GW electrolysis,	Green H2		~USD 1.0 billion

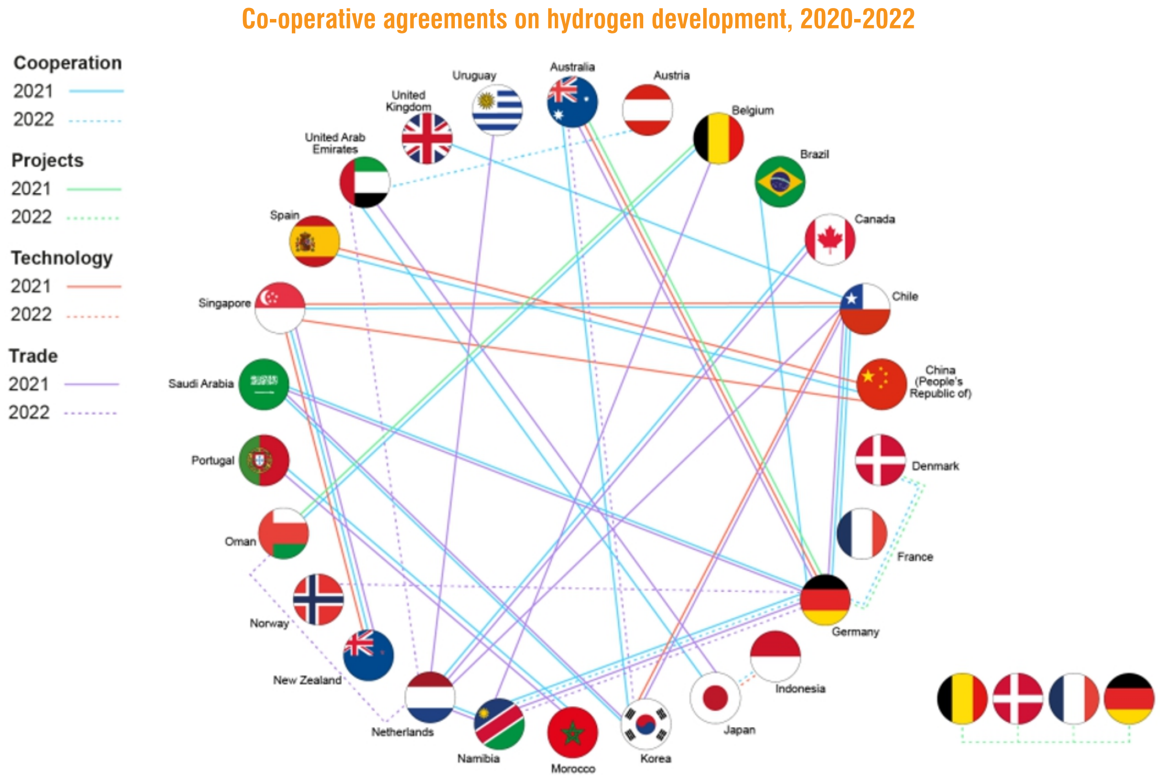
[14] IEA 2022- Global Hydrogen Review

Countries	Year	Targets	Production	Uses	Public Investment Committed
Russia	2020	Exports: 2 Mt H2	Green H2 Blue H2	Buildings, Industry, Transport, Exports	NA
Spain	2020	4 GW electrolysis 25% industrial H2 decarbonized 5 000-7 500 FC LDVs-HDVs 150-200 FC buses 100-150 HRSs	Green H2	Aviation, Buildings, Industry (steel), Refining, Transport, Shipping	~USD 1.8 billion
United Kingdom	2021	5 GW low-carbon production capacity	Blue H2 Green H2	Aviation, Buildings, Electricity, Industry, Refining, Shipping	~USD 1.3 billion

Buildings | Exports | Shipping | Mining | Aviation
Electricity | Industry | Transport | Refining | Industry (steel)

International co-operation on hydrogen is also growing, demonstrated by an increasing number of bilateral agreements (see Figure 12). Both the demand and supply sides are getting ready to either meet their own targets or support other nations in meeting their GH targets. Since September 2021, fifteen new bilateral international agreements between governments have been signed, most of which focus on the development of international hydrogen trade. European institutions are actively signing international agreements with non-European governments seeking to facilitate investment and accelerate development of international supply chains. Private sector companies across international borders have also joined forces to develop first-of-a-kind technologies.

Figure 12: Co-operative agreements on hydrogen development, 2020-2022



(Source: IEA 2022- Global Hydrogen Review)

While there are several developments happening across the globe, section 6 presents the hydrogen readiness assessment framework across several ISA member countries to identify the geographies with the most supportive business environment for GH space.

04

CHALLENGES IN DEPLOYMENT OF GREEN HYDROGEN

Any new technology deployment carries a set of challenges and risks. For hydrogen, these are mainly related to cost, safety, technology readiness and commercialization (see Figure 13).

Figure 13: Potential risks and challenges in green hydrogen

Some of the key challenges and risks associated with GH are listed below:

Table 3: List of risks and challenges for GH

Category	Risks and challenges for GH
Production Cost	• GH is at present more expensive than grey hydrogen, depending on the price of natural gas • Adopting GH for end uses can be expensive - vehicles with fuel cells and hydrogen tanks cost at least 1.5 to 2 times more than their fossil fuel counterparts.[15] • Utilization of electrolysers which is impacted by PLFs and stability in supply of renewables, can also result in significant cost variation
Infrastructure	• Lack of infrastructure for hydrogen production, storage and transportation • At present, only a few existing hydrogen-pipeline networks and liquified hydrogen ships are in commercial operation • Natural gas infrastructure could be repurposed for hydrogen, but not all regions of the world have this existing infrastructure
Safety	• Storage and transport challenges due to small molecule size, low volumetric density (relative to methane), and extreme flammability • Ammonia is also toxic and requires stringent safety procedures (which are in place in the existing supply chains)
Regulatory	• Missing or unclear regulation • Lack of clarity on a designated body/agency to oversee GH deployment and implementation • Lack of clarity on financing
Water	• Access to sufficient industrial grade water
Consumer Demand	• Clear demand mandates are vital for the promotion of the hydrogen supply chain • Accelerating development on the demand side is crucial for innovation and scale-up
Energy Losses	• About 30-35 percent of the energy used to produce hydrogen through electrolysis is lost[16] • Conversion of hydrogen to other derivatives (such as ammonia) can result in 13-25 percent energy loss • Transporting hydrogen requires additional energy inputs, which are typically equivalent to 10-12 percent of the energy of the hydrogen itself[17] • Using hydrogen in fuel cells can lead to an additional 40–50 percent energy loss • The higher the energy losses, the more renewable electricity capacity is needed to produce GH.
Training, communication, and marketing supply chain	• Lack of trained manpower • Lack of training and certification programmes

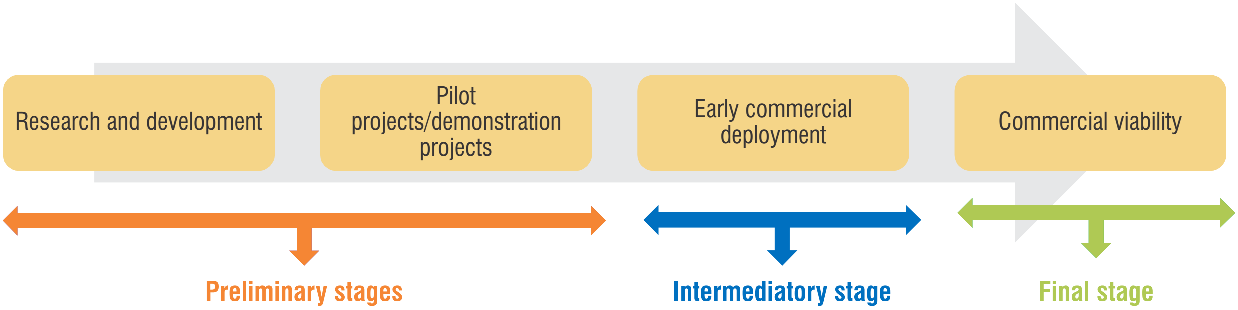
[15] NREL 2020-Hydrogen and Fuel Cells Program
[16] World Economic Forum 2021-Four technologies driving the green hydrogen revolution
[17] BNEF, 2020; Staffell et al., 2018; Ikäheimo et al., 2017

05

GREEN HYDROGEN FUNDING MECHANISMS

The public sector will play an important role in creating the GH economy. Governments will provide funding support where the private sector is unable or unwilling to provide capital on a commercial basis. In the early stages of development, public financial support can bring the sector out of the R&D stage and encourage deployment.

The flow diagram given below shows the stages of financing examined in this report



5.1. Preliminary stages

a. Research and development

The public sector plays a crucial role in the R&D of any capital-intensive nascent technologies. In the early stages of development, public financial support should kickstart this process by removing financial burdens on early technology developers.

How can financial support be provided?

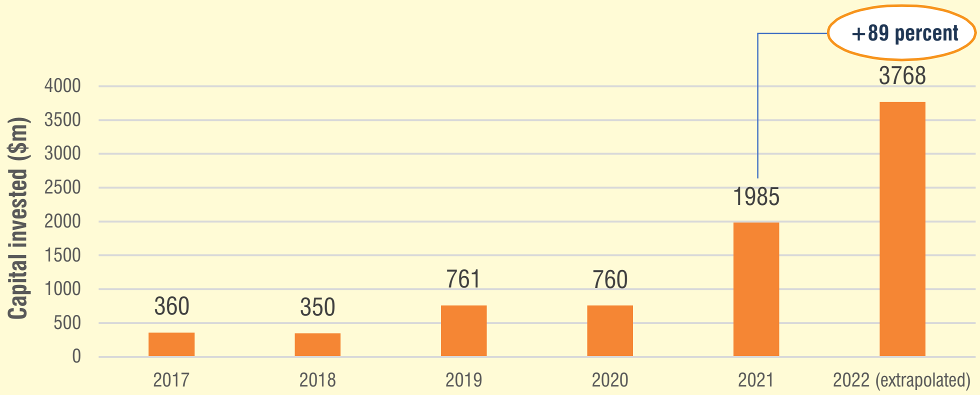
- grants to consortia via calls
- grants to solo recipients via calls
- grants via prizes (technology competitions at national & international levels-startups)

b. Pilot projects/demonstration projects

During the pre-commercialization stage, funding gaps usually arise as technologies move out of the laboratory and into pilot/demonstration projects. The GH sector as of today, however, does not appear to be suffering from this problem. The sector is flushed with capital with more than 100 pilot projects (see Figure 14).

While public institutions deserve a large portion of the credit, the private sector, as of result of recent technological breakthroughs, is also invested . Oil & gas companies, utilities, battery manufacturers and investors from the broader mobility space have all been part of deals. Companies and investors want to ensure their involvement at this stage so as not to miss out on growth opportunities. Governments should continue to encourage these deals as they provide learnings which allows for easier integration of GH across sectors.

Figure 14: Venture capital investments in hydrogen



(Source: Pitchbook)

5.2. Intermediary stage - early commercial deployment

a. Risks

GH development, like other first-mover enterprises, has trouble finding financing for projects through traditional routes. While this challenge is not unprecedented, financing GH could face a wider set of challenges than those faced by other clean energy technologies in their formative years, due to larger number of uncertainties.

- *Technology risk*

Although no new specific technologies are required to produce GH, there are perceived risks due to the pioneering nature of GH. Apart from the renewable energy plant and the pipelines, all other major components, such as the electrolysers, liquefaction and regasification units, cracking, cryogenic tanks, etc. are being adapted from other operations such as liquefied natural gas and the use of liquid hydrogen in the heavy launch space transportation segment.

- *Market risk*

There is a significant market risk involved due to the high cost and limited set of customers willing to commit to long-term offtake agreements. Further, commercial structures are yet to be fully evolved (although GH production projects can be developed in a manner similar to traditional liquified natural gas export projects). Hydrogen and its derivatives are tradeable commodities (like oil and gas) and the innovative nature of GH may discourage customers from long-term arrangements on first-mover projects.

- *Lack of financial market*

There is currently no financial market for trading hydrogen, or hydrogen derivatives, so producers cannot take out futures contracts to guarantee a price for their hydrogen. That means they cannot offer banks any confidence about the size of future revenue, even when hydrogen generation does begin, unless the buyer agrees to a price in advance (again, the liquified natural gas export business provides lessons learned for GH development).

- *Lack of operational history*

There is not enough operational history to give confidence to financiers.

b. Mitigation measures

Private finance and institutional investments can be mobilized for near-competitive technologies and demonstration projects with public finance mechanisms laying the groundwork. Owing to the indeterminate amounts of investments and timelines, harnessing private finance for the development of the GH sector will come one step at a time. Table 4 refers to mitigation strategies by public and private players.

Table 4: Mitigation strategies by public and private players

Instrument	Role of public institutions
Concessional funding	• This is important because GH is a relatively new and capital-expenditure heavy business (large requirements of heavy renewable energy installations and electrolysers) and demand is uncertain.
Partial credit guarantee	• The mechanism is prevalent around the world and is used by governments as well as international bodies such as Asian Development Bank and the International Finance Corporation to back projects with positive externalities.
Structured loan payment schedules	• Since initial demand is uncertain, and revenue may take some to increase, loan repayment schedules on developers will therefore have impact on financial viability
Hedging	• Since industry is still in its infancy, price fluctuations due to supply and demand uncertainty can occur. Hedging will provide security and confidence to investors.
Carbon financing	• Issuance and trading of carbon credits for GH production may generate additional revenue for developers and investors.
Access to international markets	• GH is expected to have differing prices around the world (owing to the difference in renewable energy costs). • Countries, especially, where GH production is considered cost effective vis-à-vis the rest of the world, should have mechanisms allowing for the export of GH.
Instrument	**Role of the private sector**
Equity financing	• Equity financing needed by specialist equipment manufacturers offers scope for companies across the energy value chain. It will allow players to get involved in the sector at an early stage and thereby also help accelerate its uptake.
Senior unsecured debt	• This will provide cheap finance to developers, yet also provide security to investors in case there is not enough early success for them to recover their funds through loan repayments.

5.3. Final stage - commercial viability

The coming of age of the value chain will allow increasingly broad swathes of the financial sector to get involved. As already observed in the renewable energy sector, asset-based financing will become an ever-increasing funding mechanism since the components used in GH production would have been confirmed as having the capability of generating revenue. This evolution will accelerate the development of the GH sector by decreasing the overall risks of financial institutions, allowing them to fund new projects and assets.

06

ASSESSING COUNTRY READINESS IN GREEN HYDROGEN SPACE

GH holds tremendous potential to help create a net zero future. The transition to a hydrogen economy requires an enabling environment that creates economies of scale which will drive down system costs. The USD 2/kg price target is regarded as the "tipping point" where GH systematically replaces grey hydrogen (permanently) which leads to the broader hydrogen economy. The experience in solar development in the last 15 years clearly shows that inherently modular technologies will decline in cost as global manufacturing capacity increases (this has also been the case for wind power and battery storage). At the national level, the solar program strategy of "go big and go fast" has been successful in general, and specifically in developing countries like China and India: based on these experiences, "going big and going fast" is the fundamental principle for driving down the cost of GH to the tipping point.

6.1. Hydrogen country readiness framework and evaluation methodology

The H2 readiness framework will help in assessing, analyzing and shortlisting ISA member countries on the basis of parameters that take into account:

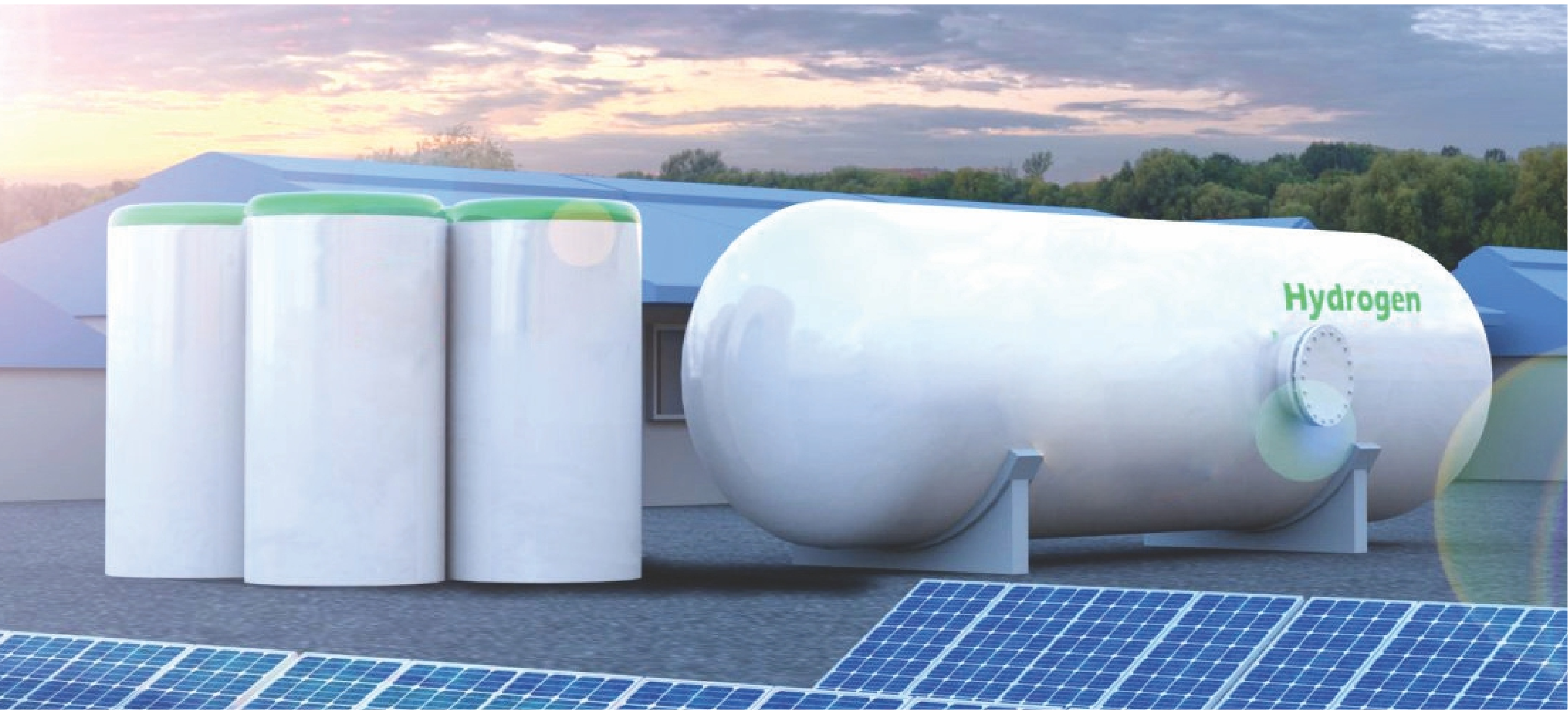
- the potential for the country to produce GH at low costs,
- the domestic demand for hydrogen,
- the ability for the country to pay for the GH it consumes, and
- the infrastructure available in the country to facilitate trade and storage of GH

Table 5 outlines the key parameters and their relevance in GH space:

Table 5: Key parameters for scoring shortlisted countries across the globe and relevance of parameters in hydrogen space

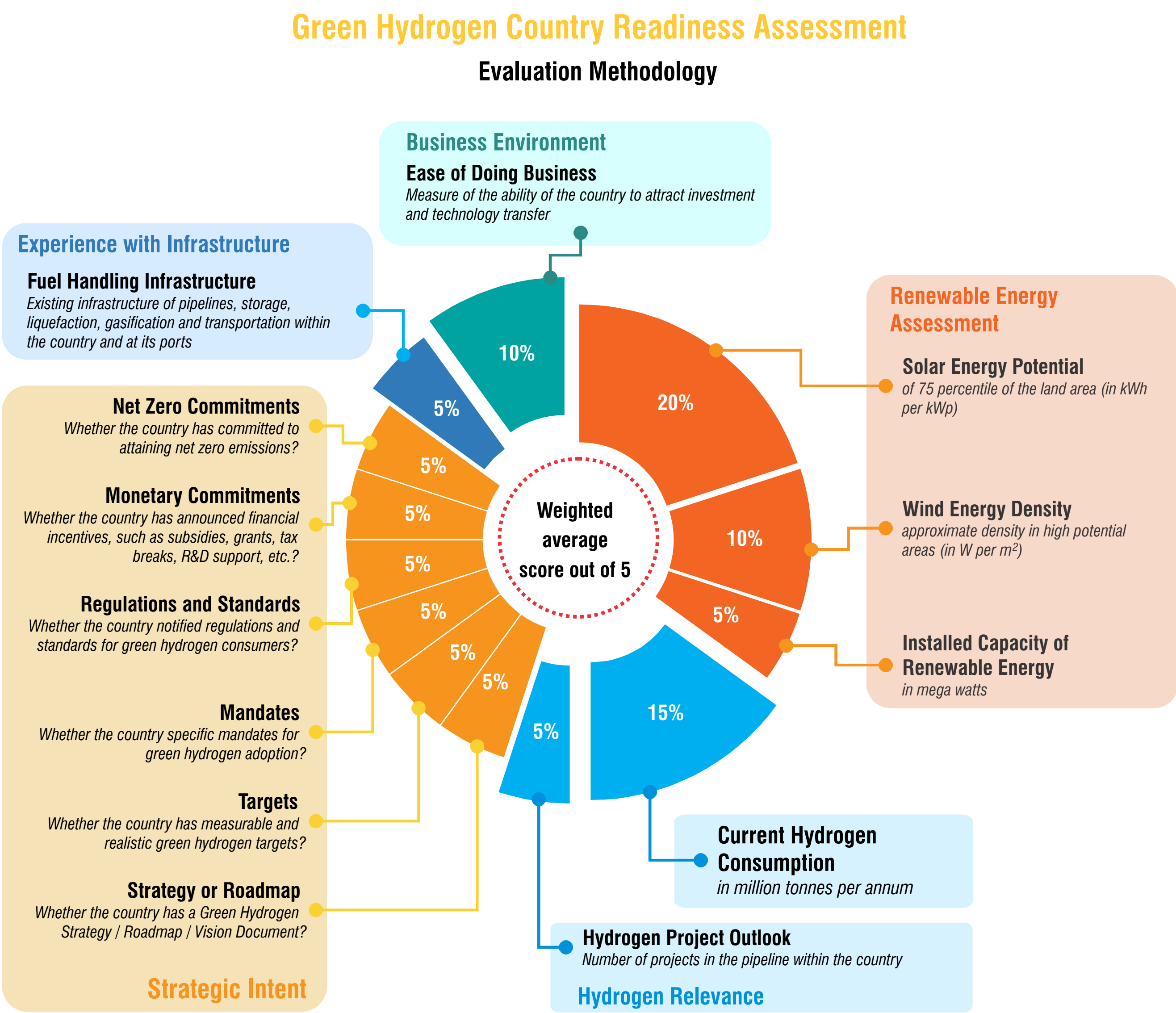
S. No.	Parameters	Relevance
1.	**High potential for renewable energy generation**	Electricity cost accounts for 50-60 percent of the green hydrogen cost of production. Availability of low-cost RE is key to achieving cost parity. The higher the RE potential of a region, it is likely to reduce the cost of energy and the cost of producing GH. Regions with a high renewable energy generation potential have an advantage.
2.	**Installed Renewable Capacity**	Countries with significant RE installations will have the experience and the capacity required to setting up of GH production facilities.
3.	**Demand for hydrogen**	Creation of a market for GH is important to ensure the long-term sustainability of the industry in any country. Consumers should not just be willing to use GH, but also to pay the costs at which it is available.
4.	**GH project outlook**	Tracking project announcements and development activities in the countries acts as a strong indicator of a progressive GH industry.
5.	**Favorable GH policy regime**	Policy framework in the country forms the backbone for accelerated deployment of new technologies, hence its crucial for all parameters to play out to their full potential. The effectiveness of the policy interventions in the framework is assessed with the presence or absence of the following key components:

S. No.	Parameters	Relevance
		• **Strategy or Roadmap** that lays out the 'big-picture' of the country's plans for GH deployment • **Concrete targets and timelines** to achieve the goal • **Regulations** allowing seamless integration of GH into the country's energy system • **Fiscal commitments** from the government in the form of incentives, rebates, subsidies, or as investments across value chain • **Net zero vision** presenting an overall commitment and willingness among the countries to move towards decarbonisation
6.	**Experience with infrastructure**	Hydrogen is like natural gas in many aspects. Countries with the required infrastructure for natural gas are adequately equipped to carry out similar processes and uses for hydrogen. This includes ports for exporting and importing LNG. This will determine the hotspots that have the potential to be developed into hubs for hydrogen supply chain.
7.	**Ease of doing business in the country**	Countries must also have a business environment that welcomes investment and technology transfusion across borders.
8.	**Availability of port infrastructure**	Transport by sea routes is considered to be the most efficient, reliable, and possibly cheapest means to carry hydrogen over long distances (as is the case for other bulk cargoes). This could either be done with dedicated hydrogen carriers, or in containerized cascades that could carry the compressed gas aboard container ships for smaller cargo loads. Making this possible requires that the country has access to a strong port infrastructure.



For assessing the country readiness for GH, a combination of these eight key parameters was taken. The methodology was applied to a subset[18] of ISA member countries by scoring each of the 8 parameters on a scale of 1-5. A weighted average score was calculated for each country. This overall approach is illustrated below in Figure 15. The methodology allows inclusion of some subjective parameters as well, such as the experience of the respective country in fuel handling infrastructure and proximity to ports for hydrogen.

Figure 15: GH readiness framework - evaluation methodology



Following this methodology, countries across regions in the world were assessed and placed into 4 broad categories based on their level of readiness for adopting GH, the highest positioned being the **Frontrunners**, followed by **Progressives, Prospectives and Potentials**. The details of the aforementioned four categories are outlined in the subsequent section.

6.2 Country readiness scoring

The shortlisted countries were analyzed and assigned scores as described above (also refer to the scoring methodology in Annexure 1). These were then placed under respective categories as presented in Table 6. Characteristics and elements for each category and the qualities of the countries falling in each have been outlined in the following pages.

[18] The countries were shortlisted for the GH readiness assessment, based on high RE potential, relevant policy framework in place, as well their hydrogen demand as of 2021. The selected ISA member countries also account for the major share of total global hydrogen demand of 94 MTPA in 2021.

Table 6: Categorization of countries based on readiness framework

Frontrunners	Progressives	Prospectives	Potentials
• USA • Australia • France • Spain • Germany • Japan • Chile • United Kingdom	• Italy • India • Egypt • Netherlands • Saudi Arabia • Republic Of Korea • Oman • Argentina • Algeria • South Africa	• UAE • Brazil • Poland • Morocco • Iran • Peru • Mexico • Namibia • Sudan	• Trinidad & Tobago • Indonesia • Somalia • Qatar • Nigeria • Bangladesh

Frontrunners

Frontrunners perform well on multiple parameters and are more likely than other countries to have a structured policy mechanism for GH in place, with clear roadmaps, attainable targets, and an alignment among stakeholders (see Table 7). These countries would also have a moderate-to-strong installed base of renewable energy solutions, which is also indicative of the technical capabilities among the industry players required to deploy, operationalize, and maintain such solutions.

With these enabling conditions in place, the Frontrunners are well positioned to scale up. Countries like the USA and Australia are leading hydrogen economy. Australia has a policy for development of GH with a clear roadmap, strong targets, and regulations. The high solar energy potential available throughout most parts of the country makes it an attractive destination. USA is also the second largest consumer of hydrogen in the world providing a captive market for any GH produced in the country. The country has a network of natural gas pipelines and a strong LNG export industry in the Gulf of Mexico, which could easily spur the development of a similar hydrogen export hub. Given that most of the countries appearing on the list are among the most developed countries in the world, capital is not a major challenge as it may be for developing countries.

Table 7: Country scoring - Frontrunners

Frontrunners Countries	RE Assessment	H2 Relevance	Strategic Intent	Experience with Infra	Business Environment	Final Score
USA	Score 4-5	Score 4-5	Score 4-5	Score 4-5	Score 4-5	Score 4-5
Australia	Score 4-5	Score 3-4	Score 4-5	Score 4-5	Score 4-5	Score 4-5
France	Score 4-5	Score 3-4	Score 4-5	Score 4-5	Score 4-5	Score 3-4
Spain	Score 4-5	Score 3-4	Score 4-5	Score 4-5	Score 4-5	Score 3-4
Germany	Score 3-4	Score 4-5	Score 4-5	Score 4-5	Score 4-5	Score 3-4
Japan	Score 3-4	Score 4-5	Score 4-5	Score 3-4	Score 4-5	Score 3-4
Chile	Score 3-4	Score 2-3	Score 4-5	Score 1-2	Score 4-5	Score 3-4
United Kingdom	Score 3-4	Score 3-4	Score 4-5	Score 4-5	Score 4-5	Score 3-4

● Score 4-5 ● Score 3-4 ● Score 2-3 ● Score 1-2

It is important to note that being a Frontrunner does not guarantee success. Further effort will be required to facilitate an uptake with incentives for potential consumers to switch and for the private sector to invest in the scaling up process.

Progressives

Progressives perform well on some of the parameters but may be lacking on a few other parameters (see Table 8). Except for certain parameters inherently derived from the climate and the geography of the country, such as the level of renewable energy potential available in these countries and the distance to coast, the score on most other parameters could be improved with concerted effort.

Positive action on these parameters can help these countries to graduate to the Frontrunners category. Gaps in GH policy framework can be swiftly addressed to have an impact on the country's readiness level. For developed countries falling in this category, plugging these policy gaps could be easier as compared to developing countries that have less expertise and affordable financial resources.

A good example of a Progressive country is Egypt, which is setting up a hydrogen economy. Their policy provides a clear strategy with targets, timelines, and monetary commitments from the government. Egypt has excellent solar energy potential, of which only a fraction has been harnessed. India also features in this set with ongoing development and research in areas including the solar energy potential, presence of natural gas infrastructure, and GH policy regime. The country is the third largest consumer of hydrogen that can be expanded with adequate focus on developing new use cases for GH in the railways and shipping industry.

Table 8: Country scoring - Progressives

Progressives Countries	RE Assessment	H2 Relevance	Strategic Intent	Experience with Infra	Business Environment	Final Score
Italy	Score 3-4	Score 3-4	Score 4-5	Score 4-5	Score 4-5	Score 3-4
India	Score 3-4	Score 3-4	Score 3-4	Score 3-4	Score 4-5	Score 3-4
Egypt	Score 3-4	Score 1-2	Score 3-4	Score 3-4	Score 3-4	Score 3-4
Netherlands	Score 2-3	Score 4-5	Score 4-5	Score 4-5	Score 4-5	Score 3-4
Saudi Arabia	Score 2-3	Score 2-3	Score 1-2	Score 4-5	Score 4-5	Score 3-4
Republic Of Korea	Score 3-4	Score 2-3	Score 4-5	Score 3-4	Score 4-5	Score 3-4
Oman	Score 1-2	Score 2-3	Score 1-2	Score 3-4	Score 4-5	Score 3-4
Argentina	Score 3-4	Score 1-2	Score 1-2	Score 3-4	Score 2-3	Score 3-4
Algeria	Score 2-3	Score 1-2	Score 1-2	Score 4-5	Score 4-5	Score 2-3
South Africa	Score 2-3	Score 1-2	Score 3-4	Score 1-2	Score 3-4	Score 2-3

Score 4-5 Score 3-4 Score 2-3 Score 1-2

Prospectives

Prospective countries score well on only a few parameters as shown in Table 9. For instance, most of the countries falling within this category have excellent renewable energy generation potential which is offset by the low levels of actual renewable energy deployment.

Many of these countries have exhibited some strategic intent towards adopting GH, either with a stated vision to develop GH ecosystem or with a nascent strategy or a roadmap. Many of these countries also have announced net zero targets.

Like many other countries from Europe, Poland is characterized by a coal-and gas-powered economy, and a policy mechanism influenced by the mandates of the European Union. However, the country has very low potential to produce GH using its own solar energy resources. Countries like, Iran, Namibia and Peru have some of the highest levels of solar energy potential in the world, but lack on the policy and experience with infrastructure for fuel logistics.

Priming these Prospective countries to step up on readiness scale could be a challenge, given the structural changes needed to boost adoption of renewable energy and GH. Integrated policies that incentivize the development of a strong renewable energy portfolio in the country, while also laying the groundwork for a GH industry in future are needed for t3he countries to graduate to higher readiness categories.

Table 9: Country scoring - Prospectives

Prospectives Countries	RE Assessment	H2 Relevance	Strategic Intent	Experience with Infra	Business Environment	Final Score
UAE	Score 2-3	Score 1-2	Score 1-2	Score 3-4	Score 4-5	Score 2-3
Brazil	Score 3-4	Score 1-2	Score 1-2	Score 3-4	Score 2-3	Score 2-3
Poland	Score 1-2	Score 2-3	Score 1-2	Score 4-5	Score 4-5	Score 2-3
Morocco	Score 1-2	Score 1-2	Score 3-4	Score 3-4	Score 4-5	Score 2-3
Iran	Score 2-3	Score 2-3	Score 1-2	Score 3-4	Score 2-3	Score 2-3
Peru	Score 2-3	Score 1-2	Score 2-3	Score 1-2	Score 3-4	Score 2-3
Mexico	Score 2-3	Score 1-2	Score 1-2	Score 3-4	Score 4-5	Score 2-3
Namibia	Score 3-4	Score 1-2	Score 1-2	Score 1-2	Score 3-4	Score 2-3
Sudan	Score 2-3	Score 1-2	Score 1-2	Score 1-2	Score 4-5	Score 2-3

● Score 4-5 ● Score 3-4 ● Score 2-3 ● Score 1-2

Potentials

Potential countries demonstrate strong developing trends which are expected to increase their energy consumption as they grow or have the potential to become a major GH export hub based on the renewable energy potential (see Table 10).

Countries like Trinidad & Tobago, Indonesia, Somalia and Qatar are early movers that yet need to establish strategies, visions or roadmaps to integrate GH in their economy. Though the countries portray a fairly favorable environment for business, along with availability of infrastructure, most of them need to strengthen the RE base and strategic intent.

As with Prospectives, Potentials need to focus on pushing RE portfolios and policy frameworks which will facilitate development of fuel handling and transportation infrastructure, and promoting GH among industrial and commercial consumers. The amount of technology transfer, fund flows and knowledge sharing would be high, which would require international support from multi-lateral agencies, development finance institutions and private sector technology companies.

Table 10: Country scoring - Potentials

Potentials Countries	RE Assessment	H2 Relevance	Strategic Intent	Experience with Infra	Business Environment	Final Score
Trinidad & Tobago	● Score 1-2	● Score 2-3	● Score 1-2	● Score 1-2	● Score 3-4	● Score 1-2
Indonesia	● Score 1-2	● Score 2-3	● Score 1-2	● Score 3-4	● Score 3-4	● Score 1-2
Somalia	● Score 3-4	● Score 1-2	● Score 1-2	● Score 1-2	● Score 1-2	● Score 1-2
Qatar	● Score 1-2	● Score 1-2	● Score 1-2	● Score 4-5	● Score 3-4	● Score 1-2
Nigeria	● Score 1-2	● Score 1-2	● Score 1-2	● Score 3-4	● Score 2-3	● Score 1-2
Bangladesh	● Score 1-2	● Score 1-2	● Score 1-2	● Score 3-4	● Score 4-5	● Score 1-2

● Score 4-5 ● Score 3-4 ● Score 2-3 ● Score 1-2

07

RECOMMENDATIONS

DRIVERS TO FACILITATE EARLY ADOPTION FOR ISA MEMBER COUNTRIES

GH is attracting great interest in developed and developing economies alike to fulfil their net-zero targets, primarily due to the falling costs of renewable energies and availability of technologies to scale up use of hydrogen. As highlighted in the section above, high production costs and lack of a dedicated infrastructure impose significant losses in the value chain, among other barriers. The hydrogen sector has received some attention from policy makers with required strategies and roadmaps, but a more dedicated policy support is needed to achieve technology readiness, target market penetration, and attract market growth.

There are three important levers areas to focus on for increased GH penetration. This includes creating **demand** for GH in different sectors, developing **infrastructure** to enable end use, and strengthening **cost competitiveness** through scaling up GH deployment.

Table 11 below lists focus areas to enable accelerated GH deployment.

Table 11: Potential focus areas for policy makers to facilitate accelerated deployment of GH

Drivers	Areas to focus
Policy	• Establish a **high-level strategy and roadmap for the development of hydrogen**, according to geographic and economic, advantages of countries. • Pass a **country-wise net-zero** emissions target • Identify and accelerate **new hydrogen business models** that will enable the highest decarbonization possible at the lowest cost. • **Implement policies that stimulate** demand and help project developers to secure off-takers, which in turn unlocks investment in production assets.
Technology	• Provide **strong innovation support** to ensure critical technologies reach commercialization quickly • Implement robust innovation programmes critical for **government and industry co-operation** • **Leverage Technology Collaboration Programmes** to facilitate international R&D and information exchange.
Infrastructure	• **Mobilize investment** in production assets, infrastructure and factories. • Interconnect major **industrial clusters** • Invest in research and development to **create mature storage solutions** • Facilitate **transport infrastructure**
Standards & Certification	• Introduce a **certification system** to allow users and governments to know the origin and quality of the hydrogen - **Guarantee of Origin" (GO)**. • E.g., CertifHy project in the European Union • **Devise and implement international standards** to execute cross-border projects and learn-from global companies that design and construct the equipment.

Drivers	Areas to focus
Research and development (R&D)	• **Research and development (R&D) funding** • International collaborations • Multilateral initiatives and projects can promote **knowledge-sharing** and the development of best practices to connect a wider group of stakeholders
Financing	• **Identify and support** (through both capital expenditure and operational expenditure subsidies, loans/ financial guarantees, public investments, contracts for difference, facilitating long-term offtake contracts, fiscal incentives) **early-stage projects and partnerships to kickstart hydrogen clusters or valleys** • **Define supportive tax regulations** to support the required uptake of hydrogen by reducing the risk for developers • **Allocating incentives to pilot and demonstration projects** that are the most promising for a decarbonized future • Organizations should work with **investors and governments** on **developing national roadmaps** to highlight areas of national focus and to assess the applications in which GH can deliver gain
Stakeholder Role and Responsibilities	**Public** • Adopt **clear policies** to decarbonise economies • **Encourage and fund pilot** programmes as pilots for dissemination of result • Promote **innovations** in reducing the cost of electrolysis **Private** • **Disseminate information** about the contribution of GH to power sector transformation and VRE integration • Work together with the public sector on **innovative projects**

As the penetration of GH technologies increases and costs come down, policies will have to keep evolving. Long-term policy targets including net zero pledges, R&D funds, mitigation policies and co-funding of pilots and demonstration projects, not only offer certainty to the private sector, but also improve the business case for GH, closing investment and operational cost gap. Dedicated innovation programmes with clear timelines and collaboration also push their market reach. Figure 16 depicts some of the target areas for ISA member countries with an aim to address challenges and mitigate risks, thereby ensuring GH deployment and growth.

Figure 16: List of potential drivers and recommendations for countries under four categories

Frontrunners

- Promote **market and technology scale up**
- Define supportive **tax regulations**
- Allocating **incentives** to pilot and demonstration projects
- **Disseminate information** about the contribution of GH to power sector
- **Research and development** (R&D) funding
- **Feasible contractual** structures

Progressives

- **Clear demand mandates**
- **Support early-stage projects** and partnerships
- **Regulatory body** to provide necessary assurance
- **International safety and technical standards**
- Strong **innovation support** to technologies and **collaboration**

Prospectives

- Facilitate **access to low cost RE**
- **High-level strategy** and roadmap for hydrogen
- Policy stimulating **demand**
- **Technology innovation** and scale up through collaborations and cooperation
- Multilateral initiatives to promote **knowledge-sharing**
- Mobilize investment

Potentials

- Establish a **policy**
- **Investment in R&D** for infrastructure
- Work with investors and governments on developing **national roadmaps**
- Access to **low cost RE**
- **Technology collaboration programmes**
- Government and industry co-operation to **encourage innovation**

The ISA Programme – Solar for Green Hydrogen – will address these barriers in close collaboration with ISA membership and other stakeholders. This consultation draft has provided a brief overview of the current status, projections, barriers & challenges to deployment of GH as a clean energy vector. The final Blueprint will build upon the Readiness Assessment Framework introduced in this report and provide a deep-dive analysis on a select ISA member countries.

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Annex 1
SCORING METHODOLOGY FOR COUNTRY READINESS FRAMEWORK

RE assessment framework

Scores	PVOUT (kWh / kW / day)	Wind Energy Density (W / m2)	RE Installed Capacity (MW)
5	>5	1500	50000
4	4.5-5	1200-1500	40000-50000
3	4-4.5	800-1200	30000-40000
2	3.5-4	500-800	20000-30000
1	3-3.5	200-500	5000-20000
0	<3	<200	<5000

H2 relevance

Scores	Annual H2 Consumption - 2020 (MTPA)	Hydrogen Project Outlook (Number)
5	>2	25
4	1.5-2	20-25
3	1-1.5	15-20
2	0.5-1	10.0-15.0
1	0.25-0.5	5.0-10.0
0	<0.25	<5

Strategic intent

Scores	Strategy | Targets | Mandates | Regulations & Standards | Monetary Commitments | Net-zero commitments
5	Yes
0	No

Fuel Infrastructure Experience

Scores	Experience with Infra
5	High
3	Moderate
1	Low

Ease of doing business	
Scores	Business Environment
5	80
4	70-80
3	60-70
2	50-60
1	40-50
0	<40

Scoring of countries	
Scores (out of 5)	Categorization
3.5 to 5	Frontrunners
2.5 to 3.5	Progressive
2 to 2.5	Prospective
Less than 2	Potential

Annex 2
TECHNOLOGY OVERVIEW- ELECTROLYSERS

Alkaline electrolysis (AE) is a mature and commercial technology. However, the technology is yet to be scaled up and reach market maturity due to rapid scale up of competing sources of energy as well as sources of Hydrogen (Eg: Natural Gas/SMR Process). AE technology is characterized by lower CAPEX compared to other technologies, primarily because they do not require precious metal inputs. However, need for further purification of hydrogen for fuel cell applications and slow ramping response are some of the challenges to long term viability of AE for integration with variable renewable energy (VRE) technologies. Cost of alkaline electrolysers is estimated to range from USD 500 to 1000/KW[19]. However, the cost is highly contingent upon the scale, with electrolysers in excess of 10 MW capacity estimated to cost below USD 500/KW.[11]

PEM electrolysis is a relatively newer technology, developed in 1960s in response to the operational limitations of AE. PEM electrolysers holds several advantages over AE such as use of high purity water as an electrolyte solutions obviating the need for recovery and recycling of Potassium Hydroxide solution used in AE: better operational flexibility more suitable for integration with VRE and providing balancing & ancillary frequency control support in power applications. Further, PEM electrolysers have an added advantage of producing highly compressed hydrogen (up to 100 bar as opposed 30 bar for AE), making them suitable for decentralized production and storage. However, requirement of precious metals such as platinum (estimated to be about 300 Kg/GW)[1] and iridium (estimated to be about 700 KG/GW)[1] increase CAPEX and are potential supply chain bottlenecks. The current cost of PEM electrolyser (without balance of plant cost) is around USD 1100/KW.[11]

Solid Oxide Electrolysis Cell (SOEC) technology is still in development/pilot phase. SOEC technology has the potential to achieve lower CAPEX with scaling up due to lower material costs due to use of ceramics as the electrolyte. Further, high electrical efficiency, high operating temperature, and use of steam make SOEC an ideal candidate for combined heat and power applications as well as production of synthetic fuels. Further, the fact that SOEC may be operated in reverse mode as fuel cells make them ideal prospect for stationary applications such as balancing services, thus potentially increasing their utilisation rate as well.

[19] Green Hydrogen in Developing Countries, World Bank, 2020

Annex 3
KEY ASPECTS OF GREEN HYDROGEN PRODUCTION PROJECTS

The figure below illustrates the key elements of a GH production project. A GH production project resembles a conventional renewable energy project wherein sites must be identified with good renewable resources. Appropriate electrolyser technologies must be identified to convert renewable electricity to hydrogen. Governments are responsible for allowing specific sites to be used as well as for the permitting processes. Government agencies can serve as the initial project developer (as has been the case in India's solar parks program) to take out early-stage risk and crowd in private investment.

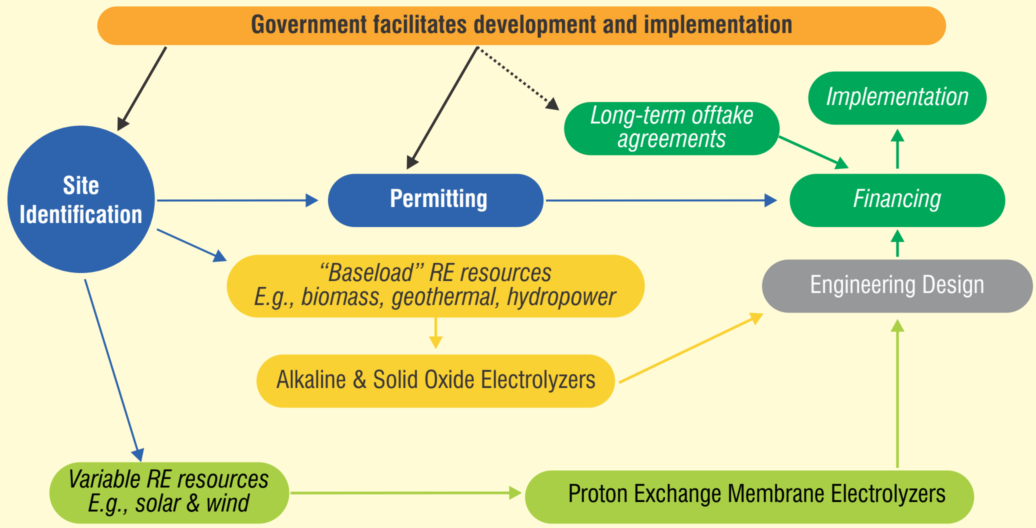

Figure 17: Key Elements of Green Hydrogen Production Project Development

By taking the initial developer role, governments can also assist in securing long-term offtake agreements which enable project financing (a traditional practice for liquified natural gas export projects is that long-term offtake agreements are necessary to secure financing). Government leadership and decision-making is critical, e.g., for projects where GH will be produced from floating solar in existing hydropower reservoirs or from offshore wind in exclusive economic zones (EEZs). Lessons learned from offshore oil and gas development can be applied as well as lessons from ongoing project development in the North Sea where offshore wind is being dedicated to GH production with no power purchase agreement.

The key differences between conventional renewable energy projects and GH projects are: (i) electrolyser technology must be matched with the renewable resources, and (ii) a price formula linked to fossil-based hydrogen may be utilized instead of a fixed price per unit of energy (informed by the liquified gas export model vs. traditional renewable energy power purchase agreements). In the absence of government facilitation, a GW scale GH production project will be "dead on arrival."

Multilateral agencies such as ISA and Asian Development Bank (ADB) can assist in project development. Specifically, ADB can assist governments in renewable resource evaluation for site selection, conceptual design, tendering to bring in commercial partners, and financing the major physical components of the project via sovereign and non-sovereign channels, employing blended finance as necessary.

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