How India Can Achieve Hydrogen Economy Accompanied By Carbon Capture Usage & Storage

By

Dr. R. K. Malhotra

IHC – 24^{TH} February 2023

Indian Economy to grow: *So will be the demand for Energy*

- Indian Economy to grow to $10 Trillion by 2030, from the present $ 2.75 Trillion
- India currently imports over 40% of its primary energy requirements, worth over USD 90 billion every year.
- India's per capita energy consumption will increase by at least 2.5 times to enter the upper-middle income group.
- Energy use has doubled in the last 20 years and is likely to grow by at least another 25% by 2030 in line with rising income levels & growing aspirations of middle class.

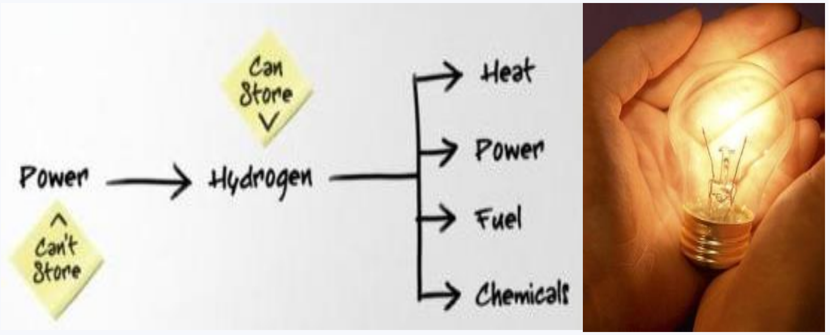
India therefore needs to focus on reduced import dependence by increasing supply from domestic energy sources to provide accessibility in an affordable and sustainable manner.

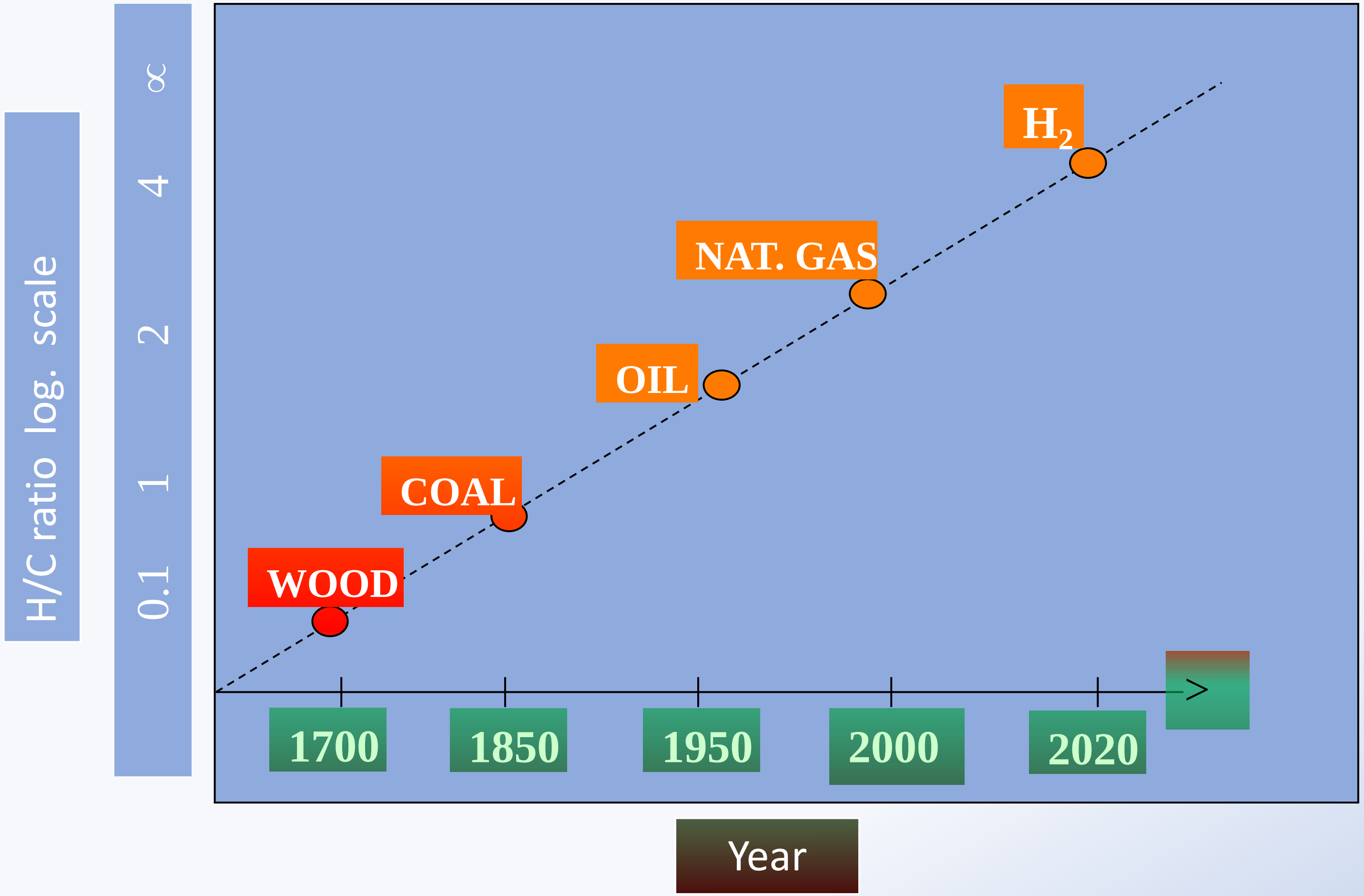
India’s Climate Related Commitments

- India will reach its non-fossil energy capacity to 500 GW by 2030
- to meet 50 percent of its energy requirements (electricity) from renewables by 2030
- To reduce the total projected carbon emissions by one billion tonnes from now onwards till 2030
- By 2030, India will reduce the carbon intensity of its economy by less than 45 percent
- By the year 2070, India will achieve the target of Net Zero

Need for reinventing the energy basket to provide affordable energy for growth amidst climate commitments

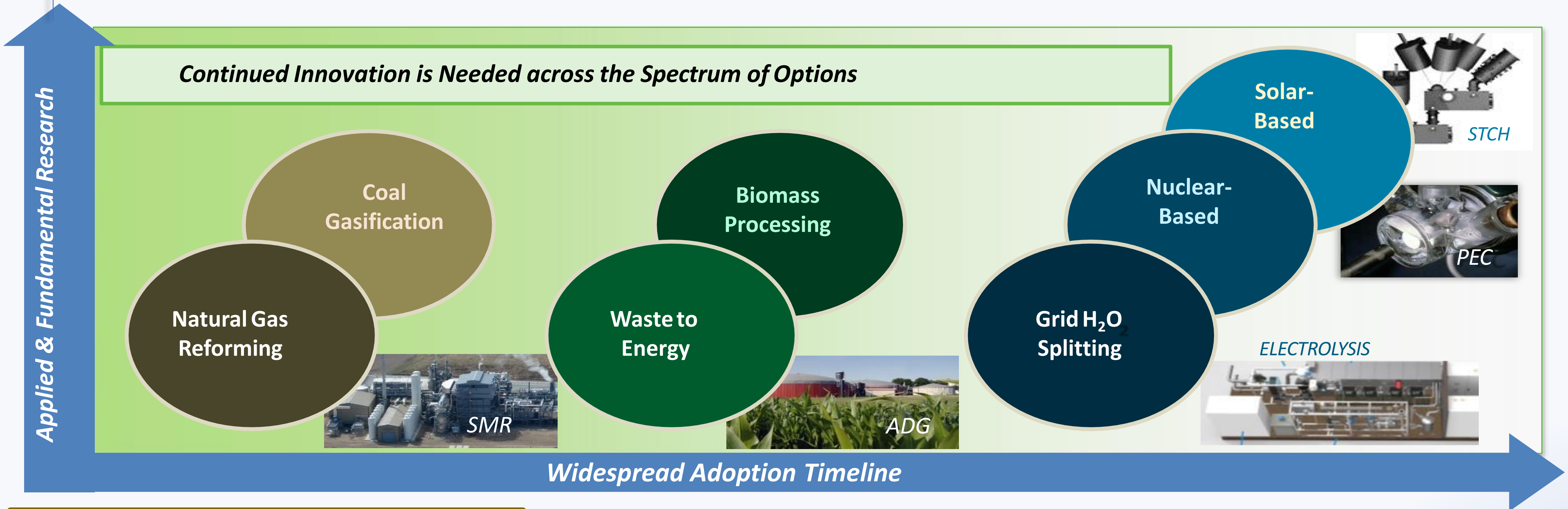
Moving towards a carbon free future





Hydrogen is the answer for meeting stringent environmental norms and mitigating climatic change without impacting the growth pace

Where will the Hydrogen come from?



FOSSIL RESOURCES

- Low-cost, large scale H_2 production with CCUS options
- New options offer scalability and byproduct benefits (e.g. CHHP)

WASTE/ BIOMASS

- Options included biogas reforming & fermentation of waste streams
- Byproduct benefits include clean water, electricity & chemicals

WATER SPLITTING

- Grid electrolysis is proven process being improved with innovation
- Emerging nuclear/solar options offer long-term sustainable H2

Presently more than 95% of total hydrogen production globally is from fossil sources mostly by reforming of natural gas

Source: US department of Energy

World is Moving Towards Hydrogen Economy

- Global Hydrogen Demand - 90 MT/Yr. to grow to over 200 MT/Yr. by 2030
- Majority of Hydrogen Globally is produced by Natural Gas Reforming except in China where Coal based Gasification technology is predominant source.
- 95% of Hydrogen today is produced from fossil sources which emits

  4-10 CO_2/Kg of Hydrogen (4-5 for SMR & 9-10 for coal gasification)
- Globally and particularly in Europe, Green Hydrogen through electrolysis using Renewable power is fast growing.
- In Net Zero Scenario of IEA, by 2050, 10% of Global Energy Demand and one third of Hydrogen demand will be for Hydrogen based fuels like ammonia, synthetic kerosene and synthetic methane.

Hydrogen as enabler for Decarbonization

Enable the renewable energy system → Decarbonize end uses

- Enable **large-scale renewables integration** and **power generation**

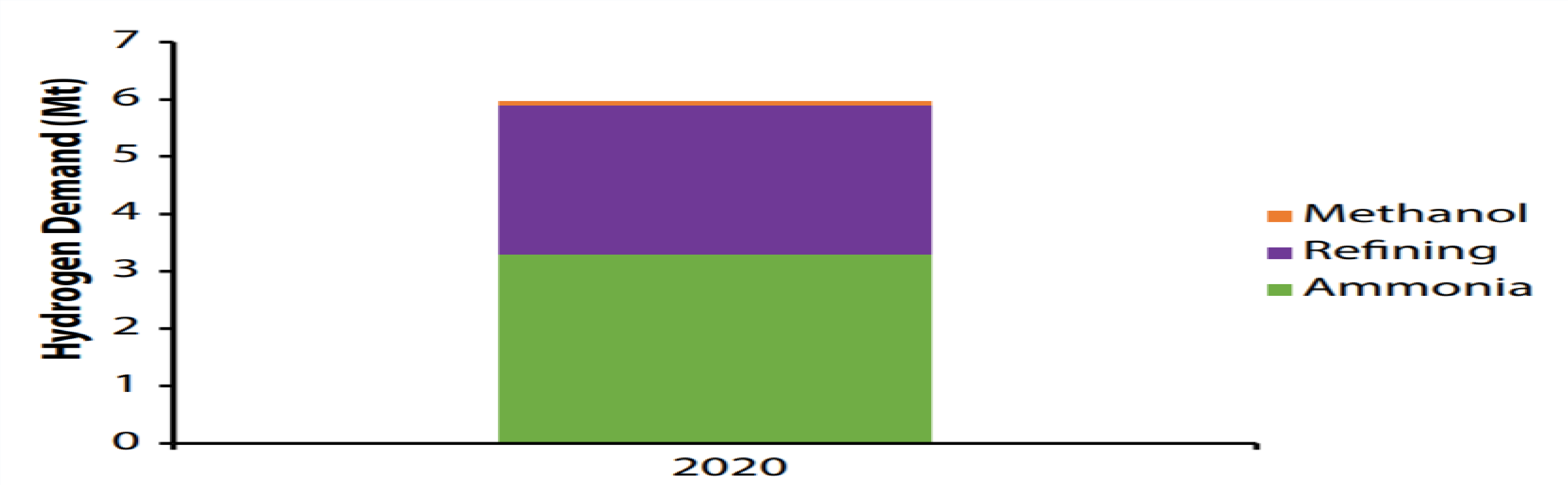
- **Distribute** energy across sectors and regions
- Act as a **buffer** toincrease system resilience

- Decarbonize **transportation**
- Decarbonize **industry energy** use
- Help decarbonize **building heating and power**
- Serve as **feedstock**, using captured carbon

Source- Hydrogen Council

Hydrogen Demand / Production

- India Hydrogen Demand – 6.7 MT/Yr. (7-8% of Global demand)
- In India, Natural gas reforming accounts for nearly all hydrogen being produced and used, though Reliance is having Petcoke Gasification units to produce hydrogen for captive use.



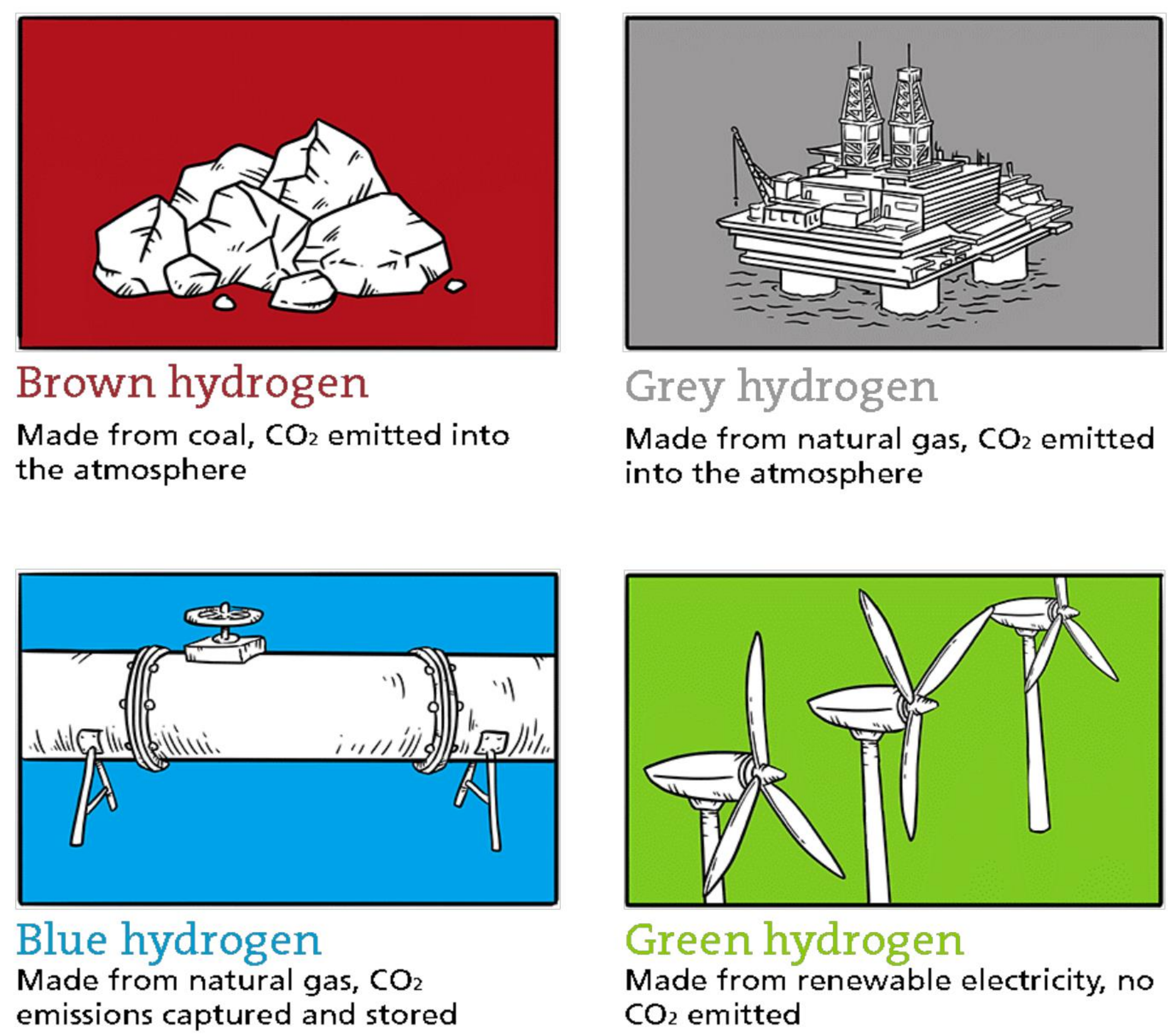
National Hydrogen Mission India

- Prime Minister of India announced, National Hydrogen Mission on 15th August 2021.
- Mission aimed at making India a Global Manufacturing Hub of Hydrogen and Fuel Cells
- Govt to facilitate demamand creation in identified sgments by suitable mandates for use of Green Hydrogen in fertilizers, steel and petro-chemicals including refineries.
- Major activities envisaged included creating volumes & infrastructure, demo projects in niche applications in transport & industry, goal oriented research & development, facilitate policy support and putting in place robust framework for standards and regulations.
- Mission aimed at helping meet the climate targets.

Green Hydrogen Mission India-January 2023

- Mission will build capabilities to produce at least 5 Million Metric Tonne (MMT) of Green Hydrogen per annum by 2030, with potential to reach 10 MMT per annum with growth of export markets.
- The Mission will support replacement of fossil fuels and fossil fuel based feedstocks with renewable fuels and feedstocks based on Green Hydrogen.
- Green Hydrogen to replace Hydrogen produced from fossil fuel sources in ammonia production and petroleum refining, blending Green Hydrogen in City Gas Distribution systems, production of steel with Green Hydrogen, and use of Green Hydrogen-derived synthetic fuels (including Green Ammonia, Green Methanol, etc.)
- Green Hydrogen to replace fossil fuels in various sectors including mobility, shipping, and aviation.
- The Mission also aims to make India a leader in technology and manufacturing of electrolysers and other enabling technologies for Green Hydrogen.

Hydrogen fuel : Various Sources & Colors Assigned



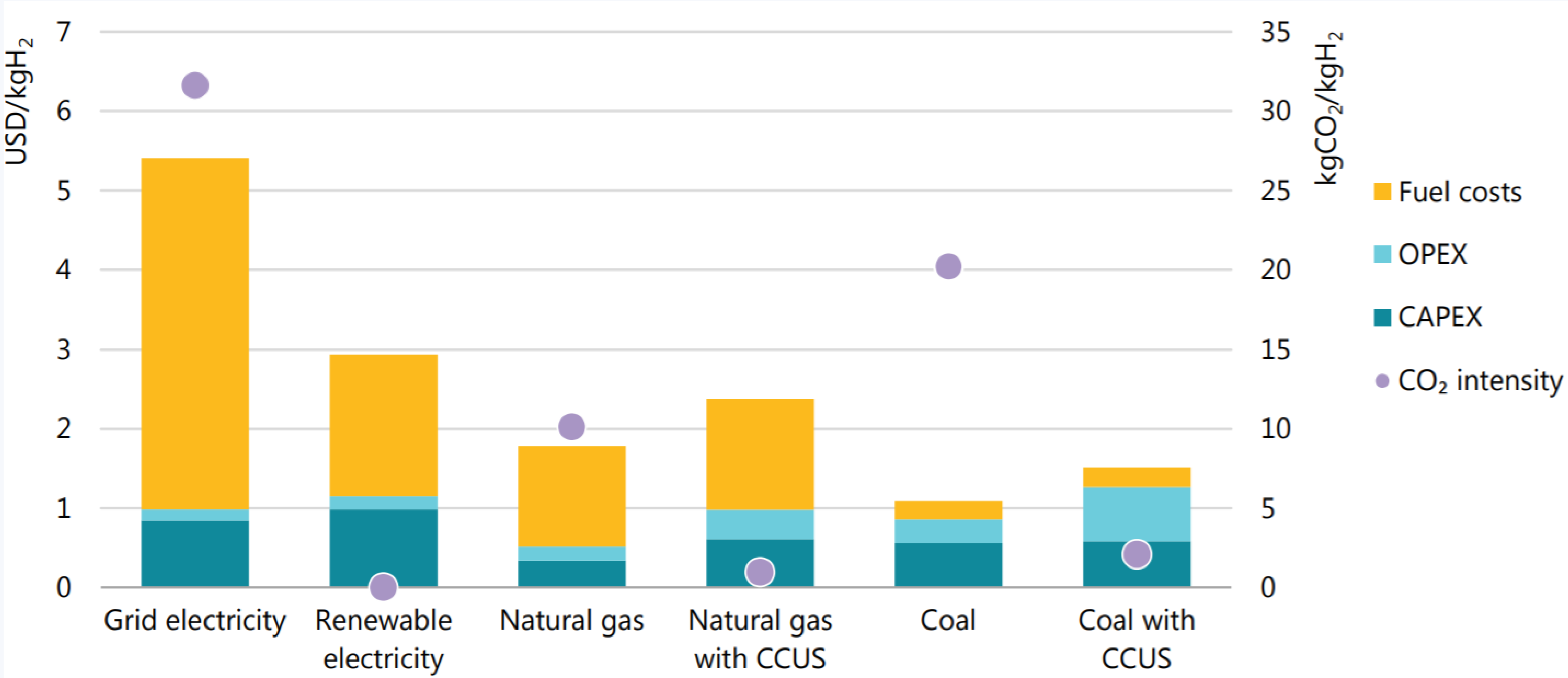
Source: WRI

Cost of hydrogen production from various sources (in $/kg)

Sr. No.	Hydrogen production method	other costs	Feedstock Cost	Cost of Hydrogen produced
1	Cost of hydrogen production from natural gas reforming in a central plant	0.29	1.03	1.32
2	Cost of hydrogen production from coal gasification with carbon sequestration	1.62	0.48	2.10
3	Cost of hydrogen production from bio-mass	0.88	1.34	2.22
4	Cost of hydrogen production from ethanol	2.66	4.82	7.48
5	Cost of hydrogen production from PEM electrolysis	0.75	3.46	4.21
6	Cost of hydrogen production from SOEC	1.35	2.48	3.83

Source: NREL

Cost of Hydrogen production in China



- The cost of hydrogen produced from coal (without CCS) in China is INR 80/kg
- Majority of hydrogen produced from coal goes to Ammonia production in China

Source: TERI Analysis based on BEIS, BNEF and IEA

Cost of H_2 production from Coal and Natural gas

Feedstock		Price	Cost of H2 production Rs/kg	Data source	Cost contribution/Major components considered
Natural gas	Case 1	$7/MMBTU	~115	based on published information from several sources	73(feed):9(Capex):18(Others)
	Case 2	$10/MMBTU	~151		79(feed):7(Capex):14(Others)
Coal	Case 1	Rs 1500/ton	~102		16(feed):44Capex):40(Others)
	Case 2	Rs 3000/ton	~118		28(feed):38(Capex):34(Others)
Basis: Plant capacity of 150 Tons/day hydrogen generation considered for all cases					
Natural gas	Case 1	$7/MMBTU	~101	Based on in-house data available in EIL	Major components of a typical NG based plant are Steam Reformer, Shift Reactor, PSA & U&O facilities
	Case 2	$10/MMBTU	~133		
	Case 3	$12/MMBTU	~154		
Coal	Case 1	Rs 1000/ton	~110		Major components of the plant are Gasification section, Air Separation Unit, Shift & Gas cleaning section, PSA & U&O facilities
	Case 2	Rs 1500/ton	~121		
	Case 3	Rs 3000/ton	~157		

Cost of Green Hydrogen from Renewable Power

- 1 kg of GH2 requires 9 litres of water and 45-55 KWh of Electricity
- At Rs 5/ KWh of Renewable electricity cost plus battery storage would be Rs 250/ Kg of GH2
- Cost of Electrolyser etc would add another Rs 150-250 depending on utilization factor
- The Green Hydrogen cost will be around at least Rs 400/Kg in current scenario, much higher than Hydrogen from Coal and Natural Gas derived Hydrogen
- Cost of Electrolysers fallen by 40% in last 5 years, need to fall further in order to be affordable.
- Another issue is availability/ allocation of Green Power for this purpose.

Coal-to-Hydrogen Opportunity

Teamed with Carbon Management, Coal-to-Hydrogen technology can help meet the primary goals of a Hydrogen Economy (energy security, economic advantages and environmental benefits)

- Coal can be a cornerstone for the diverse hydrogen supply mix, with integration of hydrogen production into co-production of power and synthetic fuels
- India holds 163 billion tons (BT) of proven coal resources out of 344 BT
- About 18% more coal would need to be mined and converted to Hydrogen to serve 1/3rd of the transportation demand

Tremendous opportunity to increase domestic energy supply without adding transmission capacity includes Hydrogen, Power, Advanced tactical fuels for the military, Fuels for energy markets and speciality chemicals

Gasification Potential Mapping

- NITI Aayog entrusted *CSIR-CIMFR & CMPDIL* **"Gasification Potential Mapping of Indian Coal"** (Notification: 17/05/2018)
- Completed mapping for **MCL** (13 mines, Ash: 20-46%), **CCL** (6 mines, Ash: 29-53%) and **ECL** (5 mines, Ash: 18-38%). Report submitted to **NITI Aayog** on 24^{th} Dec, 2019

  - Developed Coal characterization matrix for Physico-chemical properties of coal/Ash essential for gasification.
  - Suggested ***Matching gasification technology*** vis-à-vis ***Utilization pattern*** & ***gasification strategy*** for gainful utilization of Indian coal resource.
  - Inputs for selection of matching Gasifier according to coal properties.
  - High ash coal washing or blending with Petcoke to reduce ash content suitable for Entrained flow Gasifier or Moving Bed gasifier Gasifier.

Worldwide Coal Gasification Technologies

- Entrained Flow Gasifiers
  - ❖ Dry Feed
  - ❖ Slurry Feed

- Fludised Bed Gasifiers
  - ❖ Bubbling
  - ❖ Circulating

- Fixed Bed Gasifiers
  - ❖ Dry ash
  - ❖ Slagging

It is necessary to adopt the gasification technology according to the available type(s) of coal

Indian Coal Gasification strategy – Current Status

Commercially Proven Gasifiers for Methanol/Fertilizer/DRI Plant

Entrained Flow Gasifier : with Low ash (<20%) coal & high ash coal after washing/blending with petcoke to reduce ash.

- Located at plants of CIL at TFL, Talcher, WCL (Wardha), SECL (Mahamaya), ECL (Sonpur Bazari, Dankuni) Capacity: ~500 TPD Coal

Moving Bed Gasifier: Low ash (<30%) coal & high ash coal washing or blending with imported coal

- Experience at JSPL, Angul (~3000 TPD Coal)

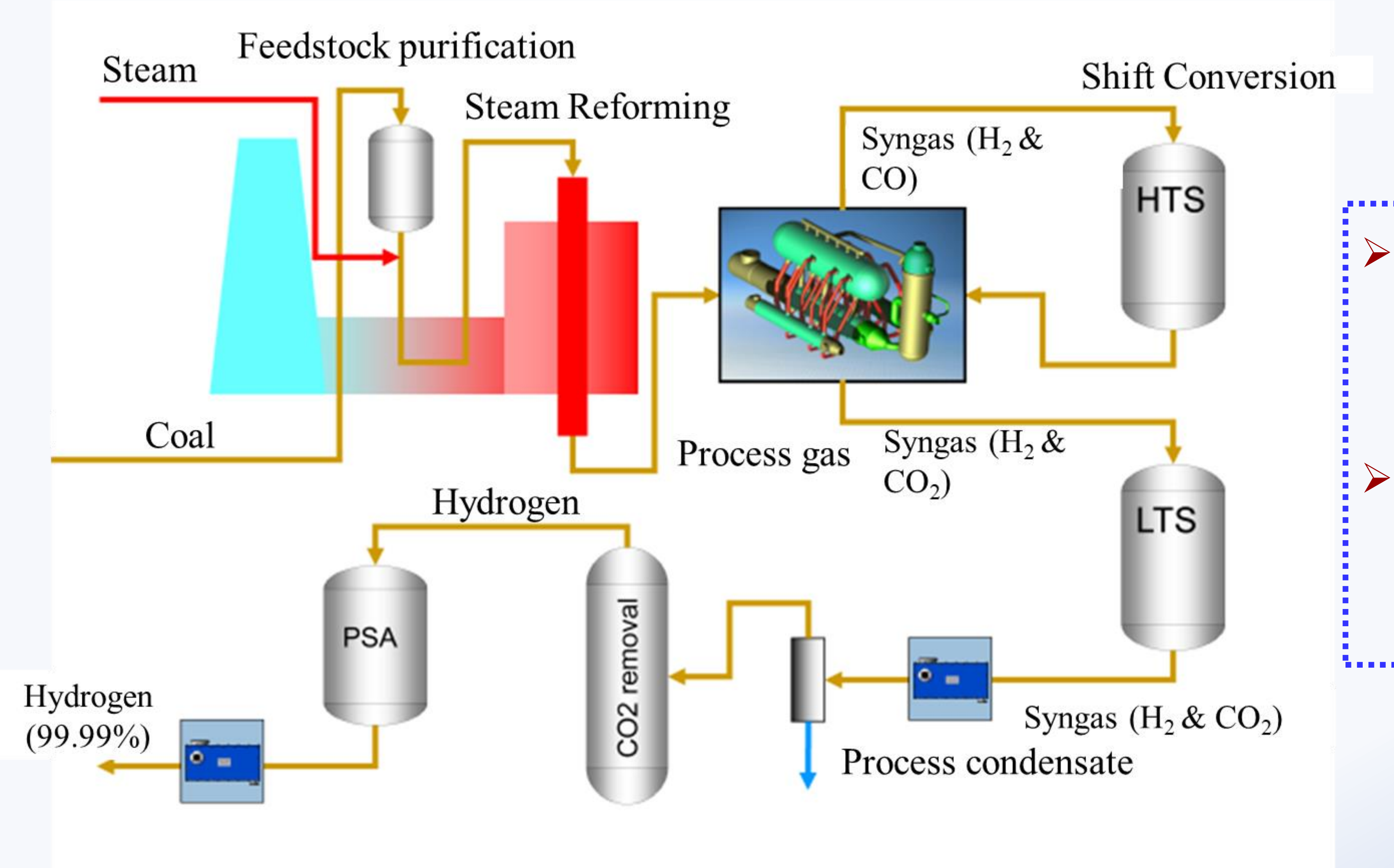
Indian Coal Gasification strategy – Indigenous pilot scale plants

Indigenous Gasifiers retrofitted with Methanol Plants

- **Pressurized Fluid Bed Gasifier(PFBG) Pilot Scale Plant**
  - CSIR-CIMFR, BHEL, IITD-Thermax & EIL: Proof of concept & Blueprint for Demo Plant
- **PFBG retrofitted Demo Plants:**
  - 500 TPD Coal, 2019-23 at ECL, CCL, SECL, WCL
    Outcome: DPR for 7500-25000TPD Plant
- **24TPD High Pressure Moving Bed Coal Gasification Pilot Plant at CSIR - IICT**

The roadmap for Coal gasification may be eventually setting up of commercial plants of 7,500 – 25,000 TPD at different pit heads locations for utilization of upto 100 MMTPA coal for production of value added products

Process Intensification for Syngas & Hydrogen

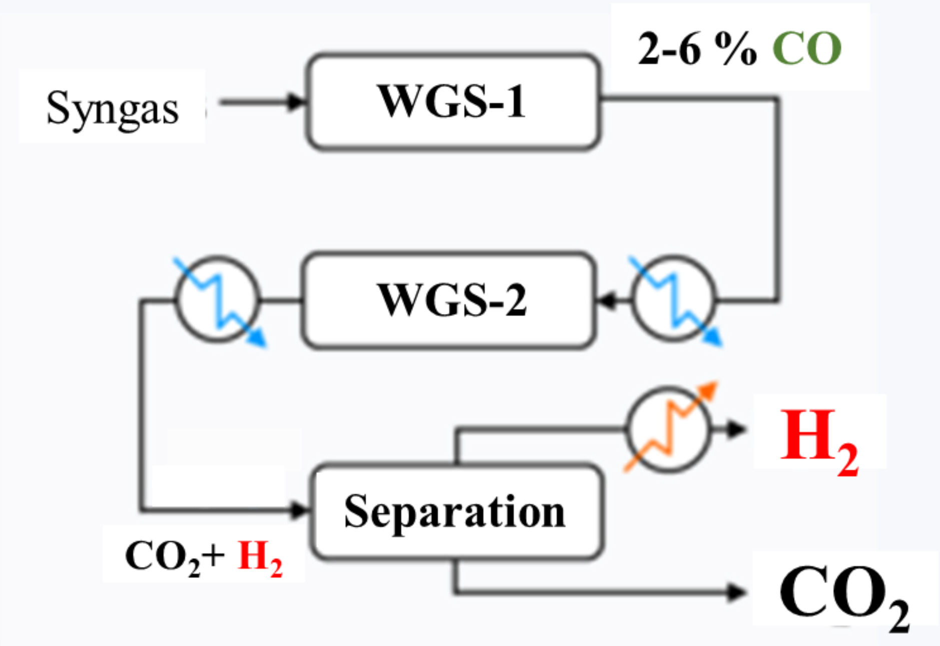


- High- and low-temperature WGS catalyst to maximize H_2 yields
- H_2 separation membrane for warm-gas purification of Hydrogen

Water Gas Shift to maximize H_2 yield

In applications where scrubbed syngas hydrogen/carbon monoxide (H_2/CO) ratio must be increased/adjusted to meet downstream process requirements, the syngas is passed through a multi-stage, fixed-bed reactor containing shift catalysts to convert CO and water into additional H_2 and carbon dioxide (CO_2) according to the following reaction known as the water-gas shift (WGS) reaction:

$$CO + H_2O \leftrightarrow H_2 + CO_2$$



- Shift reaction operates with a variety of catalysts between 400°F and 900°F
- Effect of pressure on the reaction is minimal
- H_2 production is favored by high moisture content and low temperature for the exothermic reaction.

Low temperature

- Typically uses to reduce residual CO content to below 1%
- Operates between 400°F to 500°F and uses a copper-zinc-aluminum catalyst

High temperature

- Operates between 550°F to 900°F
- Uses chromium or copper promoted iron-based catalysts

Seeding the Hydrogen Economy through Blue Hydrogen

Blue Hydrogen

- Current Consumption of ~7 mtpa (oil refining, fertilizers)
- Competitive cash cost of US$ 1-1.2 /kg
- Drive the H_2 economy (NG spiking, steel etc.) beyond current uses

Coal → Gasification → CCUS

H_2

Green Hydrogen

Renewable Electricity → Power → Power → Electrolysis

H_2

- 2030 H_2 economy: 15 mtpa
- Existing cost structure: US$ 5-6/kg
- Blue H_2, renewables at scale & greening of grid will drive green H_2

H_2 injection in Nat Gas	Power	Steel	Oil & Gas	Fertilizer & Chemicals	H_2 Distribution	Heavy Transport

Energy Security, Economic Prosperity

Source: Dastur

Carbon Capture Utilization and Sequestration

- **Enhanced Oil Recovery**
  - EOR is the process of injecting CO2 into subsurface oil reservoirs to increase overall pressure forcing oil towards production wells.
- **Mineral Carbonation**
  - Carbonation is a process that occurs naturally as part of weathering, where CO2 binds to minerals to form carbonates. The concrete sector can also benefit from carbonation by incorporating CO2 in concrete production. Carbonation during production can increase concrete strength, reducing the volume of cement required, thus reducing carbon intensity and feedstock costs

- **Food & Beverage Industry**
  - The food industry uses CO2 for a range of preservation methods, including as an additive, for packaging, as a refrigerant and to decaffeinate coffee.

- **Agriculture & Horticulture**
  - Greenhouses are sealed off from the atmosphere and therefore require additional CO2 to maintain ambient air conditions while photosynthesis is occurring, thus optimizing growth conditions. As a result, CO2 is injected into greenhouses to stabilize CO2 levels throughout the day and night

- **CO2 conversion to fuels and chemicals**

Indigenous research carried out for CCUS

- Conversion of CO2 to Platform Chemicals – multiple approaches
  - Microbial catalyzed electrochemistry (IICT)
  - Photochemistry coupled with flow synthesis (IIP/IICT)
  - Heterogeneous nanocatalysis (NCL/ IIP)
  - Biomimetic carbonation (NEERI)

- Catalytic bi-reforming of CO2 with methane to H2 rich Syn gas
  - catalysts are being prepared and studied for bi-reforming of CO_2 with methane

- Synthesis, characterization and optimization of biomass derived CO2 sorbents
  - Different biochar-based adsorbents from waste biomass for CO_2 capture have been developed
  - Process has been optimized at lab scale
  - The biomass derived carbon adsorbents are found to be efficient in terms of maintaining its adsorption capacity in repeated cycles

Carbon Capture, Utilization and Storage at IIT Bombay

National Centre of Excellence in Carbon Capture and Utilization

सत्यमेव जयते
Department of Science and Technology
Ministry of Science and Technology
Government of India

XPRIZE CARBON REMOVAL | MUSK FOUNDATION

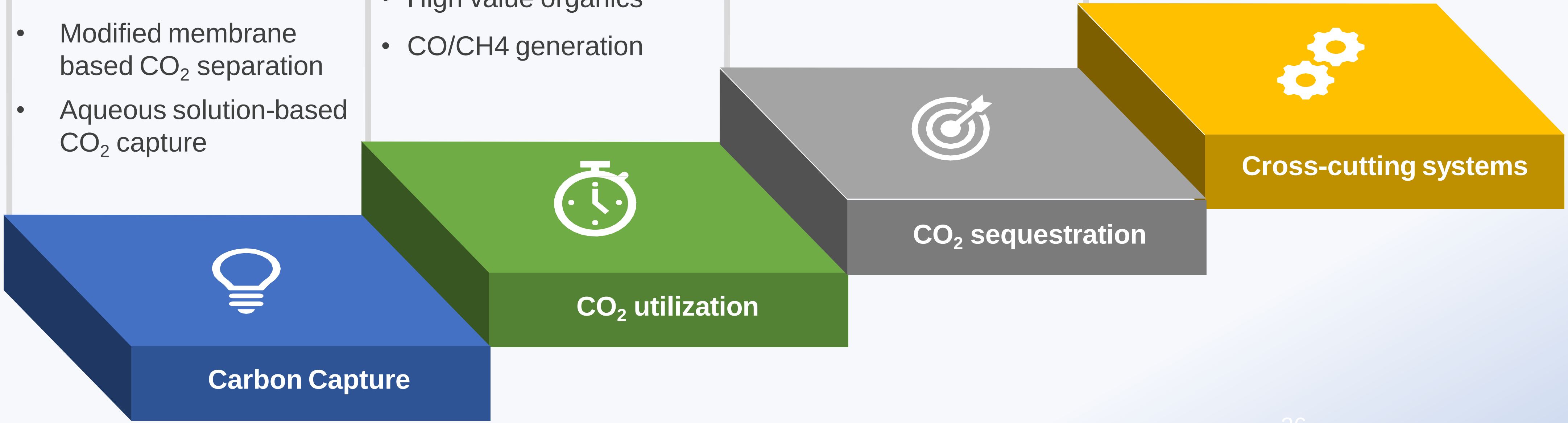
MISSION INNOVATION

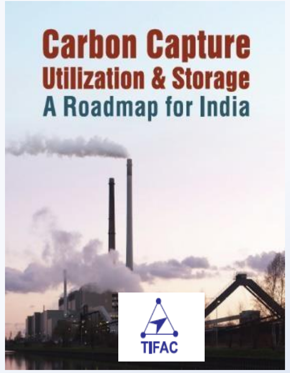
- Nanofluid amine based solutions
- Modified membrane based CO_2 separation
- Aqueous solution-based CO_2 capture

- CO_2 valorization
- Methanol production
- High value organics
- CO/CH4 generation

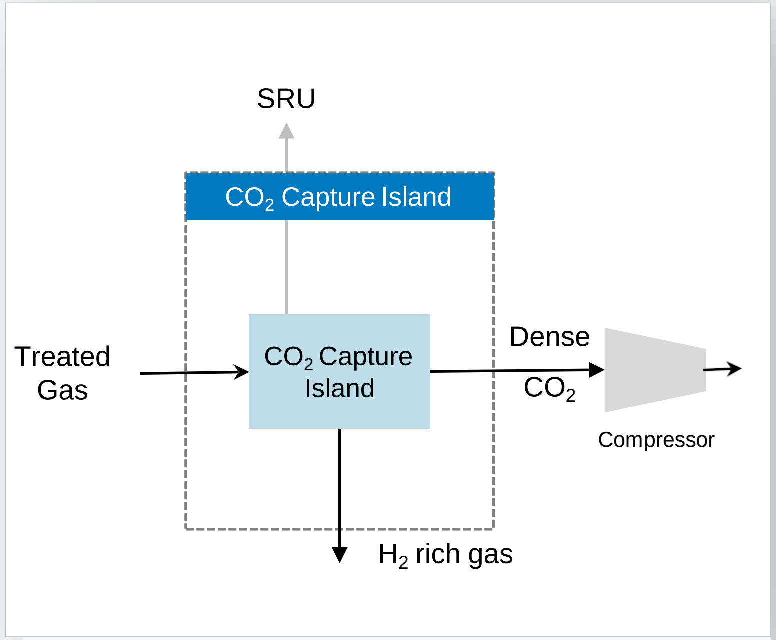
- Country-wide capacity assessment
- Enhanced oil recovery
- Enhanced CBM recovery
- Mineralization

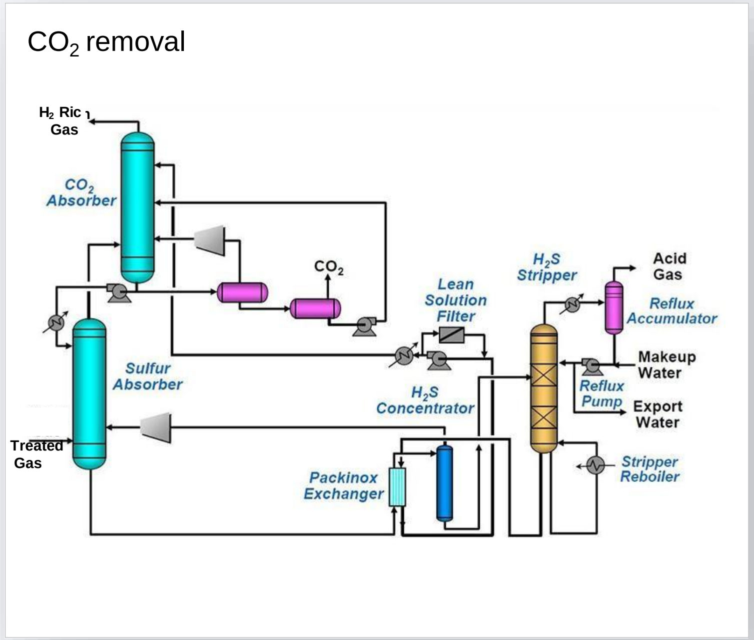
- CO_2 transportation
- Life-cycle analysis
- Techno-economic analysis
- Bioenergy based CCS (BECCS)
- Environmental Impact Assessment

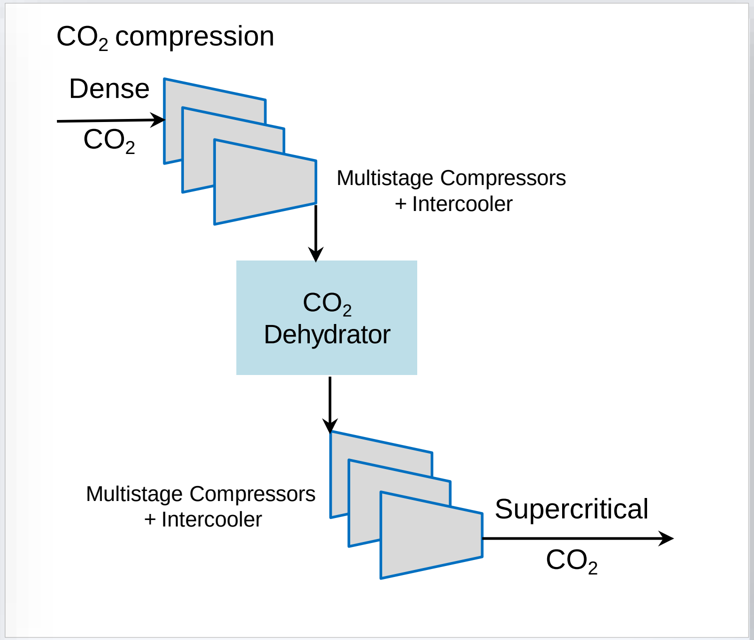




CO_2 Removal Unit







Source: UOP Honeywell

- Treated syngas input at high pressure

Physical absorption for high pressure operation

Selective removal of high concentration CO_2 and H_2S

Lower OPEX due to high CO_2 concentration and cheap solvent cost

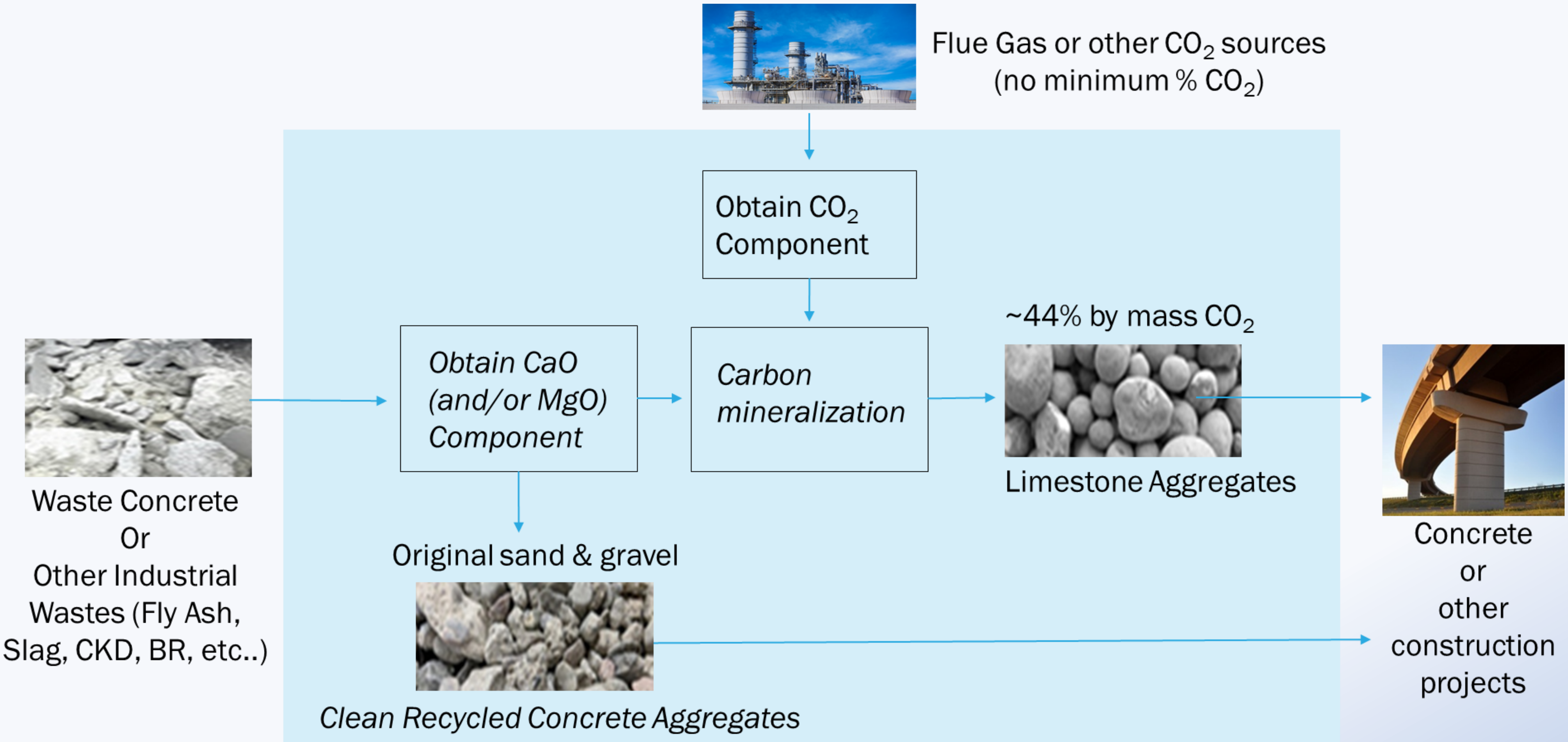
97% of CO_2 removal

CO_2 compression to super-critical stage for transportation

H_2S utilised for elemental sulphur or H_2SO4 production

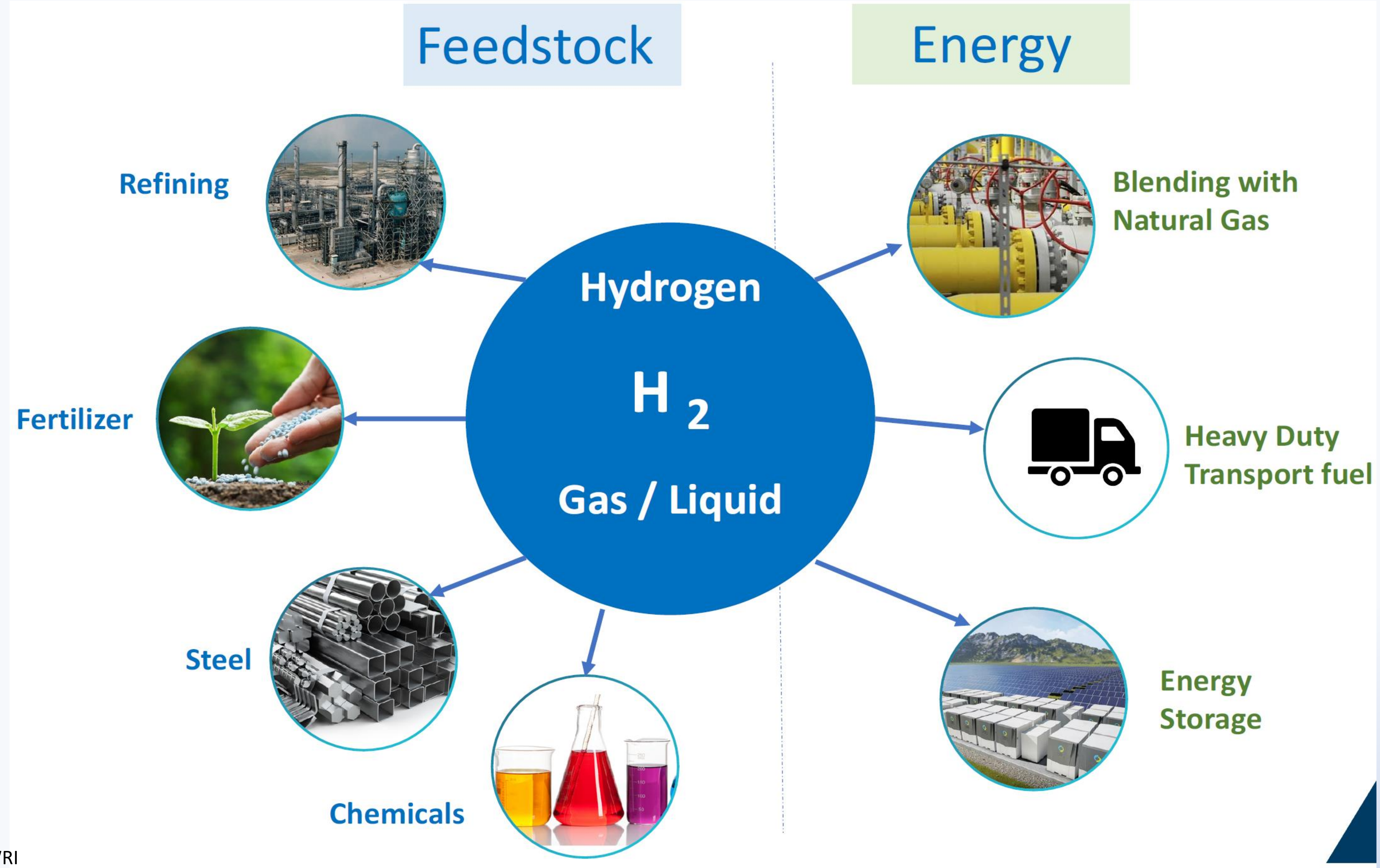
Source: UOP/Dastur

CO2 to Limestone/concrete aggregates



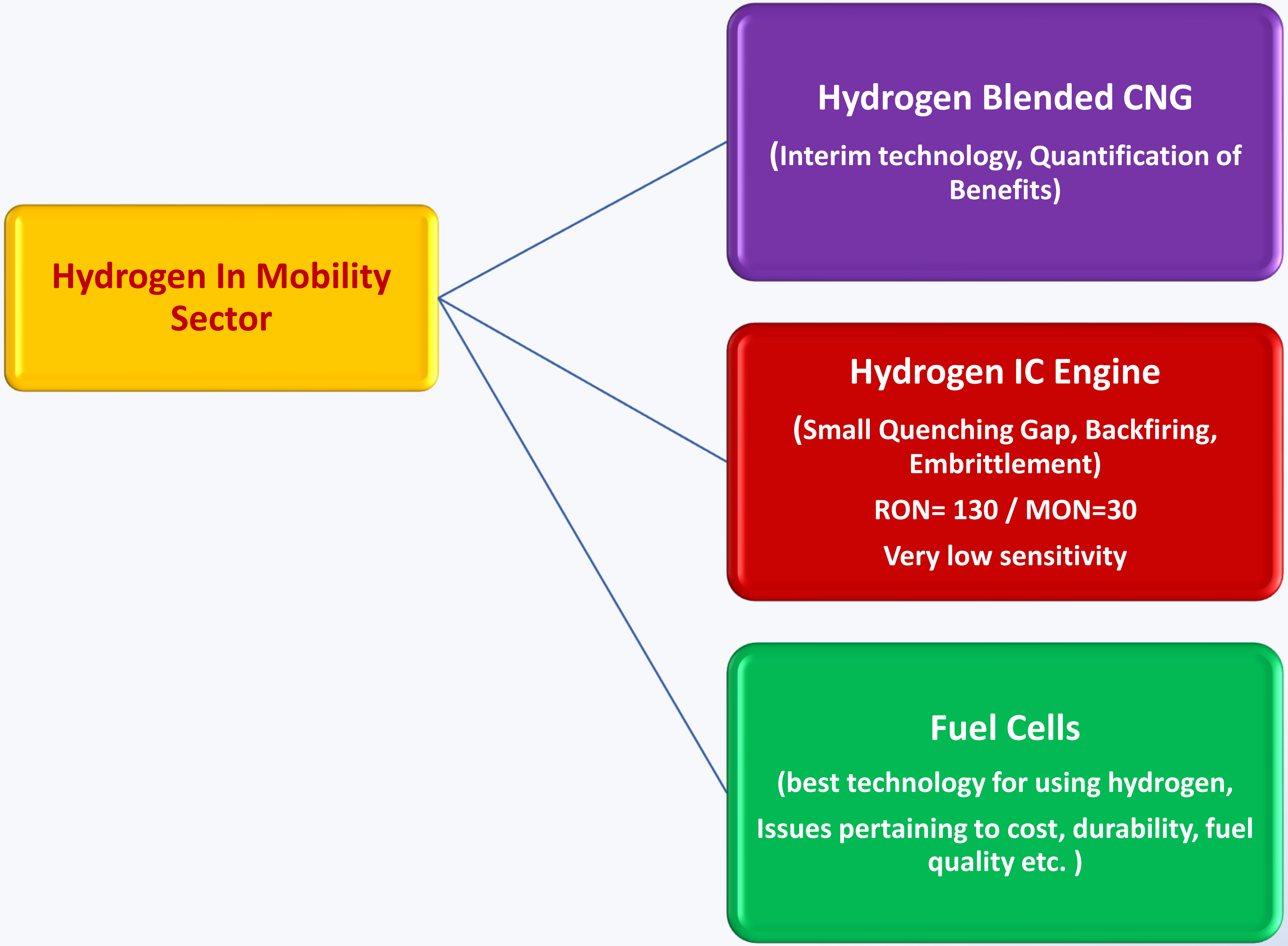
Source: Blue Planet

Applications of Hydrogen



Source: WRI

Hydrogen in Mobility Sector



Opportunities for Hydrogen in the steel sector

- India is blessed with large reserves of high grade Iron Ore and Non Coking Coal
- Natural Gas based production may be an alternative but domestic availability and cost of gas is a big constraint. Reformed Natural Gas can be enriched with Hydrogen.
- Hydrogen / Hydrogen enriched syn gas can be injected into the Blast Furnace to minimize GHG emissions.

Hydrogen usage in refineries/O&G sector

- Part of the hydrogen gets produced as by-product of Catalytic Reforming Process (~15% - 30%) while Rest is produced from Steam-Methane Reforming (SMR)+WG Shift reaction

- Hydrogen use in Petroleum Refining is for Hydro-treating of petroleum products (Desulphurization) and conversion of heavier petroleum feedstock into lighter and more valuable product

- Hydrogen produced from coal can reduce dependence on import of natural gas and Hydrogen canalso be injected in the Natural Gas and used as a HCNG fuel in vehicles and as H + PNG mixture fuel in cooking

Usage of H2 in **in** Fertilizer sector

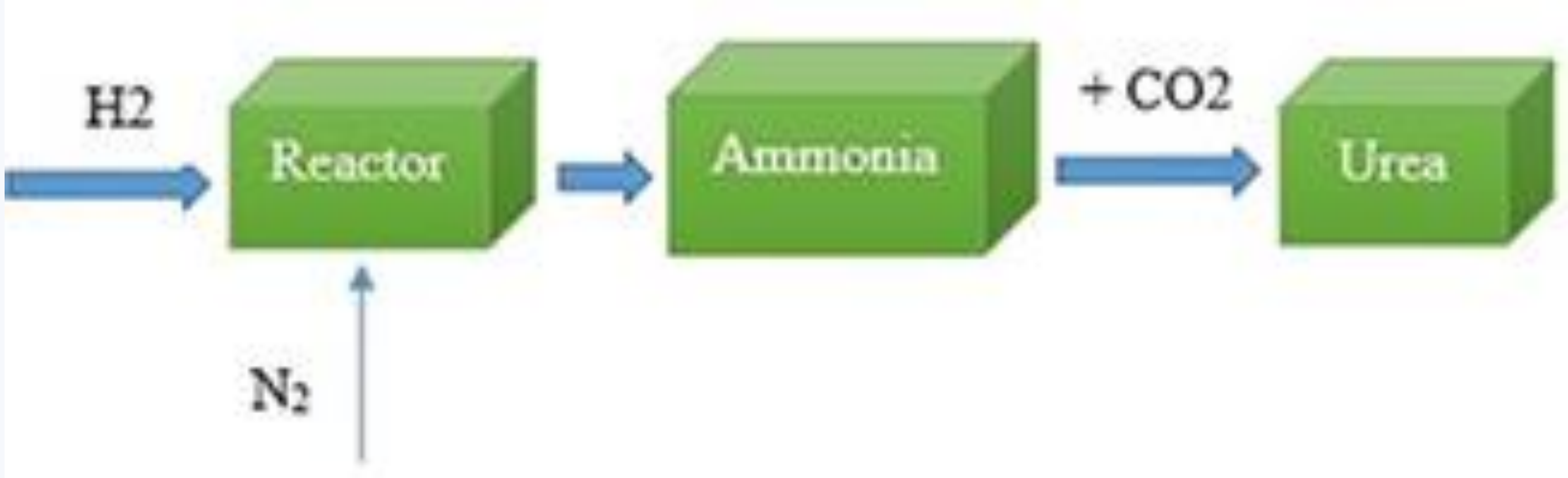
Hydrogen is used for production of NH_3 through Haber's process in Fertilizer industry

Ammonia is used for production of Urea and non-urea fertilizer like DAP

Hydrogen consumption in urea production is approximately 0.1 kg/kg of urea.

Hydrogen consumption in DAP production is approximately 0.035 kg/kg of DAP.

India consumes 3.1MMTPA of H2 for production of approximately 15 MMTPA of Ammonia



Hydrogen Storage

Most appropriate storage medium depends on the volume to be stored, duration of storage, required speed of discharge, and the geographic availability of different options

- Today hydrogen is most commonly stored as a compressed gas or liquid in tanks for small-scale mobile and stationary applications. The majority is either produced and consumed on-site (around 85%) or transported via trucks or pipelines (around 15%)

Large scale storage	Physical storage	Materials based storage
• Geological storage: Salt caverns, depleted natural gas or oil reservoirs and aquifers are all possible options for large scale and long-term hydrogen storage • Storage Tanks	• Compressed Gaseous hydrogen • Liquefied hydrogen • Cryo-compressed Hydrogen • Slush hydrogen (SH2) (stored at Hydrogen's melting point)	• Metal hydride storage systems (with materials such as Palladium, magnesium, etc.) • Liquid hydrogen organic carriers (LOHCs): LOHCs present an option for binding hydrogen chemically • Surface storage system (sorbents): hydrogen can be stored as a sorbate by attachment

Hydrogen Transmission & Distribution

The low energy density of hydrogen means that it can be very expensive to transport over long distances

The most common hydrogen transportation means, covering the needs of the different hydrogen markets, are:

- Cylinders/ Containers/ Tankers
- Pipelines
- Ships

India has a plan to expand its natural gas pipeline infrastructure from the present 17,000 kms to 27,000 kms in the next few years; designing the upcoming pipelines for hydrogen transportation will be critical for its distribution in the country

There are two potential scenarios for transporting hydrogen via pipeline:

- **Methane enrichment:** Injection of hydrogen into existing natural gas pipelines up to specified concentrations
- **Transport of 100% hydrogen** via new or existing pipelines

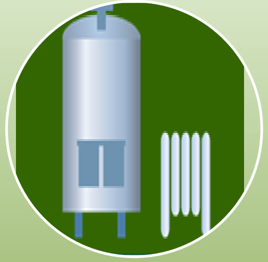
However due to existing design (designed for 200 – 250 Bar) of pipelines, transport of hydrogen from pipelines is not possible due to higher pressure (700 Bar) requirements

Hydrogen Supply-Chain

From Source to End-point

Production

Purification



Compression

Bottling & Transportation

Delivery at site

Long Supply-chain significantly increases the total delivered cost of hydrogen at site

Key focus areas

MAKE

Increased Low Cost Hydrogen Production

MOVE

More Efficient Hydrogen Transmission

USE

Low Cost Value added Applications

STORE

Improved Bulk Storage Technologies

Way Forward

- Create infrastructure for hydrogen economy by using hydrogen irrespective of color while expeditiously moving towards integration of CCUS technologies with Coal gasification.
- Blue hydrogen even today is a techno-economically feasible pathway for the hydrogen economy, industrial decarbonization and reaching India's net zero goals.
- Industrial scale and commercially established technologies amenable for gasification of Indian coals and addition of CCUS will be cost effective solution for providing low-cost clean energy with energy security.
- We could map and characterize the pore space in India for CO_2 sequestration in addition to the EOR in oil fields.
- CO_2 to value-added products (concrete and chemicals) could be a powerful tool to drive decarbonization of various sectors.
- We need to simultaneously work to reduce cost of Green Hydrogen and move towards it but need not wait for it to happen.

Action Plan – Hydrogen Production

Short term

- Focus on hydrogen production from fossil fuels and transition from Grey/Brown to Blue Hydrogen
- Hydrogen production from Coal gasification and Natural gas reforming with CCUS technologies
- R&D activities should increase in areas of hydrogen production from fossil fuels with carbon sequestration, biomass and coal gasification route
- R&D focus on improved efficiency and cost of electrolysis for green Hydrogen

Medium & Long term

- Pilot projects for hydrogen production from renewables and advance process should move towards commercialization. Achieving economies of scale to produce hydrogen through renewables route should be prioritized.
- Economy of scale to be achieved and cost of Hydrogen production to be competitive with alternate fuel.

Need not focus on green Hydrogen alone but Piggyback on Blue hydrogen to create Hydrogen Economy

Action Plan – Hydrogen Storage & Transmission

Short term

- Blending Hydrogen in Natural Gas for transportation through existing natural gas pipelines
- Cylinders with storage upto 700 bars to be developed; PESO should grant approvals and develop standards
- Create infrastructure with grey and blue Hydrogen and not wait for widespread availability of green Hydrogen

Medium & Long term

- Ensuring future pipelines are compatible when used for transporting hydrogen
- Hydrogen can be converted to ammonia, it's easier to transport ammonia over long distances, and at consumption centre it can be reconverted back to hydrogen; To work on bringing down the cost of conversion and reconversion
- Fast track approvals for type IV Hydrogen cylinders & systems for Hydrogen transmission

Action Plan – Regulatory

- **FAME like benefits & tax incentives should be extended to Fuel Cell vehicles in order to pave path for the faster deployment of hydrogen-based economy**
- **Encourage & Incentivize CCUS projects for production of Blue Hydrogen at least till 2030**
- **PLI benefits to include electrolysers, hydrogen compressors, type IV cylinders and related infrastructure for hydrogen**
- **Adoption of already existing International standards for Hydrogen production, storage and transmission and avoiding reinventing the wheel**
- **PESO to facilitate amendment of relevant policies/rules like Gas cylinder rules and Static & Mobile Pressure vessel rules for Hydrogen**
- **Promotion of Hydrogen in power to gas networks, implement incentive schemes regarding use of low carbon and clean hydrogen as an industrial feedstock, blending in transportation/cooking fuels, review gas pipeline regulations to consider including gaseous hydrogen, to create a 'market pull' for hydrogen economy**

THANK YOU

rkmioc@gmail.com