INTERNATIONAL SOLAR ALLIANCE


# ISA PROGRAMME 09– SOLAR FOR GREEN HYDROGEN

Programme
Initiation Document

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# Table of Contents


**Executive Summary** .......... **1**

**Introduction** .......... **3**

Hydrogen Market Today .......... 3

Evolutionary Factors - Technology Cost Trends, Opportunity Costs .......... 3

Potential for Transformation from Fossil $H_2$ to Green $H_2$ .......... 5

Current Green $H_2$ Development .......... 5

**Green Hydrogen Applications** .......... **9**

Immediate Market Opportunities .......... 9

Market Evolution in the Next 5-10 Years .......... 9

**Facilitating Green Hydrogen Development, Scale-up and Replication** .......... **11**

Business Models .......... 11

Creating an Enabling Ecosystem for a Global Green Hydrogen Market .......... 11

**Mobilising Investors, Including ‘deep pocket’ Corporates** .......... **13**

**Role of ISA** .......... **14**

# Executive Summary

Hydrogen has long been recognised as a pathway to deep decarbonisation, particularly in hard-to-abate sectors. Rapid scale-up of renewable energy systems, solar energy, in particular, resulting in precipitous cost reduction, has made a 'Green' Hydrogen-based economy a real possibility in several geographies. There is a renewed global interest towards this versatile energy resource, with several governments announcing Green Hydrogen policies/strategies/targets and global multilateral/private sector organisations increasingly recognising Hydrogen in their near-to-midterm strategies.

Against this backdrop, the International Solar Alliance (ISA) launched a thematic programme – 'Solar for Green Hydrogen' – at the Fourth Assembly of the ISA. The Programme is dedicated to promoting solar-based Green Hydrogen across ISA membership through analytics and advocacy support, readiness assessment and capacity building, and establishing a global network of partnerships and alliances to create synergies in the solar hydrogen value chain. ISA is being supported by the Asian Development Bank (ADB), under ADB's Knowledge and Support Technical Assistance, in implementing the programme.

This Programme Initiation Document for 'Solar for Green Hydrogen' analyses the current state of the Hydrogen sector, evolutionary trends in the Green Hydrogen sector, business models for solar hydrogen production, potential near-to-midterm end-use applications, and supporting ecosystem needed for the development of the green hydrogen sector. The document notes that the sensitivity of the price of grey and blue hydrogen to natural gas prices, prone to recurrent supply chain disruptions, makes a sensible business case for converting existing grey


*https://www.pv-magazine-australia.com/wp-content/uploads/sites/9/2021/09/Edify_Hydrogen_Lansdown_4-scaled-1-1200x675.jpeg*

Hydrogen end-uses into green in the near term. The price of green hydrogen is strongly dependent on the Levelized Cost of Electricity (LCOE) of solar energy utilisation factor and the capex of the electrolyzer. The capex of the electrolyzer is expected to drop sharply with scale, owing to its inherently modular nature. The document highlights several initiatives that already are underway to achieve GW scale in the near-to-midterm and that there is a need to ramp up demand through enabling policies and targets. Low LCOE of solar energy across several geographies and potential for rapid reduction in electrolyzer capex with a scale makes US$ 2/kg production cost a distinct possibility in the near-to-midterm.

There is global momentum in favour of Green Hydrogen as the next 'innovation' in climate mitigation efforts. ISA is at the forefront of identifying and scaling up innovative solar energy based solutions across its membership. The document aims to carve out a niche for ISA in the green hydrogen sector as well as outline its role amongst its membership and peer organisations in assessing and supporting green hydrogen value chain development. This document would serve to initiate and facilitate discussions on ISA's newest programme amongst various stakeholders, including Member Countries and peer organisations. This document would serve as a base for stakeholder engagement on developing a blueprint for solar hydrogen production and utilisation across ISA membership.

# Introduction

The solar radiation received on the earth exceeds total annual global energy consumption by a factor of more than 5000.[1] Effectively harnessing and utilising solar energy at the gigawatt (GW) and terawatt (TW) scale requires bulk energy storage, time-shifting, and location-shifting of solar output, requiring GW-scale energy storage and long-term time-shifting. Other than pumped storage, which is limited by the availability of environmentally and socially acceptable sites, no other viable and scalable solutions exist today. Hydrogen is emerging as a scalable and more flexible alternative that is based on the ability to convert sunlight (photons) to electricity (electrons) to hydrogen (protons), which can be stored indefinitely.

The hydrogen can be converted to other chemicals (molecules), which can be transported in bulk, as is the case for crude oil, natural gas, and refined petroleum products, making it a versatile energy vector for decarbonisation of hard-to-abate sectors. Like fossil fuels - which are formed by a combination of solar, biomass, geothermal energy, and geologic time-hydrogen is an energy carrier. Solar-to-hydrogen mimics the natural processes that create fossil fuels, and potential uses of solar hydrogen mimic the existing global hydrocarbons business.

## Hydrogen Market Today

The global hydrogen market today is about 100 million tons per year[2], more than 95% of which is produced from fossil fuels, primarily natural gas using the steam methane reforming (SMR) process. Almost all of this grey hydrogen is produced on-site for fertiliser production and petroleum refining operations.

The cost of production of grey hydrogen, and of blue hydrogen (grey hydrogen plus CCS) is sensitive to natural gas prices which are set in regional markets rather than global markets. Figure 1 illustrates regional gas pricing from early 2020 to April 2022, clearly showing price volatility in the European market from late 2020. As of late February – early March 2022, the cost of grey hydrogen in Europe was estimated to be about $10/kg due to natural gas price increases due to current geopolitical disruptions. Increasingly greater volatility in the price of natural gas, with a clear upward trend expected in the near-to-midterm, coupled with rapidly reducing cost of solar energy with scaling up, has the potential to make solar energy-based green hydrogen commercially viable in some regions.

Further, scaling up blue hydrogen requires significant upfront investments, with a long-term horizon, for creating the necessary infrastructure for $CO_2$ transportation/storage as well as sufficient scale to justify investments in the Carbon Capture, Utilisation and Storage (CCUS) technology. Considering this, it may be expected that green hydrogen would have a significant advantage over blue hydrogen in regions without readily available CCUS infrastructure.[3]

## Evolutionary Factors - Technology Cost Trends, Opportunity Costs

'Green' hydrogen production via electrolysis of water is possible with off-the-shelf technology. The critical technology is the electrolyzer which splits water ($H_2O$) into hydrogen ($H_2$) and oxygen ($O_2$).[4]

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1 D. Abbott. 2010. Keeping the Energy Debate Clean: How Do We Supply the World's Energy Needs? Proceedings of the IEEE.

2 A kilogram of hydrogen has the energy equivalent of a gallon (3.94 Liters) of gasoline (petrol); 100 million tons hydrogen per year is equivalent to 100 billion gallons of gasoline per year or 394 billion liters of gasoline per year.

3 Even if CCUS infrastructure is readily available, the development history in the last 15 years does not suggest that any manufacturing economies of scale are possible with industrial CCUS.

4 It is critical to note that green hydrogen is not "a technology," it is a system of components which are all available off-the-shelf. The commercial viability depends on offtake prices, as was the case when solar PV exhibited cost of production higher than $0.15/kWh.

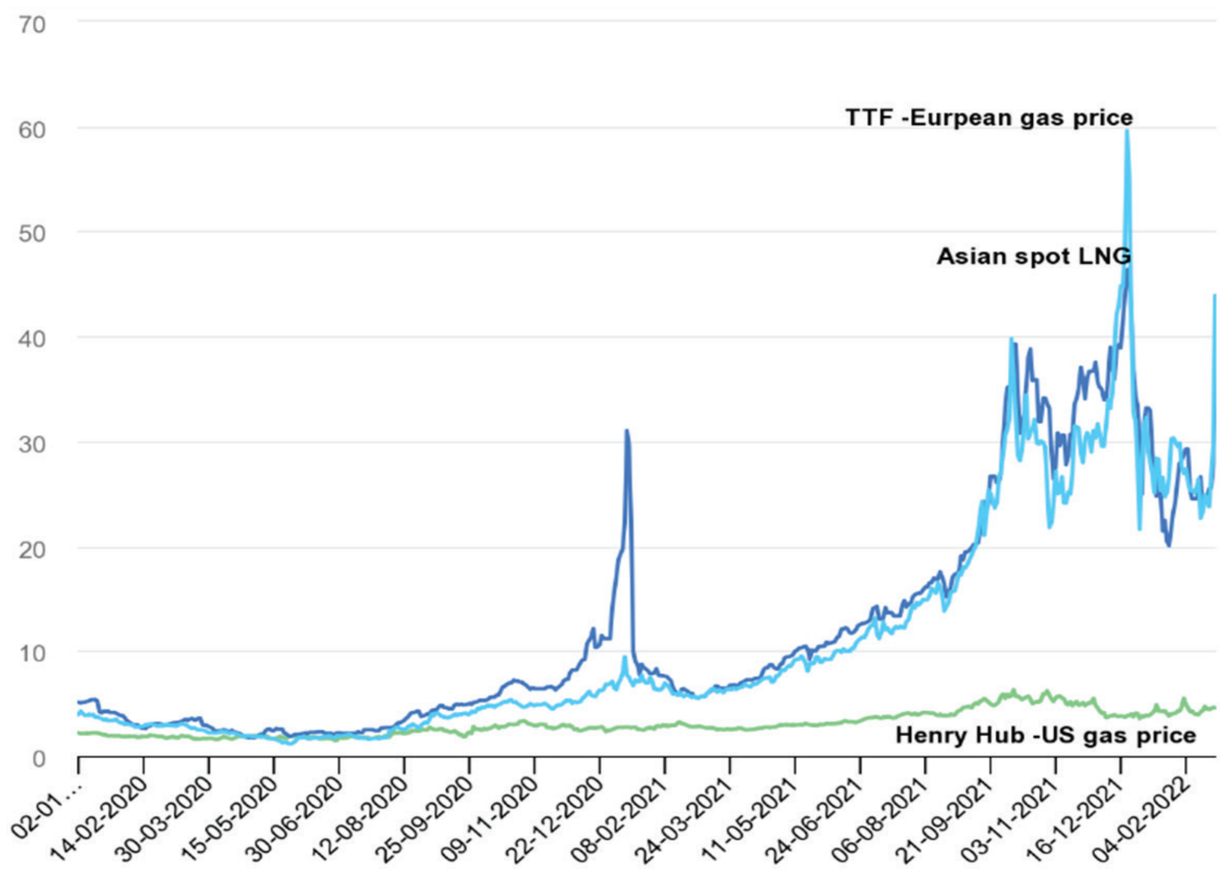



**Figure 1:** Natural gas prices in Europe, Asia, and the United States January 2020 to February 2022 ($/million BTU)
***Source:*** *International Energy Agency*

The benchmark or reference cost of production of hydrogen from natural gas is around $2/kilogram (kg), which is based on a natural gas price of $6/million British Thermal Units (MMBTU)[5] and does not consider greenhouse gas abatement cost or carbon pricing.

The cost of green hydrogen depends primarily on three factors: Levelised cost of Electricity (as a corollary on the efficiency of the electrolyzer), Capital Expenditure, and Utilisation factor (refer to Figure 2 below). Achieving $2/kg cost of hydrogen production from electrolysis requires an electricity input cost of much less than $0.02/kilowatt-hour (kWh) at existing capex levels. Electrolyzers are inherently modular, and as factory mass production ramps up, unit costs will decline, resulting in a lower cost of production of hydrogen. Thus, technology agnostic scale-up of green hydrogen through wind/solar energy would enable a rapid scale up in electrolyzer production.

Using commercially available hardware, electrolysis of water requires about 50 kWh of electricity to produce 1 kg of hydrogen (or 50 Megawatt-hours (MWh) per ton of hydrogen). Replacing the current 100 million tons/year of fossil hydrogen with hydrogen via electrolysis would require 5000 Terawatt-hours/year (TWh/y) of electricity which is almost 22% of global electricity production and just under 3% of total global energy production.[6] More than 3 TW of solar photovoltaic (PV) capacity would be required to produce 100 million tons of hydrogen per year, with total investment (including electrolyzers and balance of plant) at a maximum cost of $5 trillion[7] at current prices, which is just over

[5] The $6/MMBTU benchmark is also the landed cost of liquified natural gas in Asia, assuming the gas originates in the US at $3/MMBTU.

[6] Total global energy production includes coal, oil, and natural gas (CONG), nuclear energy, and renewable energy.

[7] Key cost assumptions: $3 Trillion for 3 TW solar PV including marine floating solar, $1 Trillion for 2 TW of electrolyzers, and $1 Trillion for project development and balance of plant costs including land acquisition, desalination, temporary hydrogen storage, etc.

5% of global GDP in 2021. The total land requirement (assuming 100% ground mounted capacity deployment) would be about 5 million hectares (1 MW solar requires about 1.6 hectares). Thus, the deployment of green hydrogen presents a significant opportunity cost in terms of investment needed, which would otherwise go to renewable energy for direct end-uses. A second critical constraint is the availability of sites for GW-scale renewable energy production (see further discussion below).

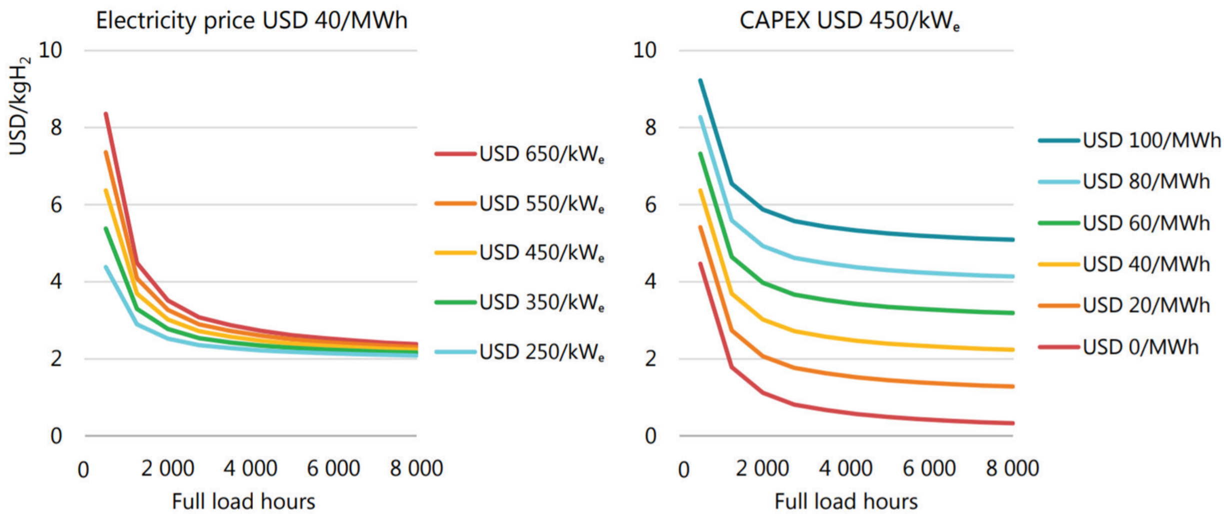



**Figure 2:** Relationship of Costs and Electrolyzer Load Factor on $H_2$ Cost

## Potential for Transformation from Fossil $H_2$ to Green $H_2$

Conversion of existing end-uses, primarily in the petro-chemical sector, present an anchor demand, particularly in geographies with higher natural gas prices, for deployment of green hydrogen through cluster-based production in industrial corridors/ports & logistics clusters and/or blending with existing natural gas supply chain thereby, leveraging the existing transportation/distribution infrastructure. In addition, sectors such as residential heating applications through blending with natural gas and existing direct reduced iron production present additional anchor demand for green hydrogen. Such conversion would be instrumental in market creation as well as providing a long-term signal for investments in the green hydrogen sector.

The solar resources are available, particularly in the tropical belt, but monetising that energy in the form of tradable hydrogen, oxygen, and other molecules remains a challenge due to lack of demand - and more specifically, the willingness to pay - for green hydrogen.

## Current Green $H_2$ Development

As noted above, green hydrogen is commercially viable depending on the offtake price, which is a moving target. Many projects have been announced but commercial operations today are rare. There are a few boutique projects at kW scale which have proven that the various renewable energy, electrolyzer, and fuel cell technologies can be assembled into systems which do work. At the MW scale, HDF Energy has multiple projects in operation and at different stages of development, including a proposed utility-scale project in Indonesia[8] which combines solar PV, batteries, electrolyzers for $H_2$ production, and fuel cells to convert $H_2$ back to electricity. This system provides reliable electricity 24 hours per day and is competitive with diesel-fired electricity generation.

[8] https://www.hdf-energy.com/en/contact/

Most of the GW scale projects are being developed in 3 geographic areas: (i) Australia, (ii) Western Europe and the North Sea, and (iii) the Middle East. Projects in Australia and the Middle East will be powered by onshore solar and wind, as summarised in Table 1. Projects in Western Europe and the North Sea will be powered primarily by offshore wind,[9] while projects in Southern Europe will use solar. The projects in Australia are intended primarily for the export of hydrogen and green ammonia. The Neom Project in Saudi Arabia is intended for green ammonia export.The Europe / North Sea projects will produce hydrogen for use in existing markets as a chemical feedstock and for blending with natural gas in existing pipeline networks. Of these 3 geographic areas, the Europe / North Sea projects appear to be more advanced with respect to investment commitments and enabling regulatory frameworks.

**Table 1: Gigawatt Scale Solar and Solar-Wind to Hydrogen Projects Under Development**

| Project / Investment | Developers | Usage | Capacity | Development Stage |
|---|---|---|---|---|
| Asian Renewable Energy Hub<br>**Pilbara, Western Australia**<br>**$36 Billion**<br>**https://asianrehub.com/** | InterContinental Energy, CWP Energy Asia, Vestas, Macquarie | Green hydrogen and green ammonia for export to Asia | 14 GW of electrolyzers powered by 16 GW of onshore wind and 10 GW of solar<br>1.75 million tons per year of hydrogen to produce 9.9 million tons per year of green ammonia | Environmental permitting was in suspense as of mid-2021 due to concerns over impacts on nearby wetlands<br>Final investment decision expected in 2025, construction to start in 2026, completion in 2027-28 |
| Murchison Renewable Hydrogen Project<br>**Kalbarri,Western Australia**<br>**$10-12 Billion** | Hydrogen Renewables Australia and Copenhagen Infrastructure Partners | Demonstration phase to provide $H_2$ for transport fuels<br>Expansion stage to produce $H_2$ to blend into local natural-gas pipelines<br>Final expansion to produce $H_2$ for export to Asia, with a focus on Japan and South Korea | 5 GW electrolyzers | Completion by 2028 |
| **Base One**<br>**Pecém, Ceará state, northeast Brazil**<br>**$5.4 billion** | Enegix Energy, in conjunction with Italian wind turbine maker Enerwind, EPC provider Black & Veatch, and the Ceará state government | Green hydrogen for 'major international markets via ocean freight' | 3.4 GW electrolyzers powered by combined 'baseload wind and solar'<br>600,000 tons $H_2$ per year | Project announced in March 2021<br>Enegix says it has "contracted" 3.4GW of solar and wind capacity through its partnership with Enerwind<br>Completion by 2025 |
| Beijing Jingneng Inner Mongolia<br>**Eqianqi, Inner Mongolia, China**<br>**$3 Billion** | Chinese utility Beijing Jingneng | Not known | 5 GW electrolyzers powered by onshore solar and wind<br>400,000-500,000 tons $H_2$ per year | Under construction<br>Planned completion 2021 |

[9] The green hydrogen development in the North Sea region is due primarily to the maturity of the offshore wind industry and the willingness of commercial consumers to buy green hydrogen (albeit with some government incentives).

| Project / Investment | Developers | Usage | Capacity | Development Stage |
|---|---|---|---|---|
| Helios Green Fuels Project<br>Neom, Saudi Arabia<br>$5 billion | Air Products, ACWA Power, Neom | Green ammonia, for export and converted back into $H_2$ for use as a transport fuel. | 4 GW electrolyzers powered by onshore wind and solar<br>About 240,000 tons per year $H_2$ to create 1.2 million tons per year of green ammonia | Initial production in 2025 |
| Pacific Solar Hydrogen<br>**Location: Callide, Queensland, Australia**<br>**Investment not known** | Austrom Hydrogen, a start-up | Export to Japan and South Korea | 3.6 GW electrolyzers powered by solar<br>> 200,000 tons $H_2$ per year | Announced in June 2020 |
| HyEx<br>**Location: Antofagasta, Chile** | Engie and Enaex | Green ammonia, half of which will be used at Enaex's ammonium nitrate plant; the remainder will be targeted for fuel, green fertiliser and export markets. | 1.6 GW electrolyzers<br>Solar conversion to 124,000 tons hydrogen per year which will be converted to 700,000 tons per year of green ammonia | Announced in October 2020<br>26 MW pilot by 2024 powered by existing coal-fired power plant.<br>Scale up with 2 GW solar |
| **Geraldton**<br>**Western Australia**<br>**Investment unknown** | BP / BP Lightsource | Production of green ammonia for domestic and export markets | 1.5 GW electrolyzers<br>Onshore wind and solar for 1 million tons/year green ammonia | Feasibility study under way as of December 2020 |
| **HyDeal Espana** | Arcelor Fertiberia Enagas | Production of green steel and fertilizers | 9.5 GW PV + 7.4 GW electrolyzers | Designing and engineering phase ongoing, production in 2025 |

These GW scale projects are driven in part by government commitments to international climate change objectives as well as commercial interests in the solar and wind industries and fossil fuel companies which see green hydrogen as a foundation of their future businesses (in effect, hydrogen will replace oil and gas). These GW scale projects are effectively 'kick-starting' the global green hydrogen industry by creating demand for electrolyzers. As global electrolyzer manufacturing production increases, the cost of production will decline, and the levelized cost of green hydrogen production will decline, which will spur further development and the creation of a virtuous cycle.

These 3 centres of development highlight the issue of land availability and long-term growth opportunities and limitations. Australia and the Middle East have abundant available land for onshore solar and wind. However, the North Sea developments are not large enough to make a difference in the global equation because there is not sufficient area available due to competing uses of the maritime space. There are opportunities for ISA Member Countries with large exclusive economic zones (EEZs) to host GW-scale solar energy-to-hydrogen development. Figure 3 shows that using only 1% of the EEZs in the Asia-Pacific region for marine solar to hydrogen would be sufficient to produce about 500 million tons/year of green hydrogen worth $1 trillion/year at a target price of $2/kg. Of course, many countries in Africa and Latin America can also host a large share of ground-mounted solar plants close to some energy-intensive industrial users.

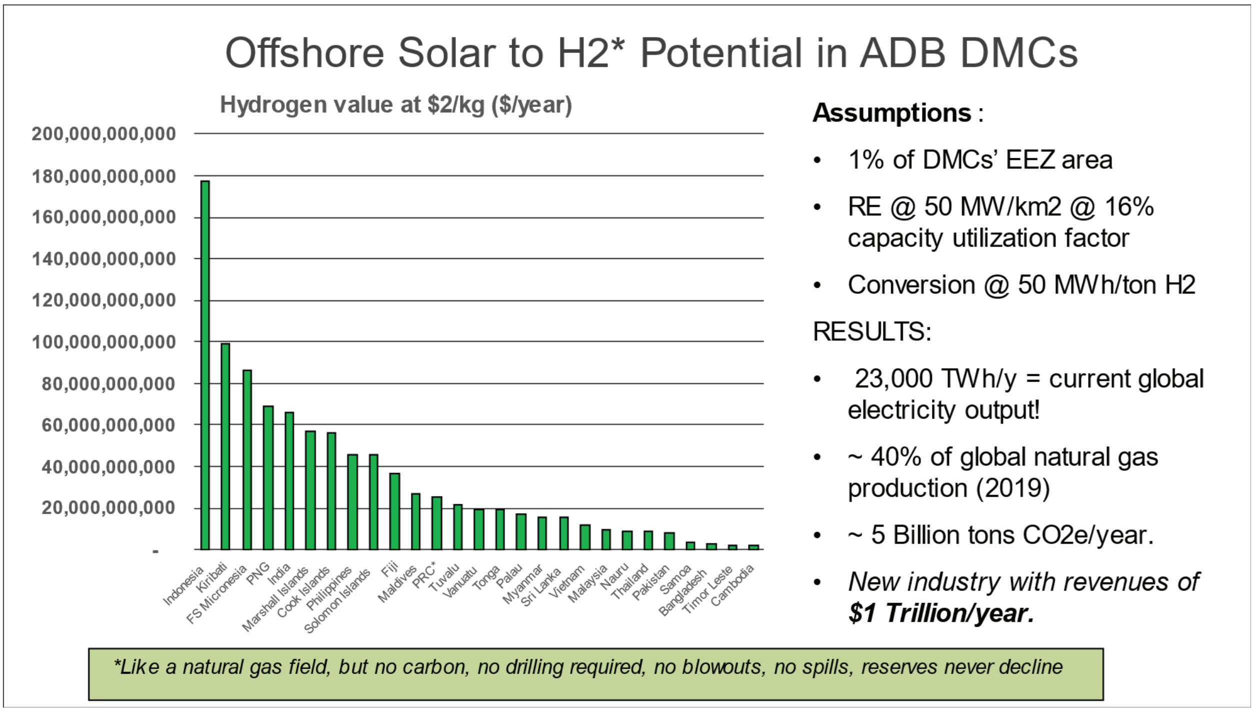
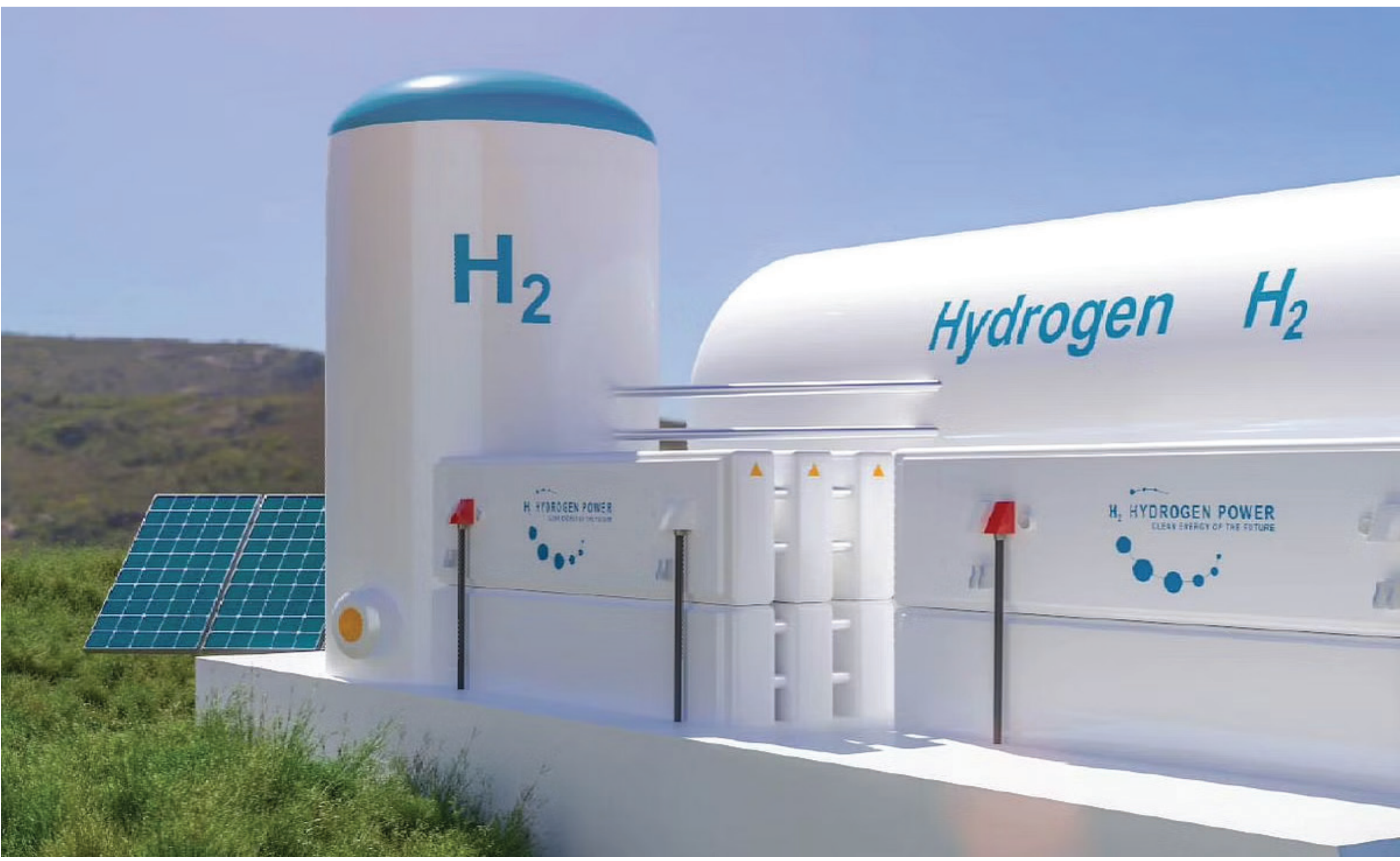



**Figure 3:** Marine Solar to Hydrogen Potential in Developing Asia and the Pacific

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# Green Hydrogen Applications

## Immediate Market Opportunities

There are 5 market segments where green hydrogen can be used immediately:

(i) Displacement of existing grey hydrogen, as discussed above.

(ii) Feedstock for other higher-value products such as ammonia, methanol, and other chemical manufacturing.

(iii) Decarbonation of some current industrial processes such as steel manufacturing (direct reduction with $H_2$), refineries, and the cement industry.

(iv) Blending in existing natural gas systems, including pipeline networks and gas-fired power plants; blending at 5-10% by volume is possible with no or minimal modification of existing gas infrastructure.

(v) Long-term energy time-shifting in grid-connected renewable energy systems, analogous to pumped hydro storage.

(vi) Back-to-Base transportation (buses/taxi fleets), heavy-duty trucking/commercial transportation.

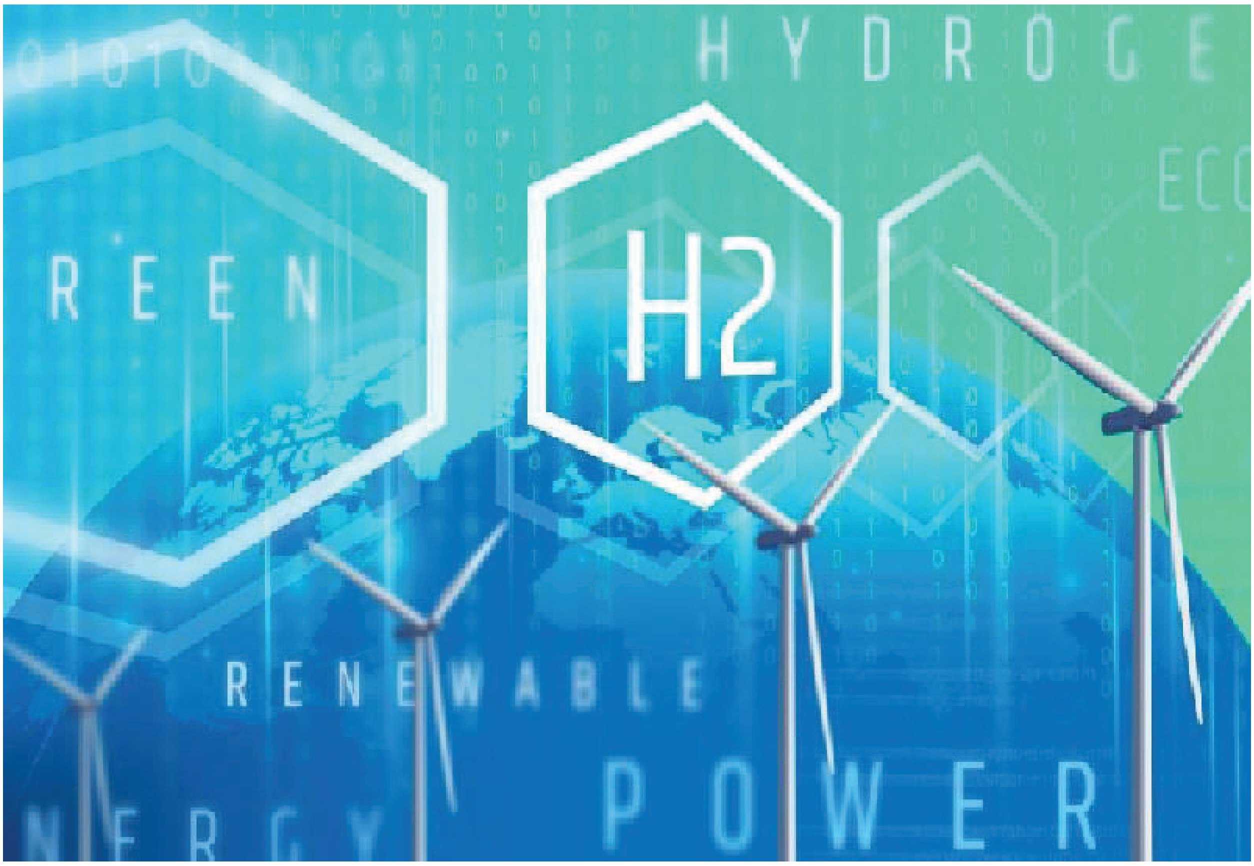
The financial viability of green hydrogen depends on several variables, including electricity input cost, electrolyzer cost, capacity utilisation factors (CUF) of renewable energy and electrolyzers, cost of financing, etc. Different electrolyzer technologies have different sensitivities to the variability of electricity inputs. Although solar CUF is a rate-limiting factor for solar-based hydrogen production pathway, solar energy remains one of the most attractive RE resources for green hydrogen on account of rapidly falling capex due to scale and, consequent lower cost of electricity. Further, wider geographical availability of solar energy resource, as compared to other resources such as geothermal (with high CUF), enables scaling up.

There may be immediate opportunities at older solar power plants which have been fully amortized and depreciated, where the effective cost of electricity production is close to zero (e.g., at some of the early solar parks in India), and CUF does not matter. This is a relatively small market niche (maybe a few GW at present), but some of these plants may be good candidates for rehabilitation and upgrade including green $H_2$ production, which could be done at a much lower capital cost than a new greenfield solar-hydrogen project. A larger potential market exists for floating solar in existing hydropower reservoirs, where the solar output might be primarily for green hydrogen production, and the hydropower output supplies the grid as per the initial project design. At older hydropower plants which have been fully amortized and depreciated, combined hydropower plus solar output could be dedicated to hydrogen production with better electrolyzer utilisation factors.

## Market Evolution in the Next 5-10 Years

Hydrogen production from solar and other renewable energy will be constrained by willingness-to-pay until sufficient scale drives the cost down to the $2/kg tipping point (or if carbon finance can be mobilised and/or carbon taxes implemented).[10] Governments can facilitate market evolution through

[10] As of Q1 2022, there is ongoing disruption and uncertainty in natural gas markets, specifically in Europe as well as in the global LNG trade. As of April 2022, green hydrogen appears to be cost-competitive with grey hydrogen in Europe due to natural gas price spikes in the European market. There is no global market price for natural gas (as is the case with crude oil prices), however, LNG prices have also increased in response to market disruption in Europe. It is not possible to predict whether a step-change in gas prices will result from an extended boycott of Russian gas.




https://www.powerengineeringint.com/hydrogen/exponential-growth-predicted-for-green-hydrogen-market/

regulatory requirements such as advanced market commitments (AMCs) wherein specific industries, e.g., steel and fertilizer production, would be required to buy green hydrogen at market prices. Regulated industries can be expected to demand price support for an interim period until price parity is achieved ($2/kg). Experience from other renewable energy programmes such as solar and biofuels can inform policymaking and roadmaps for hydrogen markets. The market scale-up for hydrogen, including green hydrogen, is expected to be achieved in a phase-wise manner with an initial focus on large-scale capacity addition to feed large anchor consumers, leveraging local grids as well as ensuring long-term offtake arrangements to provide strong/stable price signals. Following scale-induced fall in electrolyzer capex, as well as the creation of robust supply chains, decentralised production and distribution are expected to scale up. Finally, scaling up inter-continental trade of hydrogen as a well-established tradeable commodity may be expected. However, such phase-wise scale-up is strongly contingent upon the availability of local RE resources as well as demand/supply dynamics. Geographies such as Europe and Asia-Pacific (India, Japan, and China) are expected to be major consumers of green hydrogen, with some of the countries in the latter Region expected to be major producers as well (India, China, Australia, Africa).Consequently, international trade in green hydrogen and its derivatives (Ammonia, Methanol) could be expected to keep pace with domestic production for self-consumption across specific trade routes. Major international supply chains are expected to emerge, in the near-to-midterm, from Australia - Japan/ South Korea/China (eastern seaboard), Southeast Asia-East Asia/Europe, Middle East and North Africa (MENA)-East Asia/Europe, Africa-Europe, and Chile-North America/Europe/East Asia.

[11] For example, the US renewable fuel standards of 2005 and 2007 mandated the blending of bio-ethanol into gasoline. A tax incentive was provided for wholesale fuel suppliers to blend the bioethanol into gasoline for sale in retail markets. This incentive was not a direct financial subsidy, but rather a tax 'expenditure' which was about $5 billion per year in foregone tax revenue to the federal government. The incentive was linked to reaching a national blending target of 10% by volume (E10), after which it was phased out.

# Facilitating Green Hydrogen Development, Scale-up and Replication

## Business Models

India's solar parks programme has been very successful in mobilising GW-scale investment in a matter of a few years. The foundation of the solar parks programme is that government takes the lead in the project development process to take out risks to commercial/private investors. For a given location, the solar resource can be defined with high certainty in advance, so the energy resource risk is very low. There are several other development risks which need to be addressed; two of the most critical risks for green hydrogen are land acquisition and water supply. The solar parks programme has been very successful at crowding in commercial/private investment in India and other countries, and the experience can be adapted to solar hydrogen development. When properly structured, public-private partnerships can result in better outcomes than pure public or pure private endeavours.

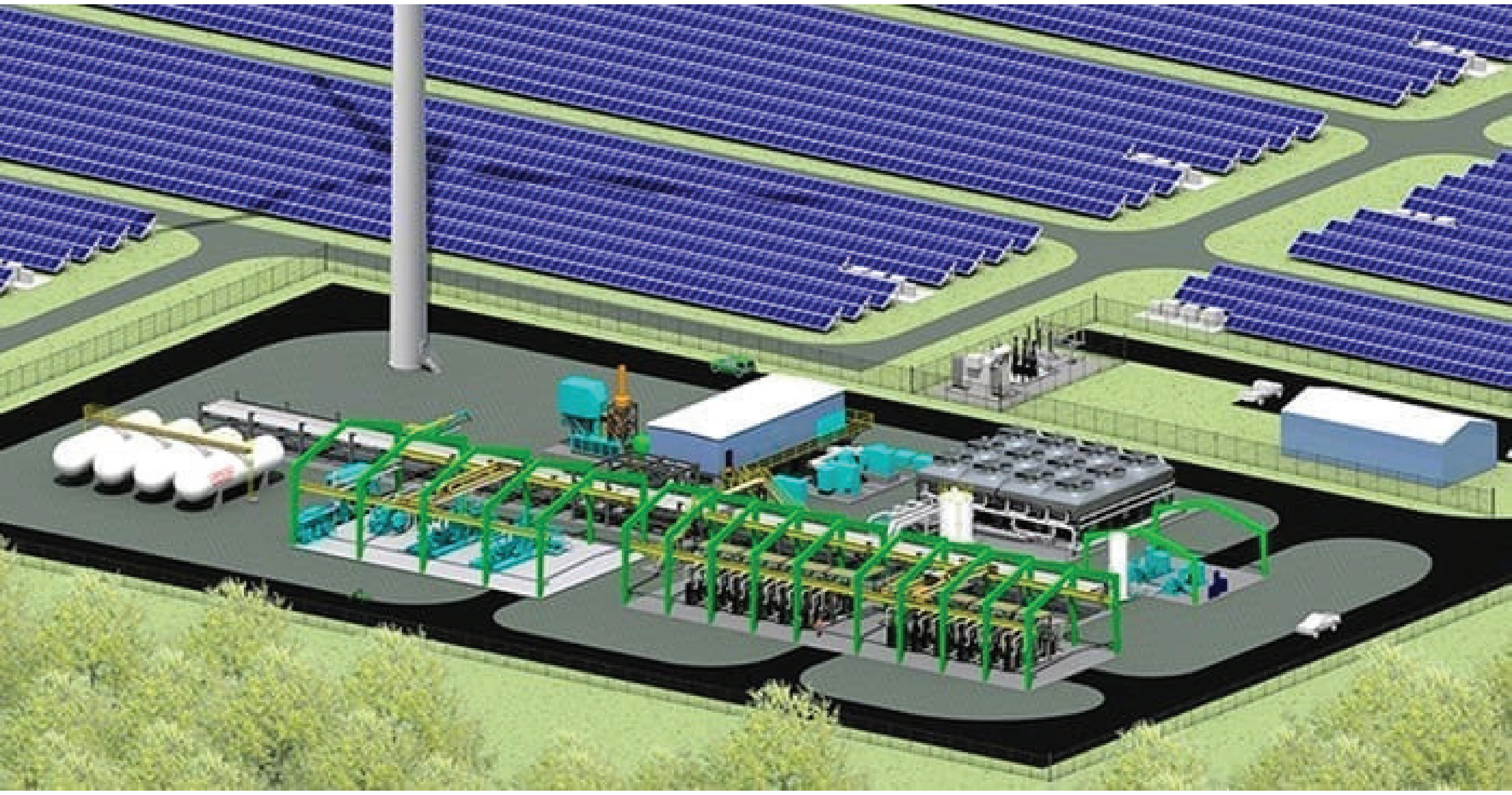
Traditional LNG export projects are anchored by long-term offtake agreements with a price formula linked to crude oil prices. This is significantly different from a traditional solar power purchase agreement which has a fixed price per kilowatt-hour. Like LNG export projects, solar-$H_2$ projects can be anchored with offtake agreements with a price formula, e.g., the initial \$/ton $H_2$ price benchmarked to a green $H_2$ cost of \$3/kg to \$5/kg with a target below \$2/kg over time. Based on the India solar parks programme's success in driving down system costs and off-take prices, the cost of hydrogen production can be expected to decline as more and more production capacity is built. The main challenges today are (i) lack of sufficient data to forecast future price movements and (ii) alignment of buyers, project developers, and investors on predetermined price formulae to enable financing.

## Creating an Enabling Ecosystem for a Global Green Hydrogen Market

A global market for green hydrogen ultimately depends on the removal of regulatory barriers vis-à-vis blending (lack of harmonisation of standards across end-use applications/geographies) for market creation; harmonisation of global standards (carbon accounting, origin, classification of hydrogen as an energy carrier, end-use equipment standards); enabling policy frameworks to incentivise investment; and internationally agreed monitoring and reporting framework for GHG accounting. A robust carbon pricing mechanism could provide a stronger foundation for global market development but does not appear to be forthcoming.

Foremost, GW and TW scale deployment of hydrogen across various end-uses and geographies, requires a concerted and collaborative global effort, considering disparate production cost-competitiveness and demand as well as electrolyzer manufacturing capacity. Further, clear national/regional level roadmaps are needed to provide clear demand certainty for potential investors in the sector. Financial support mechanisms such as guarantees, concessional finance, and grants may be needed to overcome the first-mover disadvantage for some projects where a financial viability gap is present.

Cost parity with grey hydrogen depends primarily on natural gas prices, which are set in regional markets rather than global markets, so financial viability for most of end-use applications is sensitive to gas pricing at specific project sites. In areas where hydrogen is not being used at scale, both supply-side and demand-side interventions are needed to effect cost parity. Interventions such as strong and progressive carbon taxation framework - preventing carbon leakage - coupled with sector-specific mandates/quotas/public procurement for hydrogen use are needed for market creation. Supply and demand-side 'push-pull' for market growth may be created through instruments such as Contracts for Difference with a strike price pegged against a 'benchmark' grey $H_2$ cost and Carbon Contract for Difference, respectively. Other financial instruments may be utilised to 'level the playing field' for investment projects. Applying a cost of carbon of \$50/ton of $CO_2$ adds \$80/1000 $m^3$ of natural gas, which implies cost parity at \$2.75/kg of green hydrogen. On an energy equivalent basis, 1 kg of green hydrogen displaces about 3.5 $m^3$ of natural gas. If a carbon credit transaction could be made at \$100/ton $CO_2$, the carbon revenue would add about \$0.56/kg to the price of green hydrogen.



https://www.powermag.com/wp-content/uploads/2021/04/mcdermott-newenergy_hydrogen.jpg

# Mobilising Investors, including ‘deep pocket’ Corporates

Early experience in the Europe / North Sea area indicates that GW-scale development is possible without piloting at kW and MW scales if the following conditions are present: (i) a transparent and predictable regulatory framework is in place to enable programme development and investments; (ii) governments facilitate GW-scale site availability based on prior experience in the offshore petroleum and offshore wind industries; and (iii) hydrogen customers are in proximity to the production centres (minimising the need for long-range transport of hydrogen). The North Sea hydrogen development also suggests that the traditional petroleum industry sees a pathway to corporate transformation and reinvention in the hydrogen business but only if GW-scale development opportunities are available for investment.[12]

[12] The traditional upstream petroleum exploration and production industry is a high risk / high reward business based on molecules, while the traditional renewable energy industry is a moderate risk/low reward business based on electrons. Large corporates such as BP, Shell, et al, simply have not seen the electrons business as a good bet for preserving and expanding shareholder value. The green hydrogen business is based on molecules, with reasonable risks and reasonable rewards, and scalability that will preserve and expand shareholder value. Green hydrogen should eliminate the price volatility observed in crude oil and natural gas markets, given that solar energy inputs have predictable and stable costs.

# Role of ISA

ISA has identified four key pillars of support for its membership: Analytics & Advocacy support, Capacity Building & Ecosystem Readiness support, Programmatic Support, and Risk Mitigation Instruments to support investment mobilisation. ISA's support for its membership under the 'Solar for Green Hydrogen' programme, launched at the Fourth Assembly of the ISA, is envisaged to intersect each of the above four pillars, as per the readiness level of a Member Country.

ISA's role will be to assess and facilitate the solar $H_2$ readiness level of the ISA Member Countries, which includes framing supporting policies and regulations and creating an investment environment so that the members are ready to identify investment opportunities in commercially viable solar-hydrogen systems. The Programme would focus on:

1. Consolidating global analytics in the sector, including best practices/case studies as knowledge exchange and capacity-building toolkits;
2. Facilitate country-level analytics to track current status/potential for hydrogen production, transport/trade, and end-uses across its membership, including continual tracking of the economics of Solar PV based green hydrogen vis-à-vis blue/grey hydrogen;
3. Thread together a 'Global Alliance' of stakeholders encompassing, inter alia, frontrunner member & non-member countries, peer organisations, private sector stakeholders including OEM manufacturers, and other stakeholders to develop common harmonised standards, identify and assess policy & regulatory gaps in the green hydrogen sector, and further political and business momentum in favour of green hydrogen as a mid-to-long term energy vector for net-zero emissions;
4. Support national priorities/ambitions of its Member Countries through readiness assessment and facilitate the development of national roadmaps for transitioning towards a green hydrogen economy;
5. Undertaking capacity building across ISA membership, in accordance with assessed readiness level, and providing policy/regulatory advisory support; and
6. Identify opportunities for and facilitate the setting up of pro-active strategies and market creation (demonstration projects, enabling policies/regulations/growth) across ISA membership as per respective investment readiness.

ISA's programmes on Utility-scale solar PV (including floating solar PV), Scaling Energy storage and E-mobility applications have substantial synergies with the 'Solar for Green Hydrogen.' ISA aims to leverage these synergies through joint implementation of these programmes wherever feasible.

ISA will support its membership in enhancing investment readiness in the solar hydrogen sector by identifying, assessing, and mitigating investment barriers through the identification of country/region-specific risk mitigation instruments as well as facilitating mobilisation of concessional finance in Member Countries at high readiness level.

Key planned activities of the Programme are:

1. Knowledge products, working groups and reports to accelerate capacity building among Member Countries: a series of stakeholder workshops and seminars are being scheduled, including participation at the Global Hydrogen Convention in Barcelona, Spain from 17-18 May 2022, and the Asia Clean Energy Forum 2022 in June 2022 hosted by the Asian Development Bank.
2. Capacity building: ISA will develop solar hydrogen case studies and guidelines and host them on the ISA solar hydrogen webpage. This will be a dynamic online hosted knowledge sharing exercise with information about technologies related to hydrogen production, utilisation sectors/application scenarios, standards and guidelines,

case studies, business models, partners / investors and collaboration opportunities.The objective is to support ISA Member Countries in keeping track of this developing sector and identify *go-to* partner companies/countries and investors.

3. Training workshops: Conduct training /capacity-building workshops for ISA Member Countries; selected experts will be invited to give talks on various aspects related to the $H_2$ sector.
4. ISA will develop a '$H_2$ Readiness Framework' to assess the GH2-readiness status of Member Countries through a wide range of screening parameters. This will help provide support in identifying bottlenecks, assessing pilot/prototype projects and infrastructure building opportunities, investments/policy support required for building green hydrogen capacity and R&D/innovation etc.
5. Mapping of existing hydrogen production and utilisation in ISA Member Countries, a compilation of information on announced green hydrogen projects, and preliminary identification of projects which may be candidates for financing by ADB, World Bank, and other partner MDBs of the ISA (see Appendix 1).
6. The Programme will prioritise identification of preliminary identification, development, and potential financing by ISA partners such as the Asian Development Bank, the World Bank Group,[13] and others such as the African Union. ADB's focus is on the identification of investment-ready projects in the South Asian region under ADB's regional technical assistance to ISA (see Appendix 1).

Based on the above activities, an ISA GH2 Blueprint Document will be developed for the Member Countries for the 'Production and Utilisation of Solar Hydrogen'. This will be presented in the ISA Assembly scheduled for October 2022 and COP 27 in November 2022. Subsequently, ISA will initiate Member Country-specific dialogue with the countries shortlisted through the Readiness Framework screening.

[13] The World Bank is providing support to ISA on the global risk mitigation mechanism.

# APPENDIX 1: Solar to Hydrogen Possibilities for ADB Support

The Asian Development Bank (ADB) is a multilateral development bank (MDB) established in 1966 (www.adb.org). ADB is primarily a lending organisation, the bulk of which is directed toward transport, energy, and urban development in the form of project loans with sovereign repayment guarantees. Figure A1-1 shows ADB's overall organization. In 2020, ADB committed a total of $31.6 billion in loans, grants, equity investments, guarantees, and technical assistance, of which $16.1 billion was for COVID-19 response. Of this, non-sovereign investments totaled $4.5 billion, including $2.9 billion for COVID-19 response. Investment operations in 2020 included a record high project co-financing of $16.4 billion, of which $10.8 billion was pandemic related.

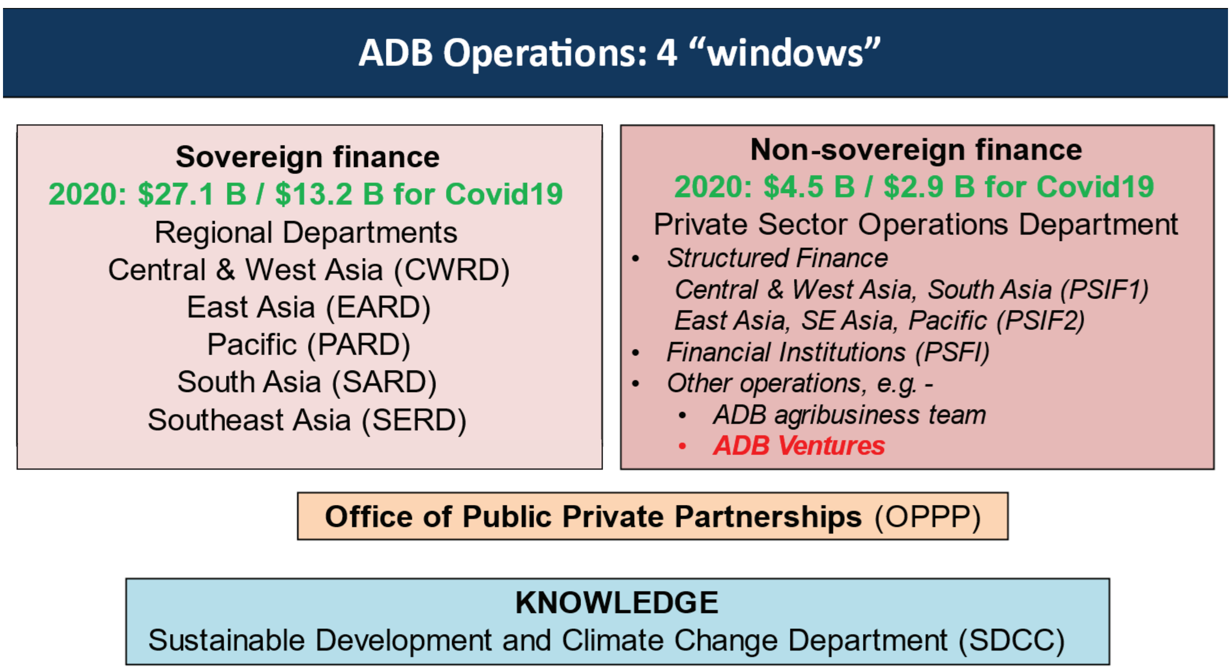



**Figure A1-1:** ADB Operations Overview

ADB has provided technical and financial assistance for solar energy development in Asia and the Pacific for well over a decade, although financing for utility-scale solar power projects commenced only in 2010. ADB has provided a variety of financing modalities and instruments including loans, grants, equity, and guarantees. The bulk of ADB investment operations are in the form of project loans, which have supported large-scale solar development across Asia and the Pacific. Blended finance has been provided selectively for 'pioneer' projects. In selected lower-income countries, ADB is provided grant financing, e.g., for floating solar development in Kiribati and Tuvalu.

ADB is supporting ISA via a regional technical assistance (TA) which covers the 6 developing

Member Countries (DMCs) in South Asia: Bangladesh, Bhutan, India, the Maldives, Nepal, and Sri Lanka. ADB has provided TA for solar energy assessments in all 6 of these countries and has provided financial support for large-scale programmes and projects in India, the Maldives, Nepal, and Sri Lanka. Financial intermediation (FI) loans are being provided for rooftop solar programmes in India and Sri Lanka. In Nepal, a special viability gap financing instrument was developed to crowd in private sector investment in on-grid utility-scale solar; this is a unique case using grant funds to jump-start the private sector solar business.

In the Maldives, ADB has supported a national programme to integrate solar energy into existing diesel mini-grids on the outer islands with blended finance. The next phase of solar expansion in the Maldives is to tender floating solar sites to independent power producers (IPPs). FENAKA, the state-owned utility serving the outer islands, will manage the tendering process and will sign power purchase agreements with IPPs. In parallel, FENAKA will procure, own, and operate energy storage, which could be batteries or a combination of batteries plus hydrogen to enable '24/7/365' renewable electricity services.

In the 6 South Asia DMCs, India is by far the largest user of hydrogen today (6.6 million tons/year) and represents the biggest initial market for green hydrogen development. India is arguably one of the best countries in the world, if not the best, for solar hydrogen given the track record of MW and GW scale solar development with almost all investment from the private sector. India's National Solar Mission, specifically the solar parks programme, provides a template for rapid deployment and scale-up of solar hydrogen production. The ongoing National Rooftop Solar Programme in India (and Sri Lanka) supported by FI loan from ADB is a replicable model for a single investment operation to support multiple individual projects. The ADB FI modality has built-in leverage in that ADB provides a 'wholesale' loan to a financial intermediary (e.g., a state-owned bank or non-bank financial institution) which then makes 'retail' loans to specific projects for the debt financing portion; the retail borrowers are expected to provide equity. Other co-financing can be channelled through the financial intermediary and/or secured by individual retail borrowers. This investment scenario is illustrated in Figure A1-2.

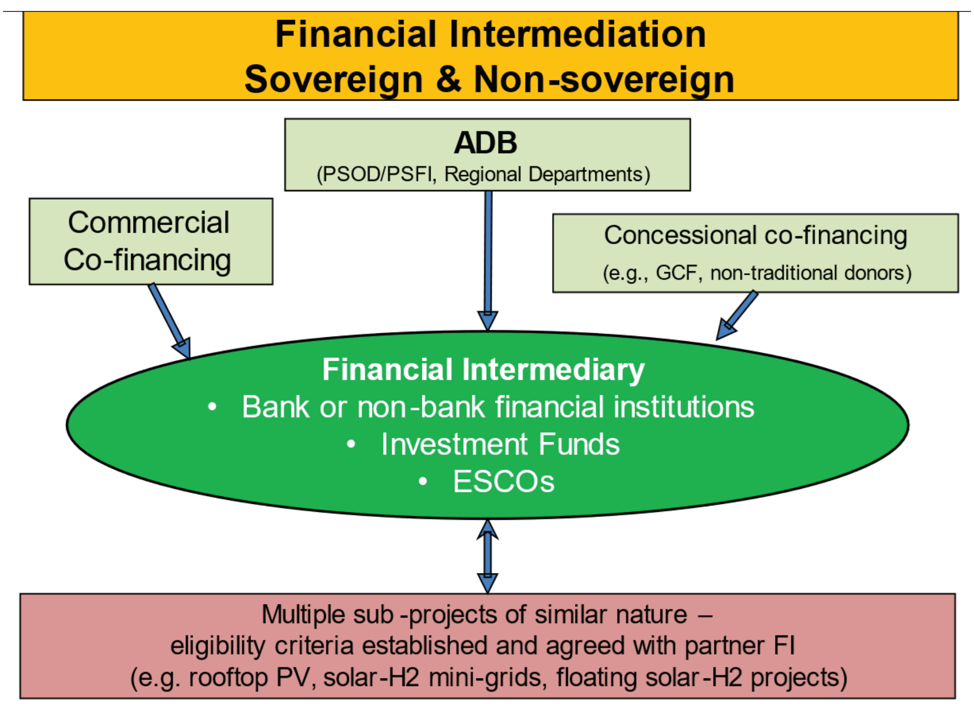



**Figure A1-2:** ADB Financial Intermediation for Gigawatt Scale Investments

An initial summary of prospective investments opportunities for ADB support is presented in the table below. ADB will work closely with ISA to further map out the prospective market development and specific projects which are amenable to ADB investment support.

**Table A1-1: Prospective Investment Opportunities in South Asia for ADB Support**

| Country | Use Cases / Possible Projects / Development Issues | | | |
|---|---|---|---|---|
| | **Grey $H_2$ Replacement** | **Green $H_2$, Ammonia, etc.** | **Blending with Natural Gas** | **RE Time-shifting / "Power to X" /Other** |
| Bangladesh | Current $H_2$ use in refining / chemical manufacturing to be identified. | Production opportunities are dependent on creating a surplus of renewable energy which does not yet exist. | Green hydrogen could be blended in existing gas pipeline network and gas fired power plants. | RE penetration (including solar) is still too low to require utility-scale investment in energy storage for long-term time-shifting. |
| Bhutan | There is no existing refining / chemical manufacturing in Bhutan using brown or grey hydrogen. | Theoretically possible to use surplus RE (hydro + solar) for green $H_2$ based chemicals for domestic use and possible export. | Theoretically possible to use surplus RE (hydro + solar) and inject into gas pipelines in northeastern India. | Need for time-shifting is not obvious given existing generation base and grid architecture.<br>Potential for modular solar-$H_2$ for heavy transport applications is to be explored. |
| India | India currently produces and uses about 6.6 million tons/year of grey hydrogen, to be replaced with green hydrogen by 2030-35<br>ADB proposed TA for National Hydrogen Energy Mission<br>https://www.adb.org/projects/55173-001/main<br>Feasibility study on Turquoise Hydrogen in the petrochemical sector study in North East of India (still at initial discussions). | Alkaline electrolyzer manufacturing: 2 plants each with 1 GW per year capacity<br>green hydrogen: Greenko, John Cockerill to set up 2 electrolyser giga factories for green hydrogen - The Economic Times (indiatimes.com)<br>Note: this appears to be close to "shovel ready"; Greenko is backed by companies which have partnered with ADB on other activities. | Need to map the prospective sites where surplus solar generation is adjacent to gas pipeline nodes or gas-fired power plants. | Upgrade and retrofit of existing solar plants to produce green $H_2$, targeting early-stage solar parks with generation assets more than 10 years old.<br>Potential for modular solar-$H_2$ for heavy transport applications is to be explored. |

| Country | Use Cases / Possible Projects / Development Issues | | | |
|---|---|---|---|---|
| | Grey $H_2$ Replacement | Green $H_2$, Ammonia, etc. | Blending with Natural Gas | RE Time-shifting / "Power to X" /Other |
| Maldives | There is no existing refining / chemical manufacturing in the Maldives using brown or grey hydrogen. | Limited industrial activity at present. Future production of $H_2$ is dependent on next-generation marine floating solar to create sufficient surplus energy for green $H_2$ production. | No natural gas infrastructure in place and none is proposed. | ADB POISED programme: pending procurement for bulk energy storage from marine floating solar (initial focus on BESS, but $H_2$ may be viable).<br>HDF Energy solar+batteries+$H_2$ for private sector resorts. Possible non-sovereign financing. |
| Nepal | Current $H_2$ use in refining / chemical manufacturing to be identified. | $H_2$ production from seasonal hydropower surplus. | No natural gas infrastructure in place and none proposed. | Potential collaboration with AEPC for solar+batteries+$H_2$ for 24/7 electricity in remote mini-grids. |
| Sri Lanka | Current $H_2$ use in refining / chemical manufacturing to be identified. | $H_2$ to ammonia for domestic fertilizer market. | Theoretically possible for displacement of or complement to imported LNG. | |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The International Solar Alliance (ISA) is an action-oriented, member-driven, collaborative platform for increased deployment of solar energy technologies as a means for bringing energy access, ensuring energy security, and driving energy transition in its member countries.

The ISA was conceived as a joint effort by India and France to mobilise efforts against climate change through the deployment of solar energy solutions. It was conceptualised on the sidelines of the 21st Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris in 2015.

The ISA strives to develop and deploy cost-effective and transformational energy solutions powered by the sun to help member countries develop low-carbon growth trajectories, with particular focus on delivering impact in countries categorized as Least Developed Countries (LDCs) and the Small Island Developing States (SIDS). Being a global platform, ISA's partnerships with multilateral development banks (MDBs), development financial institutions (DFIs), private and public sector organisations, civil society, and other international institutions is key to delivering the change it seeks to see in the world going ahead.

isa INTERNATIONAL SOLAR ALLIANCE

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