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SAARC ENERGY CENTRE

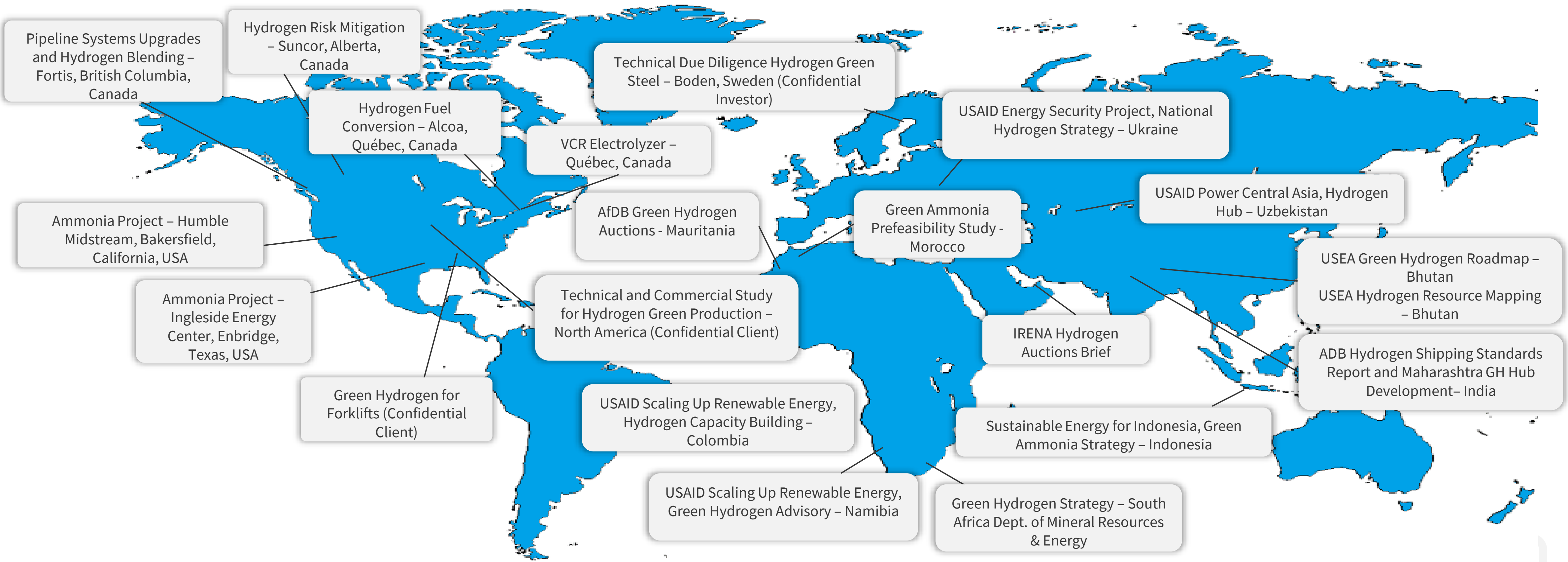
Energy for Peace & Prosperity

Hydrogen as Energy Carrier:

Key issues and learning from pilot projects in SAARC region

2nd September 2025

Tetra Tech has global experience in clean hydrogen sector



- **Clean hydrogen strategies and roadmaps**
- **Feasibility studies**
- **Policy, Regulatory and Market Reform**
- **Resource mapping and hub design**

Agenda

- Hydrogen Ecosystem in SAARC countries
- Drivers for success of green hydrogen projects
- Recent experience in hydrogen pilot projects in the region
- Case Studies
- Conclusion and Summary
- Questions and Answers

Section 1

Hydrogen Ecosystem in SAARC countries

To achieve its objective of becoming Global Hub for Green Hydrogen Production, India launched the *National Green Hydrogen Mission (NGHM)* in January 2023

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Objective :

Make India the global hub for production, usage and export of Green Hydrogen and its derivatives

Build capabilities to produce at least **5 Million Metric Ton (MMT)** of Green Hydrogen per annum by 2030

With potential to reach **10 MMT** per annum with growth of export markets

Mission's strategic interventions for :

- Demand Creation – *Making Green Hydrogen produced in India competitive for export and domestic consumption*
- Incentive Framework - *Addressing supply side constraints*
- Enabling Ecosystem - *Supporting scaling and development*

Demand Creation

Export market – *capturing global demand*

Substituting imports– *fossil fuels & fertilizers*

Domestic demand– *multiple sectors*

Incentivizing Supply

Strategic Interventions for GH2 Transition (SIGHT)
Direct Financial Incentives for:
- *Electrolyzer Manufacturing*
- *Green Hydrogen Production*

Key Enablers

Resources– *Finance, renewable energy – banking and storage, transmission, water*

Infrastructure & supply chain– *Ports, Re-fueling, Hydrogen Hubs, pipelines*

R&D– *Result oriented, timebound, including through PPP, grand challenges*

Regulation & standards– *Testing facilities, standards, regulations, safety & certification*

Ease of doing business– *Simpler procedures, taxation, SEZ, commercial issues*

Skill development, public awareness– *Coordinated Skilling programme, online portal*

Expected Outcome :

- India's Green Hydrogen production capacity at least *- 5 MMT per annum*
- RE capacity addition of *~125 GW*
- Total Investment – over *INR 8 lakh crore*
- Full time job creation – *6 lakhs*
- Expected aversion of CO_2 emission – *50 MMT per annum*

With a supportive ecosystem, many pilot projects are being rolled out by government and private companies, covering different use cases for green hydrogen

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Phase wise approach to make the green hydrogen commercially viable

Phase I (2023- 2026)	Demand creation
Expected decline in Green Hydrogen cost	• Increase indigenous electrolyzer manufacturing capacity • Pilot projects on Green steel, Heavy duty steel mobility and Shipping

Phase II (2027-2030)	GH cost competitive with fossil fuel-based alternatives
Enhanced penetration of GH2 across potential sectors to drive deep decarbonization of economy	• Explore commercial scale GH based projects in Steel, Mobility and Shipping • Pilot projects in railway, aviation, etc.

- *Aligning themselves with national mission many states - **Andhra Pradesh, Maharashtra, Rajasthan, West Bengal, Gujarat, Tamil Nadu, Kerala,** and **Uttar Pradesh** have issued their own green hydrogen policies*
- ***Madhya Pradesh** and **Odisha** have included green hydrogen in the RE policies. Haryana, Kerala, and Punjab released draft policies last 2 years,*
- ***Gujarat, Tamil Nadu, Kerala** are working on setting up of green hydrogen hub*

To reduce hydrogen production cost, GoI will provide financial incentives under the mission- *The initial outlay for the Mission will be **INR 19,744 crore**, including an outlay of*
*-**INR 17,490 crore** for the SIGHT program*
*-**INR 1,466 crore** for pilot projects,*
*-**INR 400 crore** for R&D, and*
*-**INR 388 crore** towards other Mission components*

Recently announced pilot projects in different sectors for the use of Green Hydrogen

***Shipping Sector** (budgetary outlay- INR 115 crore till FY2025-26). Pilots will focus on two areas under the pilot projects:*

- *Retrofitting of existing ships to run on Green Hydrogen or its derivatives*
- *Development of bunkering and re-fueling facilities*

***Transport Sector** (budgetary outlay -INR 496 crore till FY2025-26). Pilots will support:*

- *Development of technology for fuel cell-based propulsion / ICE based propulsion*
- *Support development of infrastructure such as hydrogen re-fueling stations.*

***Steel Sector** (budgetary outlay -INR 455 crore till FY2029-30). Pilots will support use of green hydrogen in :*

- *Direct Reduced Ironmaking process*
- *Blast Furnace*
- *Substitution of fossil fuels in a gradual manner*

From Himalayan Hydropower to Hydrogen Pilots: Bhutan's National Green Hydrogen Roadmap Driving Carbon-Neutral Prosperity

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Bhutan has significant green hydrogen potential due to its abundant hydropower resources. With 36.9 GW of hydropower potential, of which 32.6 GW is technically and economically viable, Bhutan can produce green hydrogen at competitive costs

Bhutan's Key Strength

Firm RE Power: 2.3 GW of installed capacity of hydropower

Ample Fresh-water: 70.6 bn m3 total flow from five major hydrological basins

Strategic Roadmap

- In June 2024, Bhutan outlined a **strategic roadmap** to develop **its green hydrogen** ecosystem with clear targets
- The plan includes laying the foundation with policy, technology, and infrastructure development; growth and diversification in hydrogen use across sectors; and rapid market expansion to fully realize the benefits of green hydrogen

Mobility, industry, and export are prospective channels to use Bhutan's GH2

Mobility

- The number of hydrogen-powered vehicles in Bhutan is projected to reach 2,700 by 2030 and 44,600 by 2050.
- To meet hydrogen demand, 370 MW of electrolyzer capacity will be required by 2050.
- Bhutan's first hydrogen project is envisaged to focus on the mobility sector, featuring 5 MW and 1 MW electrolyzers and on-site refueling stations.

Industry

- Bhutan's **emerging industries,** such as ferro-alloys, steel, and cement production, **will demand more and more energy**.
- The challenge of expanding industries can be **addressed by using green hydrogen.**
- By integrating green hydrogen in industry, Bhutan can **enhance energy security**, **reduce carbon emissions,** and **drive sustainable growth.**

Export

- **Cost-competitive renewable electricity** from hydropower plants provides a **competitive advantage** in producing **cost-effective green hydrogen.**
- **Niche products for export** should be studied:
  - Green steel
  - Nitrogen-based fertilizers
  - Green methanol
  - eSAF and Synthetic Fuels

Bhutan has announced its first Green Hydrogen pilot plant at Gidawom near Thimpu-Paro Highway. The plant is expected to begin with a 1 MW facility and scale up to a 5 MW electrolyser with on-site refueling infrastructure.

Nepal’s Strategic Green Hydrogen Roadmap focusses on Energy Security and Industrial Decarbonization

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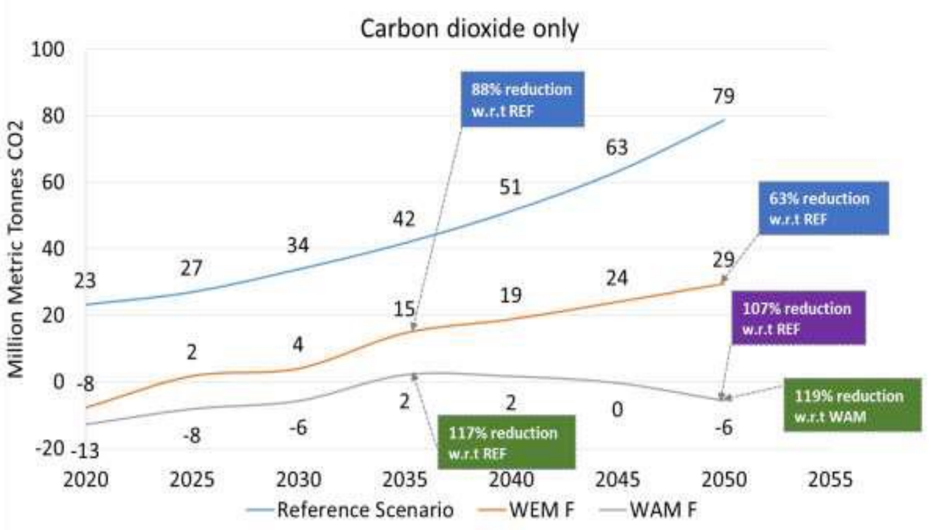
Vision of Nepal's Long-term Strategy for Net-Zero Emissions : *Nepal aspires to minimize emissions and sustainably achieve* ***net-zero by the year 2045***



Source: Ministry of Forests and Environment, Government of Nepal, “Nepal’s Longterm Strategy for Net-Zero Emissions,” (2021),

Strategic Roadmap

- In **January 2024**, Government of Nepal (MoEWRI) launched the **Green Hydrogen Policy**
- The policy promotes green hydrogen to replace petroleum and boost energy security, with a detailed framework to address costs and engage stakeholders.
- Goal - Widespread green hydrogen adoption across key sectors by 2050, significantly contributing to decarbonization and energy security

In 2019, Nepal emitted 23 million metric tons of CO_2 (mMtCO_2), projected to rise to 34 mMtCO_2 by 2030 and 79 mMtCO_2 by 2050 under a business-as-usual scenario. Two mitigation pathways are proposed:

- ***WEM (With Existing Measures):*** *Based on policies adopted by 2020, it could reduce emissions by 30 mMtCO_2 in 2030 and 50 mMtCO_2 in 2050. However, post-2030 emissions would still grow at 11% annually, making net-zero targets unattainable without further action*
- ***WAM (With Additional Measures):*** *Builds on WEM and adds feasible actions like fuel cells, biofuels,* ***green hydrogen****, and CCUS. According to Nepal’s Long-Term Strategy (LTS), WAM could achieve net-zero by 2045 and reach –5.7 mMtCO_2 by 2050*

Different phases of Nepal’s Strategic Roadmap

Phase 1: Feasibility and Demonstration Phase (2024-2027)

Focuses on establishing taskforce, conducting feasibility studies, developing regulatory framework, finalizing national strategy with targets and establishing 2-5 pilots

Phase 2: Deployment (2028-2035)

Focuses on initiating commercial scale production for key sectors, conducting R&D activities to reduce cost and assessing export feasibility to neighbouring countries

Phase 3: Expansion and Integration (2036-2050)

Focuses on scaling of hydrogen production, achieving hydrogen fuel cell vehicle target and integrating hydrogen into specific industrial processes, establishing commercial scale fertilizer production

Expected Outcome by 2050

- 25% replacement of coal, 20% replacement of diesel and 15% replacement of LPG
- 60% reduction in fertilizer imports
- Creation of 27,000-54,000 new jobs in green hydrogen-related sectors
- Sustainable economic development of energy-intensive sectors of Nepal

Solar Shores and Island Winds to Hydrogen Hubs: Sri Lanka's National Hydrogen Roadmap Advancing Decarbonization, Energy Security & Industrial Growth

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Sri Lankan sets its NDC target of achieving ***70% renewable energy generation by 2030*** , becoming **Carbon Neutral by 2050** and ***0% Coal Addition***

Precursor for Green Hydrogen

- Sri Lanka currently relies heavily on **imported hydrocarbon fuels**, posing significant **risks to electricity generation** in terms of supply security and affordability—a risk that materialized in 2022 with fuel shortages and high prices.
- The national energy policy aims to ensure universal electricity access, anticipating a shift toward **clean cooking** and **domestic technology adoption**, and must include **provisions to support this transition**
- To address energy variability, Sri Lanka is **prioritizing domestic energy development, focusing on renewable sources** and **utilizing hydrogen as a storage solution**

Abundance of Renewable Energy

As a tropical island on the equator, Sri Lanka is blessed with many renewable energy sources, which is the prime mover of green hydrogen economy

*Having only two seasons of monsoonal rains, Sri Lanka is mostly having a dry climate for the rest of the year which maximizes its window to grab full potentials of **solar power***

*Further, as an island nation**, onshore and offshore wind potentials** (~ 40 GW) are enormous*

Sri Lanka's National Hydrogen Roadmap was officially launched in May, 2024 with the targets :

4000 *Job Creation*

4 GW *of Offshore wind and associated Hydrogen production infrastructure*

USD 10 Bn *of FID for Offshore energy production and export*

USD 1 Bn *investment in domestic production and utilization*

USD 500 Mn *export revenue from green energy value chain components*

Sri Lanka's National Hydrogen Roadmap

Phase 1: Policy Regulation, Demonstration, Pilots, Off-Shore Studies (2022- 2025)

Focuses on Policy formulation, pilot projects, offshore energy studies, capacity building

Phase 2: Domestic Ramp-Up, Supply Chains, Offshore Blocks (2025-2028)

Focuses on Medium-scale market activation, supply chain development, pilot manufacture of hydrogen engines and fuel cell vehicles, hydrogen distribution network expansion.

Phase 3: Leverage Scale for Expansion in Domestic Consumption and Production Scaling Up, Green Ammonia Manufacturing, and Export of Green Hydrogen and Derivatives (2028-2035)

Scale-up offshore production capacity (2 GW to 10 GW), green ammonia manufacturing, export market capitalization.

Phase 4: Green Hydrogen Market Stabilization and Capitalization of Export Markets (2035-2048)

Large-scale offshore production (up to 30 GW), market stabilization, full commercialization, and export expansion..

Overview of developments in Pakistan, Bangladesh and Maldives

All three countries are **examining green hydrogen's role in future energy** systems and have begun integrating it into broader renewable and storage policies, but none has yet released an official, comprehensive roadmap

Pakistan

- The **Alternative & Renewable Energy Policy (2019**) introduces "power-to-X" technologies, identifying **hydrogen** as a long-term energy storage and industrial feedstock option
- Several **feasibility studies**, including **solar-to-hydrogen pilots in Sindh**, have been initiated, and a **draft Green Hydrogen Policy** is currently under **inter-ministerial review**

Bangladesh

- The **Power System Master Plan (PSMP II, 2023)** marks the first official recognition of **green hydrogen** as a large-scale energy storage solution to support the integration of extensive solar and wind power projects
- The **Sustainable and Renewable Energy Development Authority (SREDA)** has been assigned the responsibility of preparing a **national "Hydrogen Strategy"** by the end of 2025, with **initial scope documents** already **under review**

Maldives

- The **National Energy Policy and Strategy (2021)** makes a general reference to exploring "**emerging clean fuels**," but it does not **yet include a dedicated roadmap for hydrogen**
- **Ongoing technical assistance** from the **World Bank and UNDP (2024–25)** is currently evaluating the potential of **green hydrogen** for **island grid stabilization and desalination**, with the intention of releasing a **Hydrogen Action Plan in 2026**

Hydrogen policy landscape differs between countries and regions, but focus is mostly on technology and policy development and deployment

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North America

In contrast to a usually more liberal approach:

Partly substantial regulatory intervention with advantages for hydrogen technologies
– Emphasis on technology development and on deployment[2) 3)]

- Pioneering zero emission regulation on technology supply side combined with infrastructure support (ZEV)
- Setting attractive investment framework for mature H_2 applications (FC forklifts)
- Supporting national H_2 industry and individual regions following Californian regulation example

Europe[1)]

Big-bang on hydrogen strategies in 2020:

Formerly fragmented approaches replaced with overarching strategies and concrete targets
– Focus on technology leadership on green hydrogen as well as roll-out

- Setting regulatory frame for MS and supporting technology demonstration for entire value chain
- Supporting infra. and transport applications with incentives and selected regulatory measures
- Using clear deployment strategy that incentivizes H_2 ecosystems
- Incentivizing end-costumers with tax breaks and support for infra.

Asia

Stringent planning for global competitiveness:

Strict public price and performance requirements

– Policies focused on competitive FCH industry and domestic roll-out

- Implementing stringent development of technology combined with sell side regulation and locally driven deployment plans (NEV)
- Executing on central H_2 strategy with stringent technology performance requirements and infrastructure focus
- Supporting national industry with incentives and few mandatory quotas

1) Only a selection of analyzed countries for Europe 2) For selected fuel cell market segments (e.g., forklifts in USA or FCEVs in California) 3) The new "One Big Beautiful Bill Act" seeks to amend the Inflation Reduction Act (Trump tax bill risks exodus of clean hydrogen investment | Reuters)

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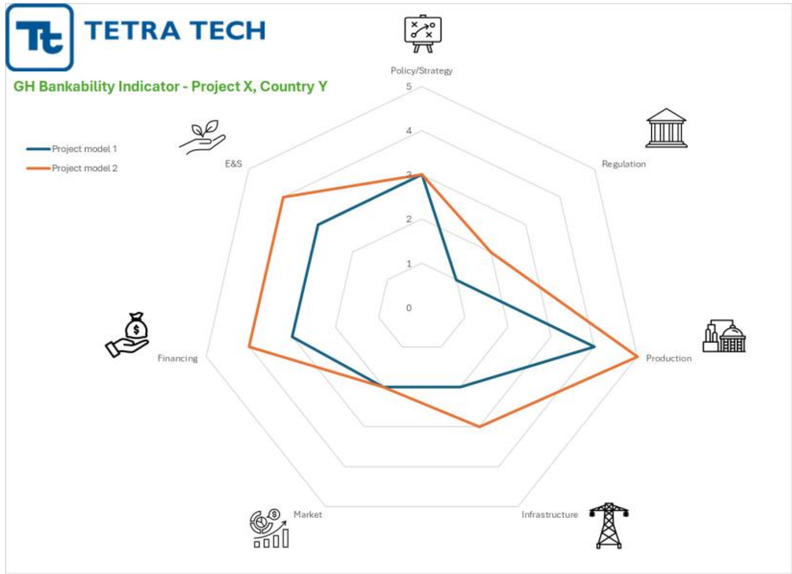
Section 2

Drivers for success of green hydrogen projects

Early green hydrogen projects face unique challenges, but global experience highlights several key drivers of bankability

Successful projects typically leverage strong policy support, secure offtake agreements, strategic location advantages, adequate infrastructure, and financial de-risking

Policy/Strategy	Regulation	Production	Infrastructure	Market	Financing	E&S
Subsidies (national)	**Certification**	**Renewable resource**	**Electricity network**	**Domestic offtaker**	**Finance/subsidy**	**Human resource**
*Subsidy agreed	*International scheme	Electrolyzer technology	*Capacity	*Industrial	*Concessional	Community support
*Tariff reduction	*Domestic scheme	LCoH	*Proximity	*Heat	*Export credit	Environmental stability
*Land concession	**Standards**	Land allocated	*Competition	*Transport	*Tax break	Environmental sensitivity
Subsidies (intl)	**Regulatory framework**		**Gas network**	*Power	*State guarantee	Science & research availability
Policies			*Capacity	**Intl exporter**	**Inflation rate**	
*Mandate			*Proximity	**Market pricing**	**Currency risk**	
*FF subsidy reduce			*Competition		**Taxes**	
*Value externalities			**Hub/clustering**			
*FF ban/phaseout			*Stakeholder support			
*Permitting suppprt			*Likely locations			
*Matchmarking/ auctions			**Water**			
*Wheeling discount			*Availability			
Political Risk			*Network capacity			
Governance			*Network proximity			
*Hydrogen strategy			*Network competition			
*Political support			**Port**			
			*Availability			
			*Port capacity			
			*Port proximity			
			Storage potential			
			Shared infrastructure			



Hydrogen policy and regulatory instruments are key imperatives – supporting both demand and supply

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		Description	Illustration	Potential beneficiaries
Technology Supply [1]	**Investment subsidy**	**One-time non repayable subsidy** directly received by the organization investing into prod. facilities	CATL investment into a battery production facility in Erfurt – Germany	All potential FCH OEMs realizing supply side investments
	Tax break	**Exclusion from tax payments** / reduction of taxes for a defined sector to incentivize private investment	Electricity tax exemptions and rebates help reducing OPEX for manufacturing businesses	All potential FCH OEMs realizing supply side inv. to increase product availability
	Special economic zone	**Areas** in which business / labor / trade laws differ from the rest of the country	Wuhan zone in China with integrated VC on H_2 fuel powered generators and H_2 FC for buses	All potential OEMs realizing supply investment – lower cost structure
	Customs tariff breaks	**Deferral of taxes** for later payment / refund on inputs imported for manufacturing goods locally	Duty Drawback on imported goods that have been exported back out of the US (e.g., chemicals)	All potential OEMs realizing supply inv. (e.g., electrolysis equipment producers)
	Guarantee	Legally binding **indemnity bond** backed by a public institution to ensure loan repayment in case of default	European Investment Bank guaranty for large-scale inv. projects to foster growth and innovation	Large scale public / private investment projects following specific political obj.
Technology Demand [2]	**CAPEX / OPEX subsidy**	**Fixed-time subsidies** to reduce initial investment requirements / increase confidence in investment	1st NIP-funded HRS (DE) obtained OPEX relief funding based on actual costs due to low use rates	All potential OEMs and infra. operators, project promoters, individual customers
	Tax breaks	**Deduction** / **tax breaks** / **tax credits** to stimulate purchase of new technologies and drive investment	Biodiesel subject to lower fuel tax when introduced in Germany	End-customers of FCH products, FCH OEMs, infra. operators, projects
	Repayable grants / loans	**Funding with expected payback** after a certain period / predetermined level of success	French Caisse des Dépôts et Consignations giving repayable advances for energy efficiency projects	Potential project promoters for FCH deployment, individual customers of the techno
	Match funding	Tool to **guide indus. activity** in a specific area of interest through **boundary conditions**	FCH JU overall budget raised by a match funding obligation (50% EU + 50% industrial players)	Hydrogen projects (indus. advances in techno / applications), individual customers
	Usual energy instruments	**Contracts for difference** / **Feed-in tariffs** / **capacity compensation** to stimulate investments	Bio-methane possibly injected into the French gas-grid based on an agreed tariff of EUR c.18 t/kWh	FCH OEMs and infrastructure operators, investors (e.g., HRS, facilities, etc.)

1) Instruments supporting the build up of H_2 and FCH technology production capacities (regular industrial policy tools with generally no specific H_2 / FCH focus)
2) Instruments supporting the deployment of H_2 and FCH technology in the market (mainly relying on public financial support)

Source: Roland Berger

Cheap Renewables: Unlocking Affordable Green Hydrogen

Electricity is 60-70% of green hydrogen production cost—each $/MWh drop in RE power directly cuts Levelized Cost of Hydrogen (LCOH)

Cheap Renewable energy can also indirectly affect the green hydrogen economy such as:

- *Low-cost power enables higher electrolyzer capacity factors (**more operating hours**) and **better asset utilization***
- *Strong long-term PPA prices (e.g. $20–30/MWh solar or wind or $50-60/MWh RTC/FDRE power) give **developers revenue** certainty and **bankable project economics***
- ***Co-location** of electrolyzer with RE plant **eliminates transmission fees and losses**, further reducing OPEX*
- *"Zero-carbon" RE ensures truly green H_2, unlocking **premium offtake markets** (e.g. refineries, steel, ammonia)*

The South Asian region—rich in solar, wind, hydro, and biomass resources—has immense potential for renewable energy and green hydrogen production. However, several structural, technical, and policy-related challenges are slowing down the pace of green hydrogen development. Some of the **regional advantage and challenges** are:

Advantages

- ***Robust hydropower base:** Significant untapped potential in mountainous and riverine regions*
- ***High solar potential:** 4–7 kWh/m²/day and 2,000+ sunlit hours annually.*
- ***Strong wind corridors:** Onshore in Punjab, coastal India and Sri Lanka's hills; offshore potential emerging*
- ***Extensive low-value land:** Ideal for utility-scale solar and wind farms*
- ***Proximity to supply chains**: China and India help keep capex low*
- ***Government targets:** 40–70% renewables by 2030 driving PPAs and incentives*

Challenges

- ***Grid instability** and limited backup increase curtailment risk and reduce renewable output.*
- ***Seasonal variability** from monsoons and cyclones causes major fluctuations in solar and wind generation.*
- ***Dense populations** lead to land-use conflicts and restrict large project sites near demand centers.*
- ***Water scarcity** hampers freshwater electrolysis and cooling for hydrogen systems.*
- ***Limited domestic capacity** for electrolyzer manufacturing and hydrogen infrastructure creates reliance on imports.*

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Section 3

Recent experience in hydrogen pilot projects in the region

All the countries in the region are progressing with pilot initiatives

Nepal

- **Kathmandu University** completed a feasibility study on using **small-scale PEM electrolysers** for hydrogen refueling in **high-altitude trekking areas**, focusing on technical and logistical needs
- On **28 August 2025**, Nepal's **Investment Board** signed an MoU with **G-Philos Co. Ltd (South Korea)** to study and develop **a 20 MW green hydrogen and fuel cell plant**

Pakistan

- **Sindh University / UNIDO (300 kW):** Solar-powered alkaline electrolyser; civil works ongoing, commissioning by Q4 2025
- **PPL Sui Field Study (1 MW):** Trial to utilize curtailed gas-turbine power; feasibility done, FEED due Nov 2025
- **National Hydrogen Roadmap:** Identifies pilot zones in Sindh, Balochistan, and Punjab; no active projects announced yet

Maldives

- **Thilafushi Micro-Grid Pilot**: A 200 kW PEM electrolyzer is being assessed to co-fire diesel gensets with 10% hydrogen; final report due Sep 2025, pilot launch in 2026
- **H_2-Powered Harbor Launch**: A concept-stage project to replace a 50 kW diesel boat in Malé harbor with a PEM fuel cell; currently in design with timeline TBD

Bhutan

- A **resource mapping study was performed on 4 sites identified by DHI**: Jigmeling in Sarpang dzongkhag, Lhamoizingkha in Dagana dzongkhag, Samrang in Samdrup Jongkhar dzongkhag, and Dhamdum in Samtse dzongkhag.
- A preliminary feasibility study has been done for a **20MW GH plant in the Thimphu Dzongkhaga** and a scoping study has been commissioned for **green-H_2 export via ammonia**

Bangladesh

- **BUET Solar-H_2 Demo:** BUET installed a solar-powered hydrogen system for campus backup, now under performance review
- **Petrobangla–DU–NREL Study:** Partners assessed 5% H_2 blending in city gas; 100 kW trial planned for Q1 2026
- **BRTC Fuel-Cell Bus Feasibility:** For a 10-bus H_2 fleet; RFP in Q4 2025, first bus by Q2 2026
- **BPC Green Ammonia Study:** BPC completed concept for 100 MW green ammonia plant; FEED expected late 2025
- **Chittagong Port Fuel-Cell Pilot:** Pilot retrofit of harbor launch with 50 kW fuel cell to test emission and noise cuts. Under design stage.

Sri Lanka

- **Hambantota Port Green Ammonia Demo:** 50 kW solar-powered PEM electrolyser producing green ammonia for coastal vessel bunkering; installed May 2025 with trials ongoing through 2026.
- **Colombo Hydrogen Bus Pilot (Proposed):** 2 fuel-cell buses under negotiation with SLTB & CEB; tender expected Q3 2025, operations targeted for Q2 2026.

India has embarked on several pilot as well as commercial scale projects – few are discussed below

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Indian Railways "Lok-H_2" Demo (Leh–Kargil): 1 MW PEM electrolyser powering an H_2-fuel-cell shunting locomotive; factory tests done, on-site trials Sep 2025

NTPC Limited has launched India's first commercial hydrogen fuel cell bus service in Leh, Ladakh, deploying five buses and establishing the world's highest green hydrogen fueling station, powered by a 1.7 MW solar plant, as part of its Green Hydrogen Mobility Project

IOCL Panipat: 5 TPD PEM electrolyser for refinery H_2 make-up; mechanical completion Aug 2025, commissioning under way

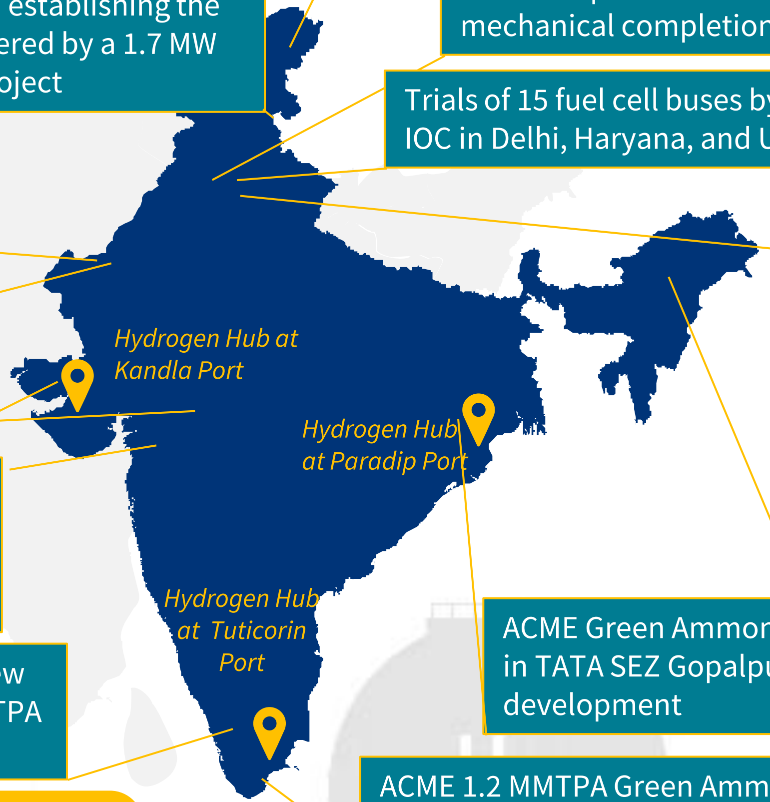
Trials of 15 fuel cell buses by IOC in Delhi, Haryana, and UP

ACME-NTPC Rajasthan: 100 MW PEM electrolyser co-located with solar PV; EPC awarded Apr 2025, first 25 MW tranche online Dec 2025

NTPC Dadri has a Pilot AEM Hydrogen Generation Plant, which was commissioned in November 2023

ReNew Power Bikaner: 10 MW demo electrolyser producing green NH_3 for local fertilizer blenders; commercial-scale RFP Q4 2025

2% of hydrogen is being blended in CNG network and 5% into PNG network at city gas station of GAIL at Indore, MP



OIL developed India's first Green Hydrogen pilot plant, with an installed capacity of 10 kg per day at its Jorhat Pump Station in April 2022. 100 kW expansion for ~5 vol% NG blending & fuel-cell back due in Q1 2026

NTPC initiated blending of green hydrogen up to 8% (vol/vol) in PNG Network at Surat, Gujarat from January 2023

Adani Green Hydrogen (Mundra, Kutch): Phase-1 50 MW electrolyser (500 MW expansion planned); feasibility & land/interconnection secured

ACME Green Ammonia Project, 1.2 MMTPA in TATA SEZ Gopalpur, Odisha under development

Near Vizhinjam Port, Renew Power has planned 220 KTPA green hydrogen project

ACME 1.2 MMTPA Green Ammonia Project, at VOC Port, Tamil Nadu under development

*While **Indian PSUs** - NTPC, IOCL, BPCL, etc. are actively pursuing hydrogen projects, the **private sector**—including corporates like Reliance, Adani, ReNew etc, and startups like Hygenco, Avaada, ACME, etc—is also driving the hydrogen economy through both partnerships with PSUs and independent efforts.*

The Petroleum and Natural Gas Regulatory Board (PNGRB) is prioritizing the use of national gas transmission pipelines of 33000 km for blending of green hydrogen with natural gas

Several major oil and gas companies, such as IOCL, BPCL have issued their own green hydrogen procurement tenders

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इंडियनऑयल
IndianOil

Indian Oil corporation Limited, IOCL **Panipat refinery** expands from a capacity of 15 to 25 MMTPA, its additional hydrogen requirement of 84,000 MTPA will be partially fulfilled by this 10,000 MTPA green hydrogen plant

In September 2024, IOCL floated a tender - ***Green Hydrogen Generation Unit (GHGU) Of 10 kTPA Capacity On B00 Basis at Indian Oil Corporation Ltd Panipat Refinery Petrochmical Complex Panipat Haryana India***.

Key features of the tender and the outcome declared in May 2025:

10 kTPA per year

For **25 Years**

selection on lowest quoted price for per kg of hydrogen through **Reverse e-Auction**

6+ bids were submitted

₹397 ($4.67) per kg with 18% GSTPrice discovered

27% lower than the global average cost of producing green hydrogen

Bidders' detail and quoted price

- ***L&T Energy Green Tech*** *will supply green hydrogen to IOCL at* ***₹397 ($4.67) per kg with 18% GST***
- ***NTPC's*** *bid value was* ***₹398*** *per kg ($4.68) with GST and* ***Renew E Fuels'*** *bid value* ***was at ₹407*** *per kg ($4.79) with GST.*

हिन्दुस्तान पेट्रोलियम
HP

Hindustan Petroleum Corporation Limited, HPCL operates a 15 million tonnes per annum **refinery at Visakhapatnam**. Various units in the refinery consume grey hydrogen. The company intends to partly replace grey hydrogen with green hydrogen

In October 2024, HPCL invited bids to supply **5 kTPA green hydrogen for 25 years at its Visakh Refinery on a BOO basis**. The winning bidder must **build the hydrogen unit, conduct pipeline surveys, secure rights of way, and ensure seamless integration with HPCL's distribution network**.

Key features of the tender and the outcome declared in July 2025:

5 kTPA per year

For **25 Years**

selection on lowest quoted price for per kg of hydrogen through **Reverse e-Auction**

8 bids were submitted

₹328 ($3.82) per kg excluding GST price discovered

even **lower** than the price discovered in IOCL green hydrogen tender

Bidders' detail and quoted price

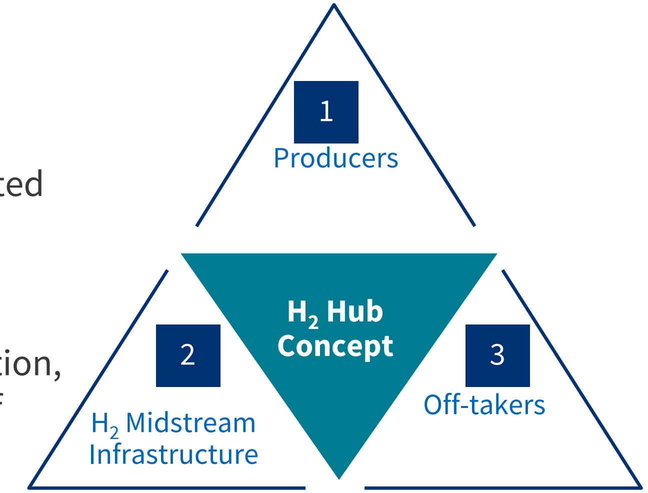
- ***Ocior Energy*** *will produce green hydrogen at* ***₹328/kg ($3.82/kg)***, ***excluding GST***
- ***Jakson Green***, *which quoted a price of* ***₹345 per kg*** *, and* ***L&T***, *which quoted a price of* ***₹393*** *a kg, were the second lowest and third lowest bidders, respectively.* ***ReNew*** *and* ***NTPC*** *quoted a price of* ***₹469*** *a kg and* ***₹505*** *a kg, respectively*

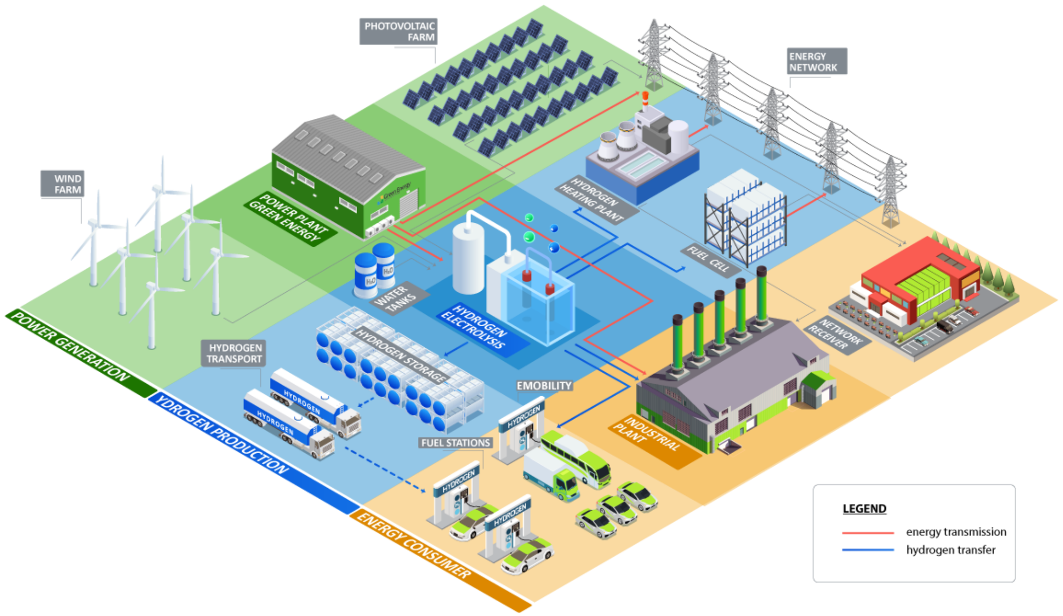
Section 4

Case Studies

Case Study 1: Andhra Pradesh, India

Hydrogen hub: Strategically centralized, integrated industrial complex designed for the production, storage, transportation, and consumption of hydrogen





India's Pudimadaka Green Hydrogen Hub

Hub Specifications

Key Features and Objective

Project Foundation	*PM Modi laid foundation stone on January 8, 2025, in Visakhapatnam, IND*
Investment and Project Scale	*USD 22 Billion (INR 1.85 lakh crore) investment in Green Hydrogen Hub to have 20 GW renewable energy capacity. Phase1 construction will be over by Mar 2028*
Hydrogen Production	*Produce 1,500 TPD of green hydrogen and 7,500 TPD of derivatives (e.g., green methanol, urea, SAF) for export market*
Location	*Pudimadaka, Anakapalle district, near Visakhapatnam, Andhra Pradesh, IND*
Collaboration	*Joint project between NTPC Green Energy Limited (NGEL) and New & Renewable Energy Development Corporation of Andhra Pradesh (NREDCAP)*
Significance	*Part of India's National Green Hydrogen Mission*
Environmental and Economic Impact	*Creation of thousands of jobs, reduction in carbon emissions, and promotion of sustainable energy solutions*
Strategic Importance	*Utilizes renewable energy sources like solar and wind*

Case Study 2: Hydrogen hub for decarbonizing hard-to-abate industries (UZ)

Context and Opportunity

- ***Strategic location*** *in Central Asia with existing gas infrastructure*
- ***Abundant solar*** *(6 kWh/m²/day) and wind resources*
- ***National roadmap*** *to diversify energy mix & reduce CO_2 emissions*

Project Overview

- *Green hydrogen electrolyzer capacity:* ***500 MW (Phase 1)*** *→ 2 GW (Phase 2)*
- *Annual H_2 output: ~**100,000 t (Phase 1)***
- *Offtake:* ***Domestic industry*** *decarbonization +* ***export*** *(Europe & Asia) via pipeline & ammonia*

Key Stakeholders

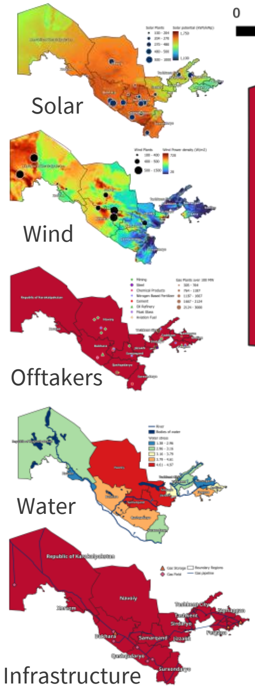
- *Government of Uzbekistan (**Ministry of Energy**)*
- *International investors & EPC contractors (e.g., **ACWA Power, Siemens Energy**)*
- *Development banks (**ADB, EBRD**) & climate financiers (**Green Climate Fund**)*
- *Technical partners (**IRENA, national research institutes**)*

Economic & Environmental Impact

- *Capital expenditure: ~**USD 1.2 billion (Phase 1)***
- *Job creation:* ***2,000 direct*** *& 5,000 indirect roles*
- *Avoided CO_2: ~**400,000 t/year***
- *Strengthened* ***energy security*** *& diversification of* ***export revenues***

Challenges & Mitigation

- *Grid integration & renewable intermittency →* ***Battery storage + demand-side management***
- *Water availability for electrolysis →* ***Brackish groundwater treatment & desalination coupling***
- *Regulatory framework →* ***Establish H_2 safety standards & offtake guarantees***
- *Financing risk →* ***Blend concessional loans & guarantees; phased development***



Key sites assessed for suitable hub location

Current Status and Next Steps

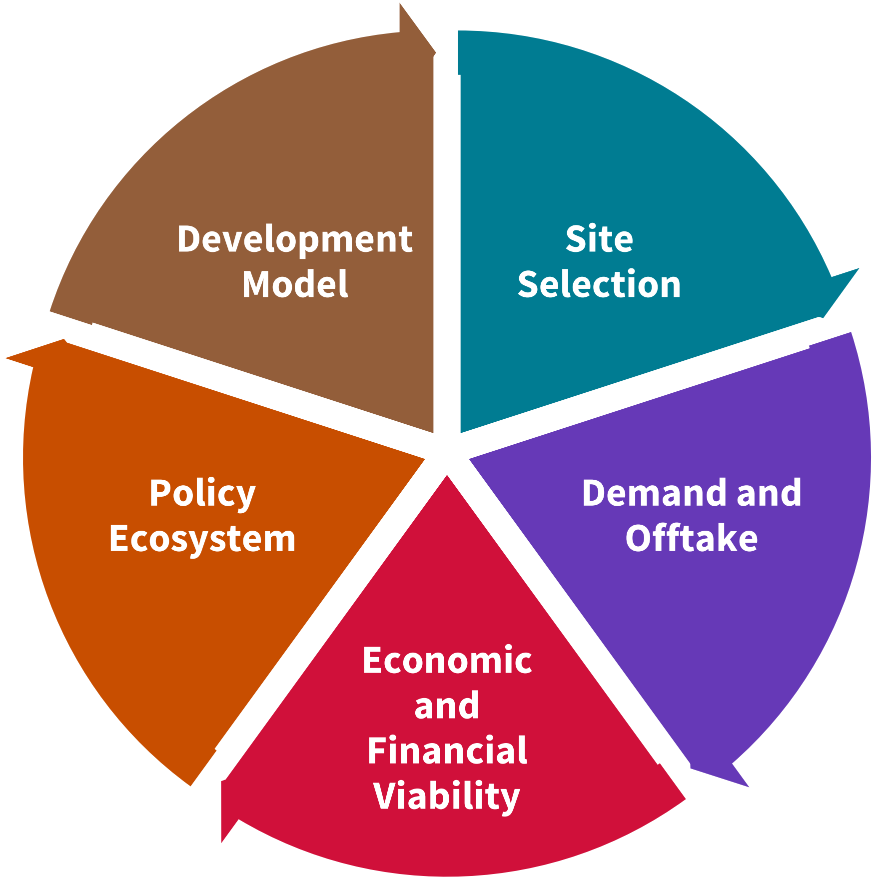
- ***Phase-1 green hydrogen facility (500 MW) at Navoi*** *is being developed as a public-private partnership*
- ***Phase 2*** *is scoped as an expansion of the same Navoi-Region facility (on the industrial land immediately west of Navoi City). Instead of commissioning a second, green-field site, the plan is* ***to add roughly 1.5 GW*** *more electrolysis capacity on-site—taking* ***total capacity to 2 GW*** *by 2030*

TETRA TECH

Section 5

Conclusion and Summary

Summary - key considerations for developing green hydrogen projects



Site Selection

Assessment of suitable sites considering constraints and advantages of several locations based on geospatial layering – RE potential, land & water availability, infrastructure & connectivity, proximity to demand centers, and EHSS factors.

Demand and Offtake

Estimate GH2 demand across key anchor industrial sectors in Maharashtra drawing on publicly available data and sector-specific benchmarks. To inform infrastructure planning, decarbonization strategies, and engagement with industrial off-takers.

Economic and Financial Viability

Assessment of cost components (capex and opex), incentives and revenue streams, under different scenarios, to assess key financial metrics. Different options for financing structure and risk mitigation to enhance viability.

Policy Ecosystem

Aligning existing state green hydrogen policy and other incentive framework with national and international benchmarks to ensure bankability of early-stage green hydrogen projects – recommendations and roadmap.

Development Model

Exploring PPP model for development, captive renewable vs third party open access, government incentives and subsidies, viability gap funding, sources of debt and equity – outcome of all preceding assessment.

Questions ?

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