sbh4 consulting

Low-carbon hydrogen, High-potential for Pakistan

Stephen B. Harrison, Managing Director, sbh4 consulting, Germany

Pakistan International Energy Expo

6th April 2021

Introduction to Stephen B. Harrison and sbh4 consulting

sbh4 consulting

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 and CCUS are fundamental pillars of his consulting practice.

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 hydrogen and carbon dioxide 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 experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers are regular clients. He is also the international hydrogen expert and team leader for an ADB project related to renewable hydrogen deployment in South Asia.

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 committee for CEM 2023 - the leading international conference for continuous emissions monitoring and air quality.

Why hydrogen?

sbh4 consulting

- Hydrogen production is possible from abundantly available renewable resources in Pakistan
- Hydrogen can be produced locally from fossil fuel resources in Pakistan and decarbonised using CCS on depleted local natural gas fields
- Low-carbon hydrogen can support national and international climate change targets
- Hydrogen has excellent long term energy storage ability for time-shifting for annual power supply security
- Hydrogen is a clean source of energy at the point of use
- Hydrogen has similar handling and safety characteristics to natural gas and existing gas infrastructure can be modified and leveraged

Hydrogen is not 'magic'...

sbh4
consulting

- Hydrogen is derived from biomass, power or fossil fuels – there are inherent conversion costs and energy losses
- Direct use of renewable power can be more cost effective – but large-scale, long-term electricity storage is difficult and expensive, hydrogen can help with energy storage
- Only low-carbon hydrogen will reduce climate change – grey and black hydrogen are dominant in the world today and this must change
- Hydrogen alone is not the answer – it deserves to be part of an appropriate and sustainable mix of solutions

sbh4 consulting

Low-carbon hydrogen: a rainbow of colours

Purple – coal (or petcoke) gasification with CCS

Blue – natural gas reforming with CCS

Turquoise – methane pyrolysis with solid carbon

Green – renewable power or biomethane

Pink – nuclear power

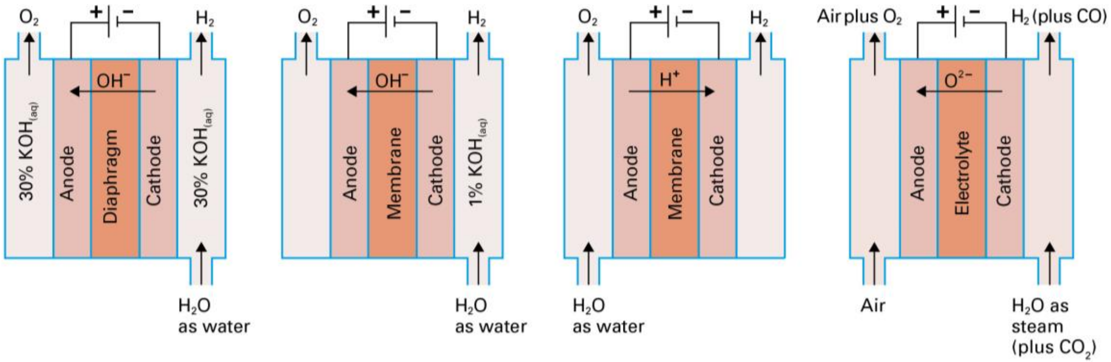
Black (or brown) hydrogen from coal or petcoke gasification and grey hydrogen from natural gas reforming are dominant in the world today – both have a significant carbon dioxide emissions footprint

Pink and green hydrogen are produced on electrolysers

sbh4 consulting

Notes:

- In the AEC, AEM and PEM, lye or water flow from the electrolyser cell with the oxygen and/or hydrogen gases. These liquids are mixed and recirculated to the electrolyser.
- Air is used to purge the SOE anode to avoid oxygen accumulation which may present a hazard at the high operating temperature.
- Bipolar plates made of stainless steel (titanium for PEM) are used to stack adjacent cells in each electrolyser type.



	Alkaline Electrolysis Cell AEC	Anion Exchange Membrane / Alkaline Electrolyte Membrane AEM	Polymer Electrolyte Membrane/ Proton Exchange Membrane PEM/PEMEC	Solid Oxide Electrolysis Cell SOE/SOEC
Electrode material	– Cathode: Ni, Co or Fe – Anode: Ni	– Cathode: Ni / Ni alloys – Anode: Fe, Ni, Co oxides	– Cathode: Pt/Pd – Anode: IrO_2/RuO_2	– Cathode: Ni – Anode: La/Sr/MnO (LSM) or La/Sr/Co/FeO (LSCF)
Electrolyte	Lye: 25-30% Potassium Hydroxide solution in water	Anion Exchange ionomer (e.g. AS-4)	Fluoropolymer ionomer (eg Nafion, a DuPont brand)	Zirconium Oxide with ~8% Yttrium Oxide
Energy source	100% electrical power	100% electrical power	100% electrical power	~25% heat from steam, ~75% electrical power
Current density	Up to 0.5 A/cm²	0.2 – 1 A/cm²	Up to 3 A/cm²	Up to 0.5 A/cm²
Hydrogen or syngas product	Hydrogen	Hydrogen	Hydrogen	Hydrogen (or syngas if fed with steam and CO_2)
Gas outlet pressure	Up to 40 bar	Up to 35 bar H_2, 1 bar O_2	Up to 40 bar	Close to atmospheric
Cell temperature	~80 °C	~60 °C	~60 °C	~750 to 850 °C

Pink hydrogen production from nuclear power and steam on an electrolyser

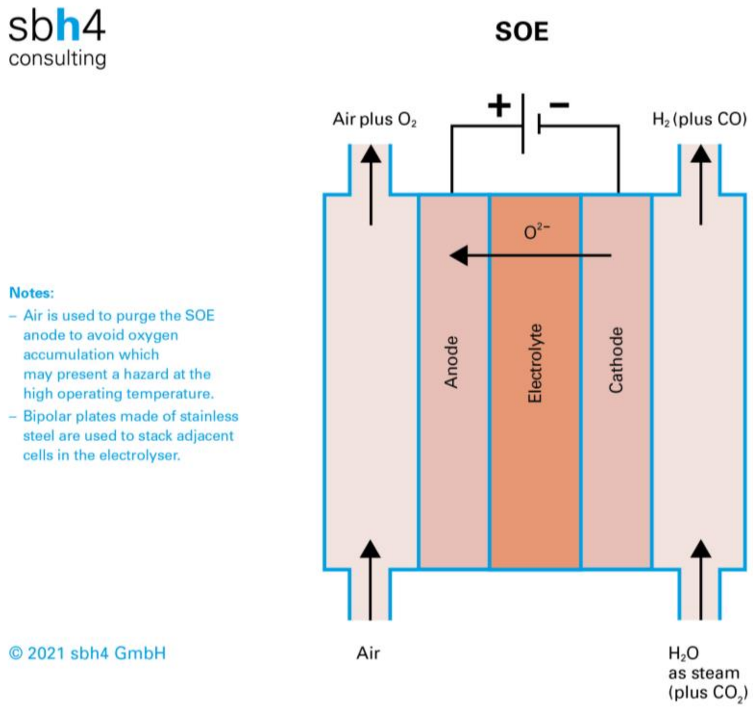
sbh4 consulting

Solid Oxide Electrolysers (SOE) are highly compatible with this application

- Waste heat (low grade steam) from the power plant can provide about 25% of the energy
- Electrical power consumption is circa 30% less than a PEM, AEM or AEC electrolyser

AEM, AEC or PEM are also suitable

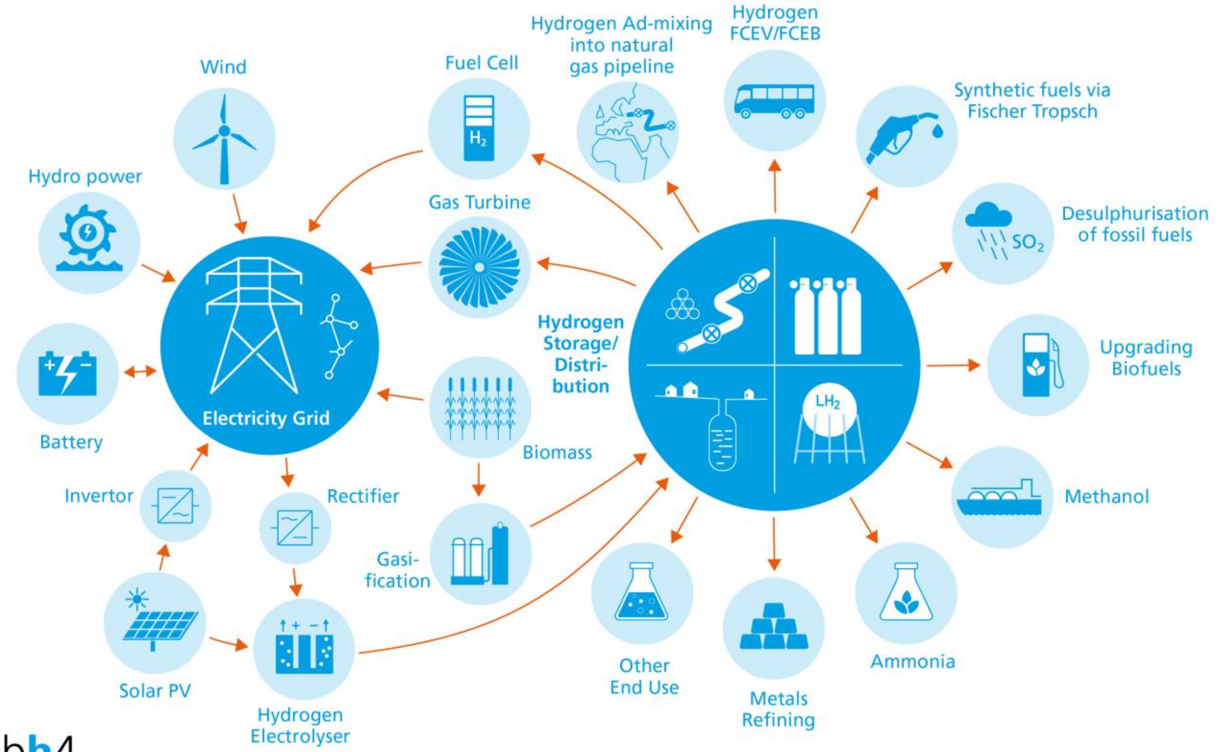
- Capex and maintenance costs for the SOE are higher
- Hydrogen outlet pressure on the SOE is lower than meaning that a hydrogen compressor would also be required



PEM = Polymer Electrolyte membrane or Proton Exchange Membrane
AEM = Anion Exchange Membrane, AEC = Alkaline Electrolysis Cell

Green hydrogen production from renewable power and water on an electrolyser

sbh4 consulting



sbh4 consulting

Pakistan has good potential for renewable wind power

sbh4 consulting

Pakistan has unrivalled potential for renewable hydro-electric power

sbh4 consulting

Pakistan has almost unlimited potential for renewable solar power

sbh4 consulting

Solar panels in a mountainous region of Pakistan

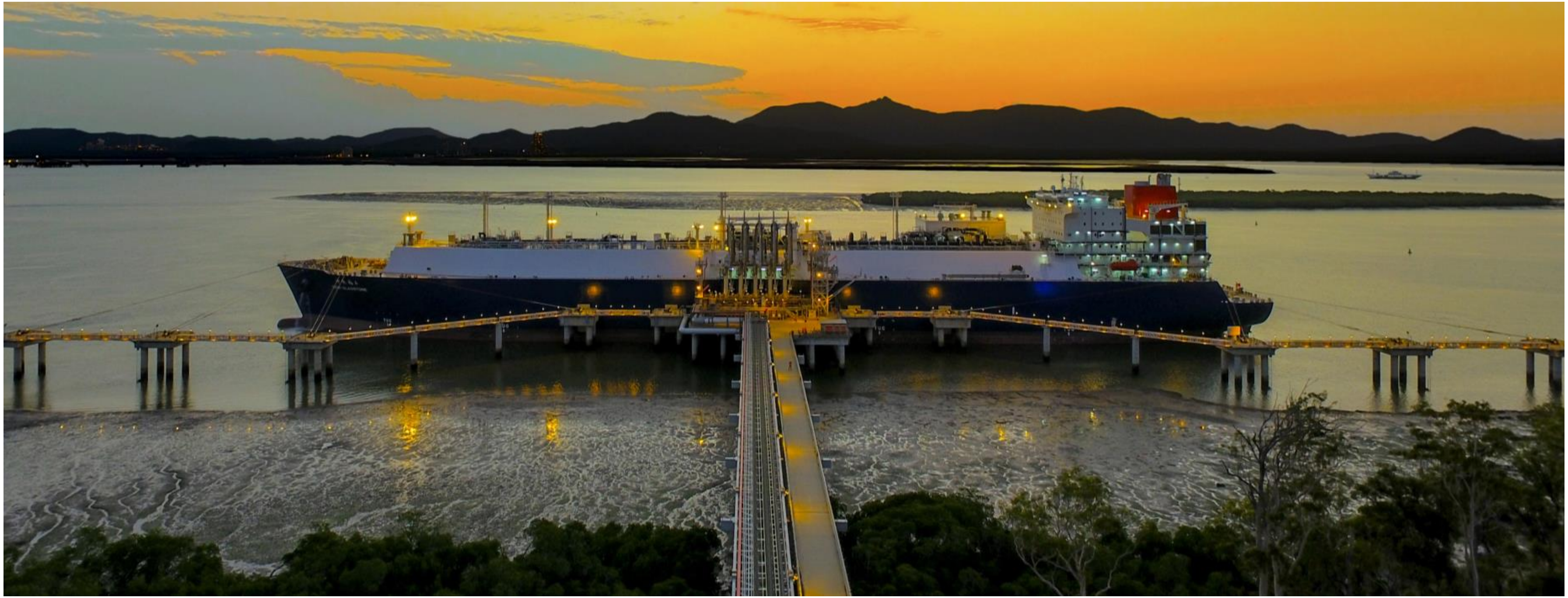
Pakistan has good potential for renewable geothermal power and energy

sbh4 consulting

Geothermal power plant in Africa

Local green hydrogen production can reduce energy import dependence

sbh4 consulting

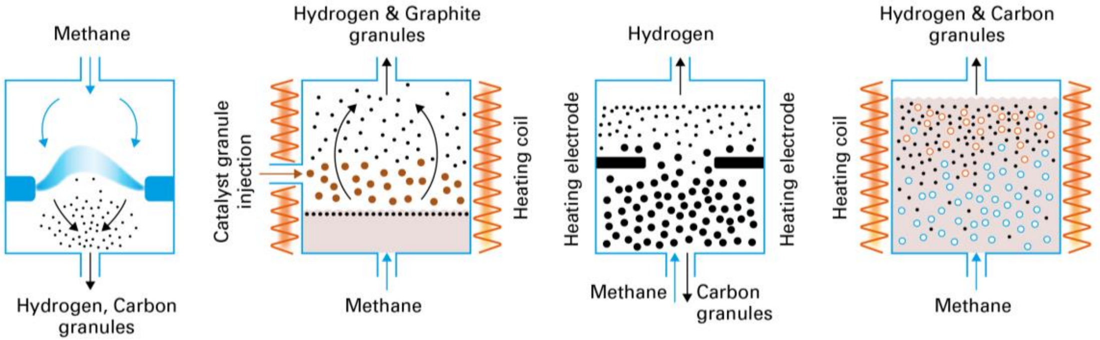


Q-Max LNG tanker from Qatar at LNG terminal

Turquoise hydrogen production consumes methane gas and renewable power

sbh4 consulting

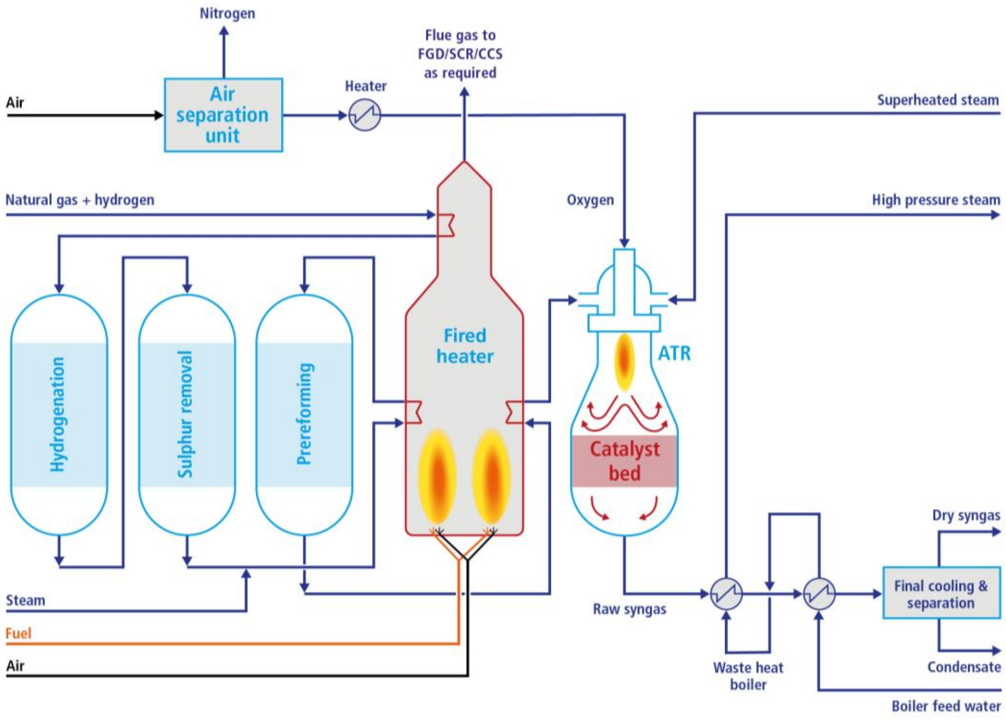
Notes:
- Unreacted methane can be separated from the hydrogen using PSA and recycled to the reactor
- The size of the carbon granules is influenced by operating conditions and the residence time of the carbon in the reactor
- Heat may be from renewable electricity
- Methane can be from natural gas or biogas



	Plasma Pyrolysis	Fluidised Bed	Moving Carbon Bed	Molten Metal or Molten Salt
Process shown	Monolith Materials	Hazer	BASF	TNO or C-Zero
Hydrogen content at reactor outlet	~95%	~92%	~92%	Up to 95%
Carbon production	Carbon black as powder or granules	80 to 95% graphite encapsulating catalyst dust particles	Carbon black as powder or granules	Carbon black as powder or granules
Catalyst required	No	Iron oxide granules	Carbon bed	Molten 27% Nickel-73% Bismuth Molten Manganese Chloride
Heating mechanism	Direct heating with plasma	Indirect heat applied around the reactor	Electrodes to heat the carbon bed and indirect heat applied around the reactor	Indirect heat applied around the reactor or electrodes to heat the melt in a separate vessel
Reactor temperature	2000 °C	900 °C	1000 to 1400 °C	Depends on melt, 650 to 1100 °C
Reactor pressure	Close to atmospheric pressure	Close to atmospheric pressure	Close to atmospheric pressure	Up to 5 bar

Blue hydrogen production consumes methane gas on a reformer

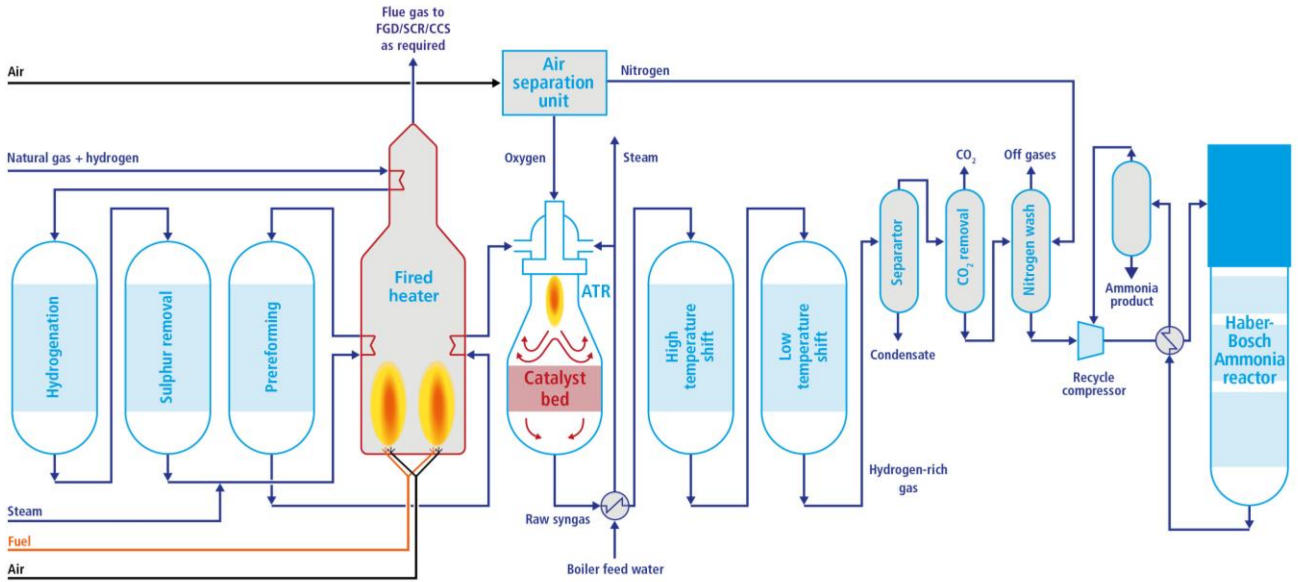
sbh4 consulting



sbh4 consulting

Blue hydrogen can make ammonia which can be a fuel and is used to make fertilizers

sbh4 consulting



sbh4 consulting

Ammonia and methanol are hydrogen derivatives which are easy to transport

sbh4 consulting

Ammonia tanker
Image courtesy of and copyright Yara

Methane gas can be from biogas or landfill gas upgrades, local natural gas or imported LNG

sbh4 consulting

Large biogas reactors can be linked to intensive farming such as milk production

Purple hydrogen production consumes coal or petcoke

sbh4 consulting

Coal is mined in several locations in southern Pakistan

Blue and purple hydrogen require carbon dioxide capture from the flue gas

sbh4 consulting

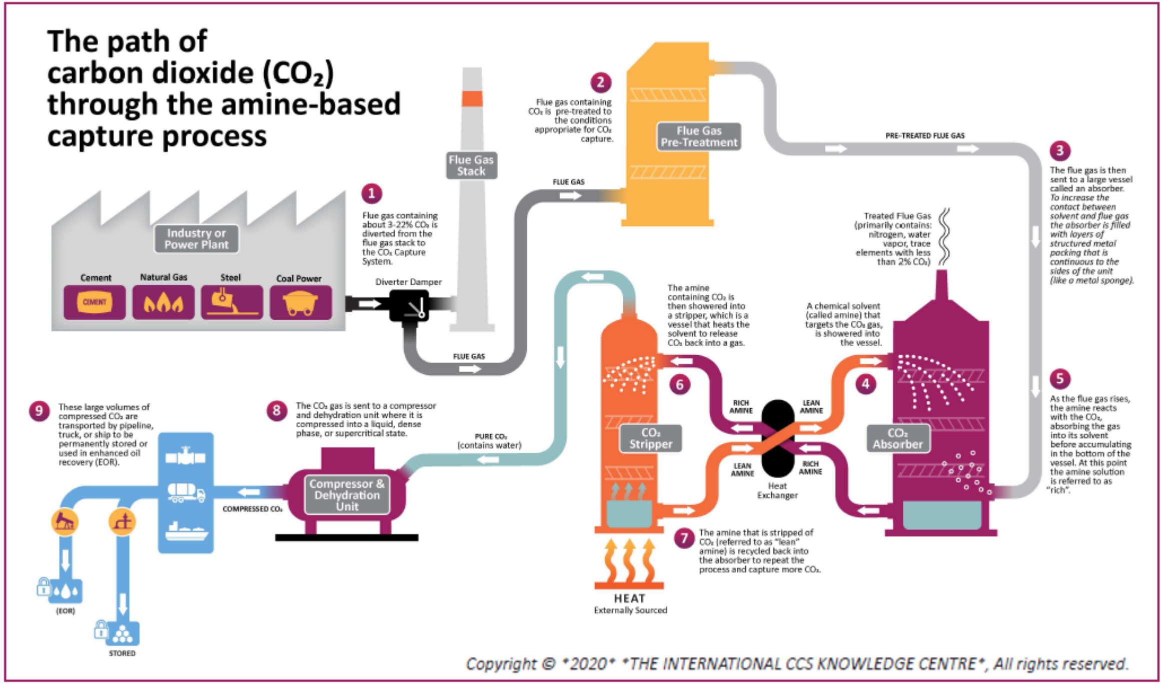


Image shown on left is a Mitsubishi Heavy Industries Amine-Wash 340 tons per day carbon capture unit at Engro Fertilizers, Pakistan
The unit recovers CO2 from the SMR for use to make urea fertilizer in combination with ammonia
Image on left courtesy of and copyright Mitsubishi Heavy Industries

Blue and purple hydrogen require carbon dioxide utilisation or permanent underground storage

sbh4 consulting

Depleted gas fields, as will soon be common in Pakistan, are ideal for carbon capture and storage (CCS)

Hydrogen transmission can be achieved by repurposing natural gas pipelines

sbh4 consulting

Gas transmission pipelines and gas distribution pipelines that were built for natural gas may also be suitable for hydrogen admixing with the natural gas, or even for pure hydrogen – a safety and feasibility study would be required prior to use with hydrogen

Waste-to-hydrogen is possible and biogenic wastes produce low carbon hydrogen

sbh4 consulting

Cattle dung and other biological wastes are renewable feedstocks for gasification as alternatives to coal

Hydrogen storage can bridge seasonal imbalances in power supply and demand

sbh4 consulting

The large Tarbela hydro dam in Pakistan produces very little power in late winter / early spring before the rainy season begins

Cost-effective large-scale, long-term hydrogen storage can be achieved in salt caverns

sbh4 consulting

A suitable underground salt layer is believed to exist in the area south of Islamabad and west of Lahore

Hydrogen utilisation can reduce air pollution

sbh4
consulting

Hydrogen powered fuel-cell electric vehicles emit only water vapour
They emit no VOCs, CO / NOx / PM and therefore do not cause smog in urban areas

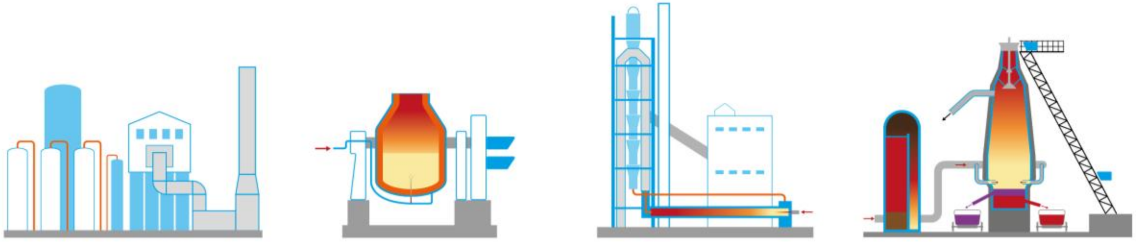
Hydrogen utilisation can support decarbonisation of power generation

sbh4 consulting

Fossil fuel fired power station in Pakistan

Hydrogen utilisation can support decarbonisation of heavy industry

sbh4 consulting



	Oil refining	Aluminium smelting	Cement making	Iron making
Application that releases CO_2	Hydrogen production from methane reforming for fuels desulphurisation	Reduction of alumina to aluminium using graphite electrodes	Reduction of limestone to calcium oxide	Reduction of iron ore to iron using coke
Chemical reaction producing CO_2	$CH_4 + H_2O \rightarrow CO + 3H_2$ $CO + H_2O \rightarrow CO_2 + H_2$	$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$	$CaCO_3 \rightarrow CaO + CO_2$	$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$ $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
Decarbonisation approach	Use turquoise hydrogen or green hydrogen to avoid the reforming reaction; or feed the reformer with biomethane instead of natural gas	Use carbon from turquoise hydrogen production instead of carbon from fossil fuels to make the electrodes	Replace a portion of the limestone with alternative materials such as calcined clay to make clinker for cement	Use turquoise hydrogen or green hydrogen instead of coke; or substitute coke with carbon from turquoise hydrogen production
Reactions for the decarbonised process	As above using renewable methane	As above using renewable graphite electrodes	Above reaction can only partially be avoided	As above using renewable carbon, or use hydrogen: $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$
Other industries with similar applications	Ammonia, Urea, Methanol, Gas-to-liquids	Gold and silver refining, electric arc furnace to melt scrap steel	Lime making Refractory bricks, $MgCO_3 \rightarrow MgO + CO_2$	None

Hydrogen is part of the team… renewable power, BES, CAES, TES, PH, ammonia, e-fuels…

sbh4 consulting

BES = Battery Energy Storage using various battery technologies, CAES = Compressed Air Energy Storage, TES = Thermal Energy Storage, PH = Pumped hydro, green ammonia, synthetic e-fuels… many technologies will be complimentary to hydrogen in a diversified sustainable energy infrastructure

An affordable, decarbonised future will require a mix of appropriate technologies

sbh4 consulting

And the transition will be worth the investment and effort, to guarantee a sustainable future for the children of Pakistan sbh4

consulting