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Renewable Hydrogen deployment in Pakistan

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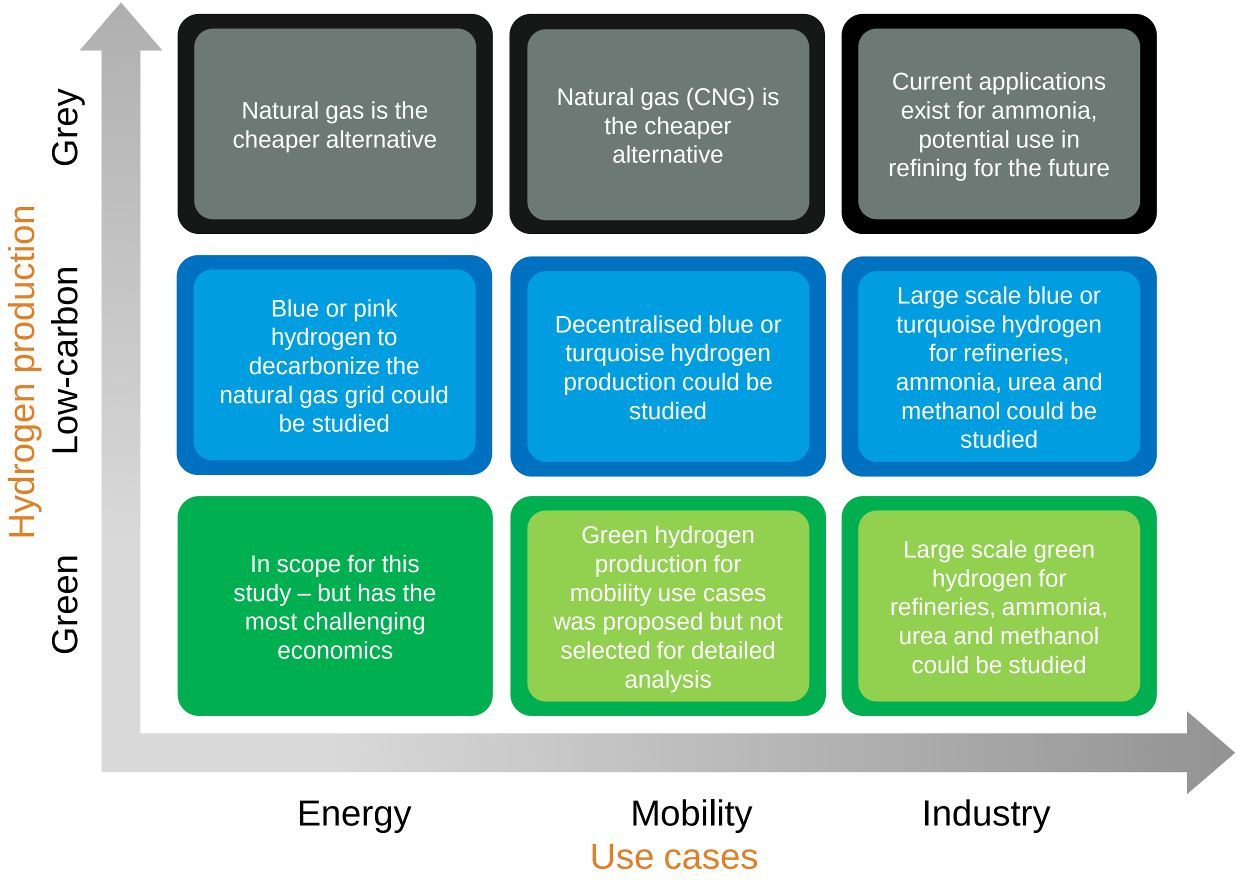
Pakistan renewable hydrogen – scope was highly focused. Future studies can cover fresh ground.



The executed study was based on the terms of reference and was then further focused through subsequent discussions with stakeholders

- Green hydrogen production (not blue, turquoise, pink, purple, grey, black)
- Energy sector applications such as heating, cooking, power generation, energy storage and mobility (not industrial hydrogen applications for ammonia, methanol, refining or steel making)

13 hydrogen value chains were proposed, three were prioritised and analysed in detail

The 13 proposed projects were screened against top 3 priorities and additional desirable benefits for renewable hydrogen deployment in Pakistan as identified during project inception discussions

Top three priorities

- **National energy independence**
- **Continuous energy supply security**
- **Affordable energy**

Additional desirable benefits

- **Carbon neutrality**
- **Pollution-free energy**
- **Export revenue potential**
- **Leverage existing energy infrastructure**

These priorities and additional benefits were determined through discussions between the project team, NEECA and ADB during the inception phase of this study as relevant directional pointers for this renewable hydrogen deployment pre-feasibility study

Green hydrogen is produced from renewable power and water by electrolysis

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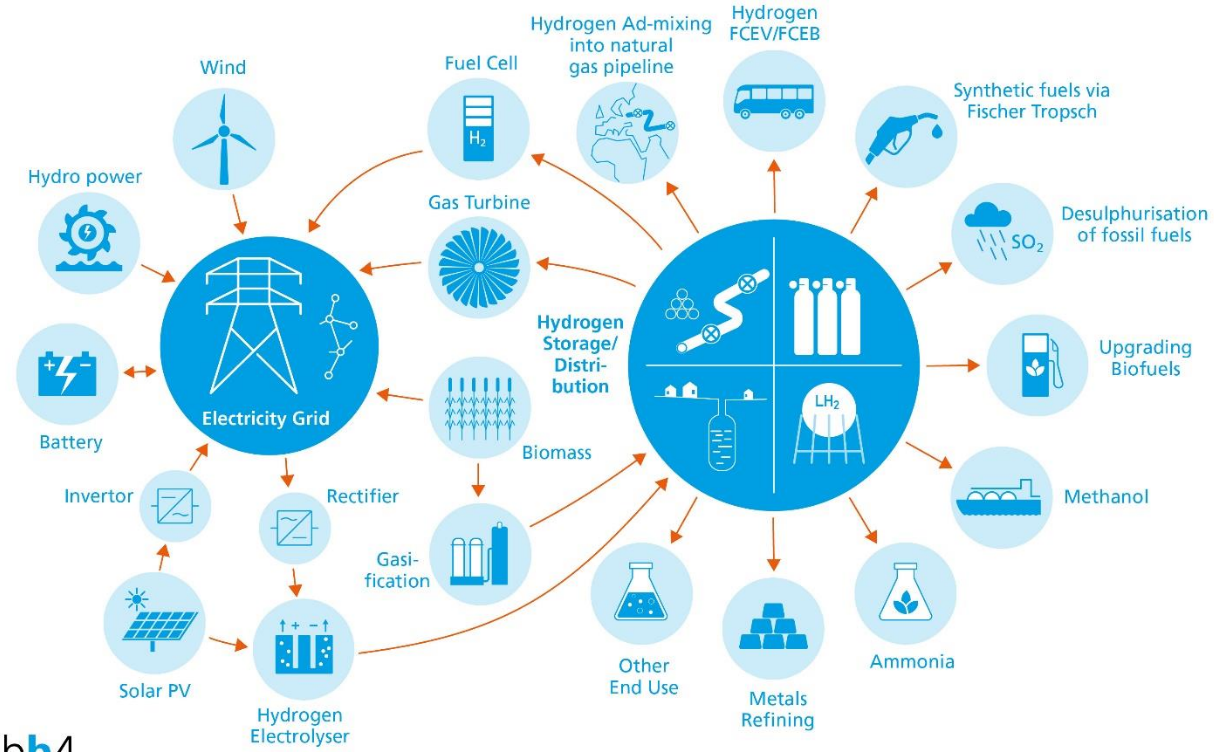
Fuel Type in Pakistan	Power cost US$ / KWh
High Speed Diesel	0.200
Residual Fuel Oil	0.130
Coal	0.080
Gas	0.055
Solar	0.140
Wind	0.130
Hydro	0.063
Nuclear	0.050

Hydro electricity is the lowest cost renewable power source in Pakistan. Two of the three value chains for detailed analysis focused here, a third considered solar power.



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National long-term potential impact of the three hydrogen value chains chosen for detailed analysis

(priority for study and benefits shown were as perceived prior to the detailed analysis)

Project & Priority	Business model / value chain	Potential initial project location	Potential locations to replicate the scheme	Fit with top 3 energy priorities	Additional benefits	Total potential impact estimate (MW H2 production)
Project #3 First	Use hydro power to produce hydrogen for gas grid admixing at between 2% to 6%	Ghazi Barotha run-of-the river hydro dam near Peshawar,	Multiple large dam and run-of-the river schemes, generally in the north and centre of Pakistan	Reduced LNG imports, reduced imported crude imports	Decarbonisation of energy, leverage gas pipeline grid, increase heating gas supply to the far north west, furthest from the LNG terminals and where winters are cold	2,500MW because circa 10GW of hydro generation exists (total national potential estimated at 50GW) - of the current 10GW, circa 2.5GW could be converted to H2. As more dams are built, this will increase.
Project #13 Second	Micro-hydro power for micro-grids in northern Pakistan	Naltar valley, Gilgit Baltisan	Many remote mountain villages (eg, Budalas, Singul or Chalat) in north east and north west Pakistan close to rivers	Security of power supply through the year, reduces imported LPG demand (current alternative)	Carbon-neutral, pollution free energy in the north, reduces the risk of deforestation as villagers seek fuel supplies for cooking and heating	Circa 200MW hydrogen, or 1000GW power if we assume 1,000 villages each with a 0.2 MW electrolyser (or 200 villages with a 1MW electrolyser).
Project #6 Third	H2 from solar power at Quaid e Azam for stable H2 production, then hydrogen for power generation on CCGT	Quaid e Azam solar park, Bahawalpurand Kot Addu power station (GE 9E turbines), Punjab	Quaid e Azam is the only major solar scheme in Pakistan at present, but the scheme canbe replicated in the future when additional solar parks are built	Reduces imported LNG & reduces imported crude demand, power supply security (peak shaving)	Peak time power generation to “shave” the evening peak using solar power from the daytime	300MW because circa 600MW of solar power is in place with a total of 1GW in plan, circa 300MW could be converted to H2. As more solar parks are built, this will increase.

Run-of-the-river micro-hydro power can be used to produce hydrogen on small PEM electrolysers for cooking, energy storage and power generation

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A 1MW electrolyser fed with power from a new micro-hydro scheme was modelled

- For 10 'wet' months of each year, power from the hydro scheme can be used for domestic applications and hydrogen generation on a 1MW PEM electrolyser
- Compressed gas hydrogen storage

Hydrogen for essential domestic applications

- Substitution of LPG or forest wood for cooking
- Release stored hydrogen to a fuel cell for electricity generation during two frozen winter months, when the hydro scheme is winterised and not operational

Several scenarios have good business cases

- Fuel substitution cost savings over the project lifetime
- Many other social and environmental benefits, eg avoidance of deforestation and access to domestic electricity would arise in addition to the financial savings

Mountain river in northern Pakistan. Water may freeze in winter meaning zero hydro power. Seasonal energy storage in these locations will need smal scale, localized solutions.

A large-scale AEC electrolyzer fed with solar power for hydrogen generation and gas grid injection to substitute LNG imports

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A 100MW electrolyser fed with solar power from the Quaid-e-Azam solar park was modelled with three different power generation scenarios:

1) Power from the existing solar park
2) Power uplift with investment in CQSola equipment
3) New solar power capacity investment

Hydrogen injection to the gas grid close to the solar park was the use-case studied. Costs were compared to three alternative energy vectors:

1) Substitution of locally produced natural gas
2) Substitution of low-cost Kuwait contracted LNG
3) Substitution of high cost spot purchase LNG

Several scenarios from the above mix have good business cases

- Long term hydrogen storage (eg in underground salt caverns) could potentially further enhance the business cases to avoid high-cost LNG spot purchases and could be the subject of a future study

Solar panels in a mountainous region of Pakistan

A large-scale AEC electrolyzer fed with hydro-electric power for hydrogen generation and gas grid injection to substitute LNG imports

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A 100MW electrolyser fed with hydro power from the Ghazi-Barotha dam was modelled modelled with two different power generation scenarios:

1) Power from the existing hydro scheme
2) New hydro power generation investment with a new canal, dam and power house

Hydrogen injection to the gas grid close to the dam was the use-case studied

1) Substitution of locally produced natural gas
2) Substitution of low-cost Kuwait contracted LNG
3) Substitution of high-cost spot purchase LNG

Only the high-cost LNG case was positive

- Use of seasonal excess power from the Ghazi-Barotha, Tarbela and / or Mangla dams, combined with underground hydrogen storage in salt caverns could potentially present a feasible business case and could be the subject of a future study

The Tarbela dam in Pakistan

Like wind and solar, hydro is also “variable renewable energy” – in slow motion!

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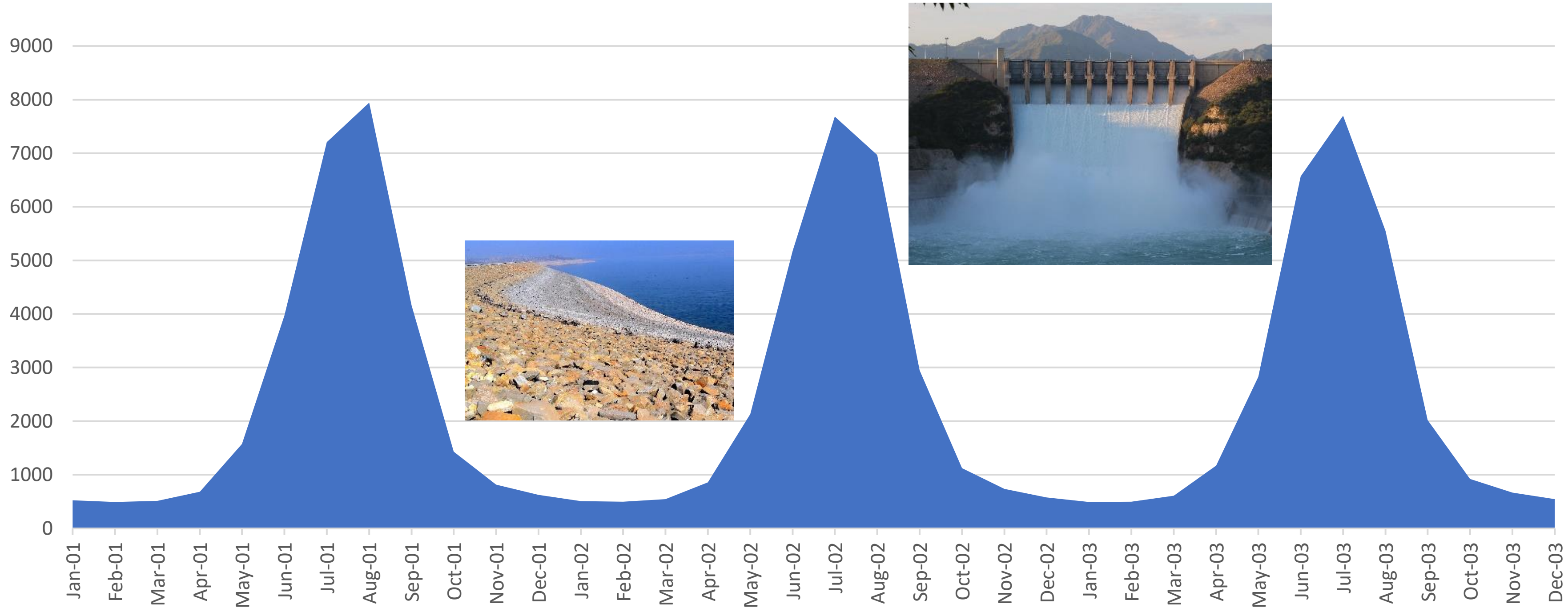

From World Bank Report No 60963-PK

Time cycles for solar and wind are day / night or week to week. Hydro power has seasonal cyclicality.

Underground hydrogen storage (UHS) can bridge seasonal imbalances in supply and demand

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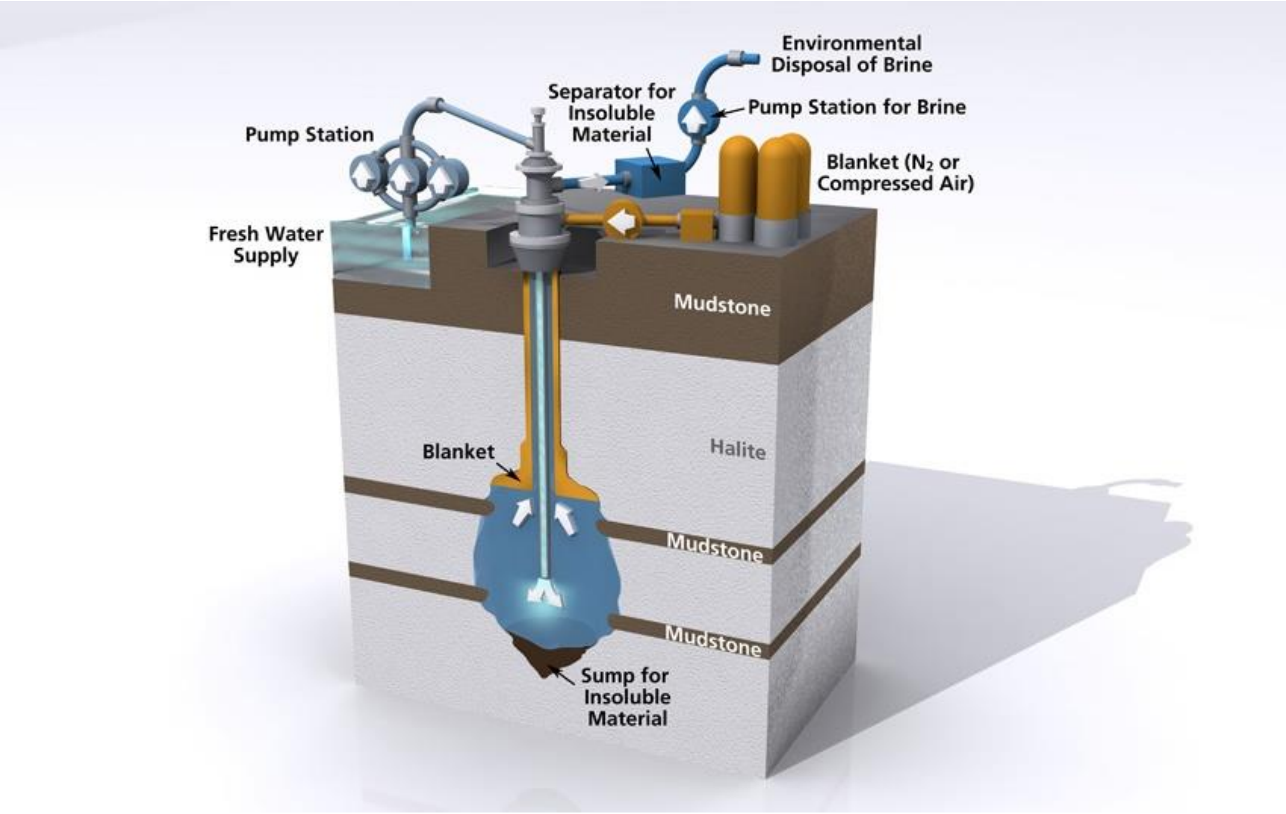


The “perfect storm” for UHS…

The mega-dams and the Potwar salt plateau are close to each other in the north of Pakistan

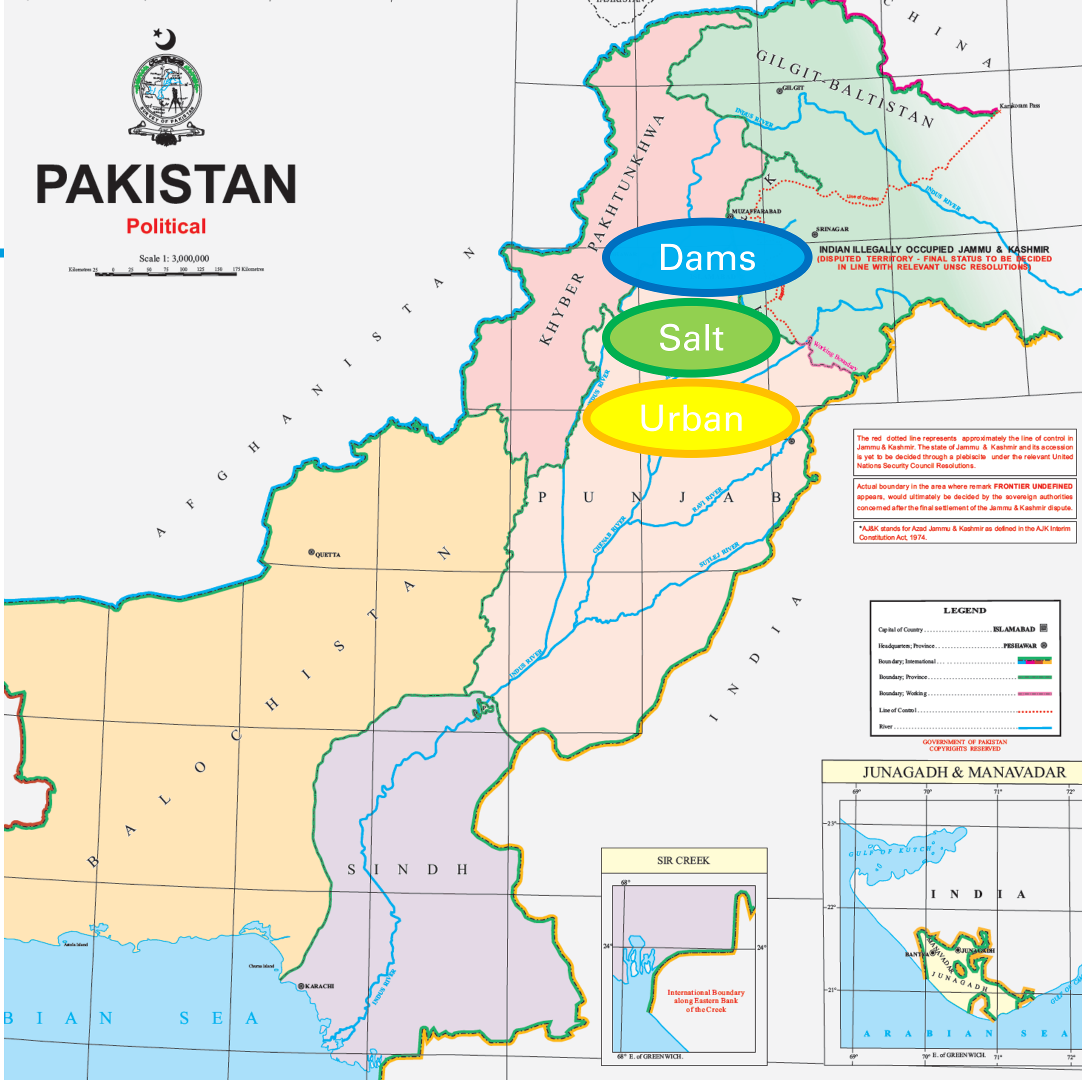
- Hydrogen or power transmission costs from the dams to the salt caverns are minimised

The salt palteau is close to the new gas grid section that unites the northern and southern transmission networks

- Ideal location for blending hydrogen into the northern and southern gas grids

The salt caverns are also close to one of the most densely populated regions

- High demand for hydrogen for cooking, heating, mobility and power generation



Key lessons and imperatives for future analysis, or regulatory review in Pakistan

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- Seasonal hydrogen production and underground storage in salt caverns could be a highly cost effective option for further analysis
- Higher value use-cases (such as ammonia / urea production or mobility to displace diesel) will improve the hydrogen economics compared to the selected cases and could be considered during further studies
- CCS potential for blue hydrogen is high, especially in the south where LNG is imported
- Turquoise hydrogen (methane pyrolysis) can be produced in multiple decentralised locations to decarbonise natural gas
- Imported LNG costs from Kuwait are very low, additional storage (eg in salt caverns) can avoid high cost spot market purchases
- Nuclear power is the cheapest power generation source in Pakistan – pink hydrogen (electrolysis from nuclear power) may be considered using SOE electrolysers to consume heat and power
- The current power pricing tariffs do not support use of excess or curtailed power for hydrogen generation during periods of excess for power generation during times of demand
- Hydrogen has huge potential to curtail CO2 emissions but in the absence of any reasonable national benchmark for CO2 emissions cost it is difficult to quantify/monetize the benefit
- The use of hydrogen (eg to displace diesel for mobility applications) can support air quality improvements and public health, but as with CO2 emissions quantification of the benefits is challenging

An affordable, decarbonised future will require a mix of appropriate and sustainable technologies, including hydrogen deployment at scale

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And the transition will be worth the investment and effort, to guarantee a sustainable future for the children of Pakistan

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Backup material

Proposed renewable hydrogen value chains summary of the 13 concepts

#	Project	Location	Fit with top 3 energy priorities	Additional benefits	Suitability for pilot on 2 to 3 year timescale	Attractiveness on 10 to 15 year timescale
1	Large hydro dam to produce H2 for transport in multiple cities in north	Mangla Dam, Azad Kashmir & northern cities	Reduced crude oil imports	Emissions reduction in heavily major northern cities, decarbonisation of transportation	High (if use only one city for H2 mobility)	High
2	Small scale hydro power close to city to produce H2 for mobility	Deg Outfall dam, Lahore, Punjab	Reduced crude oil imports	Emissions reduction in heavily polluted urban metropolis, decarbonisation of transportation	High	High (Deg is small, but can replicate)
3	Use hydro power to produce hydrogen for gas grid admixing	Any hydro scheme close to a gas pipeline	Reduced LNG imports	Decarbonisation of energy, leverage gas pipeline grid	High	High
4*	Mega-dam hydro power for H2 pipeline to Lahore	Tarbela / Mangla dams and Lahore, Punjab	Reduced LNG demand in major cities in the north of Pakistan	Decarbonisation of industry, transportation and domestic applications, leverage gas pipeline grid	Low (must be a large project)	High
5*	Mega-dam hydro power for H2 and salt caverns storage	Tarbela / Mangla dams and Chakwal, Punjab	Better energy supply / demand balance through each year: summer to winter, Reduced LNG imports	Decarbonisation of winter heating and power production, leverage gas pipeline grid	Low (must be a large project)	High
6	H2 from solar power at Quaid e Azam for stable H2 production	Bahawalpur, Punjab	Reduces imported LNG & reduces imported crude demand	H2 mobility on north / south route, decarbonise transportation, leverage gas pipeline grid	High	High
7	H2 from solar power at Quaid e Azam for daily power balance	Bahawalpur, Punjab	Better energy supply / demand balance through each day: midday to evening	H2 mobility on north / south route, decarbonise transportation	Low (lots of energy conversions vs battery)	Low (economics likely to be poor vs battery)
8	Bagasse fired power to H2 for ammonia production	Daharki, Sindh	Reduces imported LNG demand	Decarbonisation of industry & agriculture	High	Medium (small scale, low utilisation)
9	Solar power to H2 for remote areas (eg mining vehicles or rural villages)	Thar, Sindh	Reduces imported crude demand	Emissions reduction in remote areas, decarbonisation of industry	High	Medium (small scale, limited benefits)
10	Wind power for H2 to local use and LH2 import/export terminal	Jhimpir / Karachi, Sindh	Reduces imported LNG demand, better energy supply / demand balance	Enables LH2 exports, decarbonisation of energy, leverage gas pipeline grid & gas power plants	Medium (complex, mid scale project)	Medium (energy conversions)
11	Off-peak surplus power from the Orange Line Metro system for H2	Lahore, Punjab	Reduces imported crude demand, reduces imported LNG demand	Emissions reduction in heavily polluted urban metropolis, decarbonisation of transportation & heat	High	Medium (Multiple small schemes)
12	Off-peak surplus heat and power from a potential geothermal plant	Karachi, Sindh	Reduces imported crude demand, reduces imported LNG demand	Emissions reduction in heavily polluted urban metropolis, decarbonisation of transportation & heat	Low (geothermal plants do not yet exist)	Medium (good fit with H2 but small schemes)
13	Micro-hydro power for micro-grids in northern Pakistan	Naltar valley, Gilgit Baltisan	Security of power supply through the year, reduces imported LPG demand (current alternative), affordable energy for a low-income region	Carbon-neutral, pollution free energy in the north	High	High (good fit with H2, high social and economic impact

**Projects 4 & 5 may be combined*

Renewable hydrogen – alignment to the long term hydrogen deployment vision for Pakistan

Strategic energy priorities	How hydrogen can help
National energy independence	Local renewable power generation can secure energy independence.
Continuous energy supply security	Conversion of some renewable power to hydrogen can balance seasonal, weekly and daily peaks and troughs associated with renewable power.
Affordable energy	Investment in renewable power is required. Pakistan has the potential to generate low cost renewable power from solar, wind and hydro.
Carbon neutrality	As part of a renewable energy production and storage mix, hydrogen can support net-zero CO2 emissions goals in Pakistan.
Pollution-free energy	A transition to low-carbon hydrogen as an energy vector will reduce pollution in urban areas. For some hydrogen production technologies, emissions mitigation during hydrogen must be implemented to avoid shifting pollution.
Export revenue potential	There is theoretical potential to export hydrogen. However the ambitions of other regional energy mega-nations would mean that Pakistan could struggle to compete. Also, Pakistan has significant need for local energy development.
Leverage existing energy infrastructure	The existing gas transmission and distribution pipeline networks and the electricity grid can be leveraged in the transition to hydrogen.

National natural resources such as underground geological salt formations, solar potential, wind and hydro power potential can also be leveraged to produce and store hydrogen.

Beyond the cases assessed in detail through this study, Pakistan also has potential for geothermal and wind power

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Geothermal power plant in Africa, wind farm in Pakistan

Green hydrogen deployment in Pakistan - project team for this study

NEECA – Dr Sardar Mohazzam, Managing Director

NEECA – Sabieh Haider, Project Coordination and stakeholder liason

ADB – Toru Ito, Senior Energy Specialist (Gas)

Technical experts contracted to ADB

- Stephen B. Harrison – international hydrogen expert and project team leader
- Muhammad Asif Masood – local energy systems expert
- Dr Muhammad Nadeem Javaid – local economics and finance expert
- Sardar Aqsam – local legal and regulatory affairs expert

Report editor, engaged through sb**h**4 consulting

- Nadra Mahmoodi, International power and energy expert, Algeria

Introduction to Stephen B. Harrison and sbh4 consulting

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Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions control. Hydrogen, CCUS and the electrification of industrial processes are fundamental pillars of his consulting practice.

He is also the international hydrogen expert for three ADB projects: renewable hydrogen deployment in Pakistan; green hydrogen at scale in Palau and the role of hydrogen in the energy transition in Viet Nam.

With a background in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of carbon dioxide, hydrogen and other energy vectors from commercial, technical, operational and safety perspectives. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen has extensive buy-side and sell-side M&A due diligence and investment advisory experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers and green-tech startups are regular clients.

As a member of the H2 View and **gas**world editorial advisory boards, Stephen advises the direction for these international publications. Working with Environmental Technology Publications, he is a member of the scientific committees for AQE 2021 and CEM 2023 - leading international conferences for Air Quality and Continuous Emissions Monitoring.

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