GREEN HYDROGEN – AN UNDERSTANDING

Energy, Process, Technology, Sustainability - Sector Transition Advisory

Our History & Services at Glance

CHEC (C.H. Enterprise & Consultants) was setup in 2019 with aim to provide wide range of services to industrial sector including Energy, Process, Technology & Sustainability.

We offer various Consulting Services to the specific requirements by sector addressing the needs of Industries, Project Developers, Financial Institutes and Equity Investors.

CHEC is founded by professional with over 29 years of strong Energy, Process, Technology & Sustainability sector stint.

Strategic & Risk Advisory

Addressing the needs of sector & Projects, range of services with deft in understanding the problems & its resolution

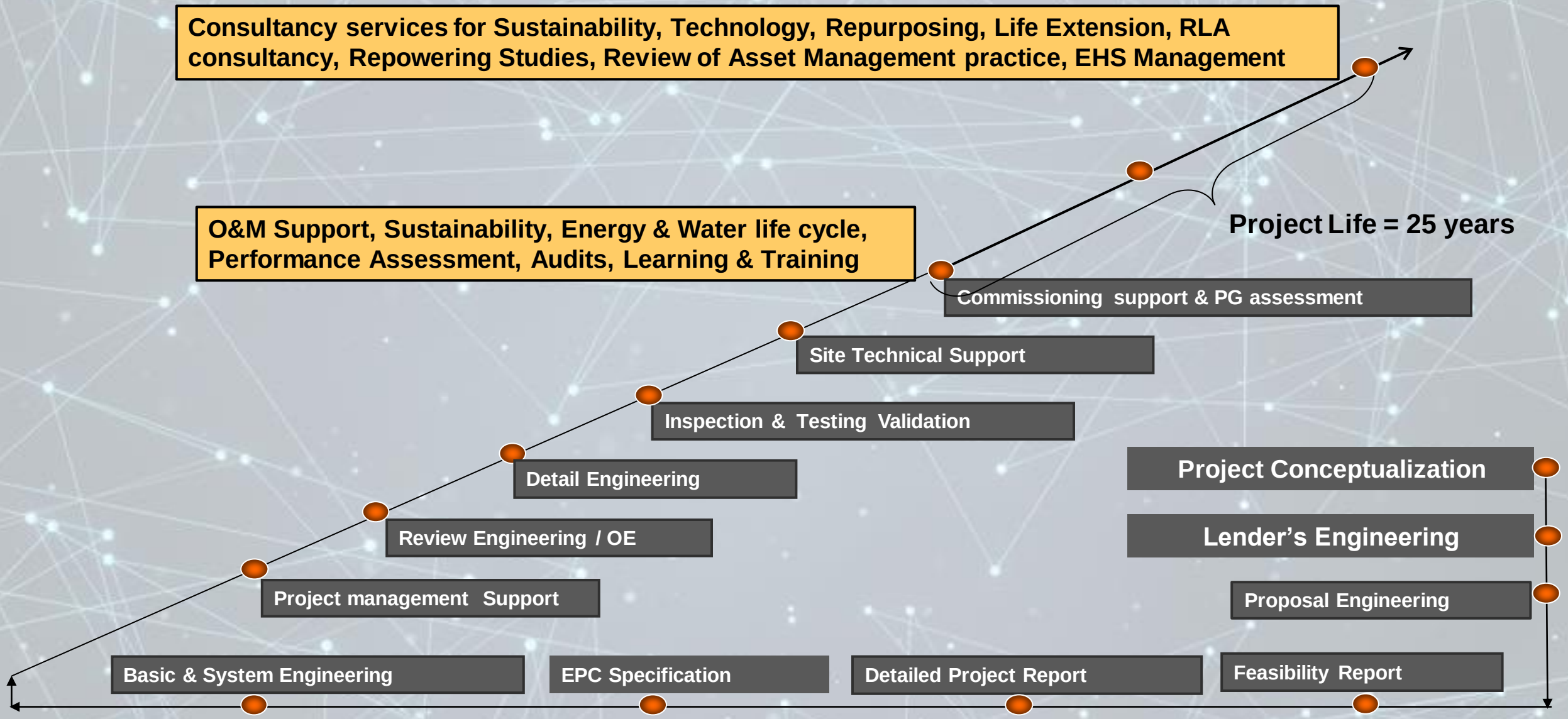
Sustainability &Technology Ideas

Looking beyond horizons, considering possibilities. Exploring upcoming trends in Energy, Process, Sustainability & Technology avenues

Prioritize Clients & Needs of Business

Responding to Client's needs. Services designed in line with requirements for Corporate compliance

Value addition across Project lifecycle



Green Energy Drive Background

- India has committed reduction of carbon emissions in steps and eventually become Net zero carbon by 2070.
- As of 31 January 2022, the total installed capacity for renewable energy in India is 152.4 GW.

Hydro Power	Small Hydro Power	Wind Power	Bio-Power		Solar Power	Total Capacity
			BM Power/Cogen.	Waste to Energy		
46512.22	4839.90	40100.93	10175.61	434.11	50303.58	152366.35

- As a country, India has committed 500 GW from Renewable sources by 2030.
- There are limitations of VRE to replace conventional energy sources during meeting peak power demand / surges. In wake of it, many other measures are studied and under deployment e.g. Batter storage, Pumped storage, hydrogen energy etc.
- For accommodating other energy requirement like transportation, industry and other demand, there has to be parallel efforts to bring up energy sources like Hydrogen which can be abundantly made available to human race.

Green Energy Growth Drivers

Government commitments

- Reduce India's total projected carbon emission by 1 bn tones by 2030, reduce the carbon intensity of the nation's economy by less than 45% by the end of the decade, achieve net-zero carbon emissions by 2070 and expand India's renewable energy installed capacity to 500 GW by 2030.

Proposed solar cities and parks

- 1 solar city per state-approved and approval setting up 45 solar parks of 37 GW across the nation
- Solar Parks in Pavagada (2 GW), Kurnool (1 GW) and Bhadla-II (648 MW) included in top 5 operational solar parks of 7 GW capacity in the country.
- The world's largest renewable energy park of 30 GW capacity solar-wind hybrid project is under installation in Kutch, Gujarat.

New areas of opportunities

- Wind – Solar Hybrid, Off-shore Wind Energy, Floating PV Projects, Green Hydrogen

Atmanirbhar Bharat

- PLI scheme in Solar PV manufacturing with financial outlays of INR 24,000 crores introduced under Atmanirbhar Bharat 3.0. Imposition of Basic Customs Duty of 25% on Solar Cell & 40% on Solar PV Modules w.e.f. 01.04.2022.
- 5 – 7% Bio mass pallets to be co-fired with coal in thermal power plants resulting in saving of 38 MT of carbon dioxide annually.

Green Energy - India Status

India Green Energy Fact Sheet

Fifth-largest solar installed capacity in the world

4th largest installed capacity of renewable energy in the world

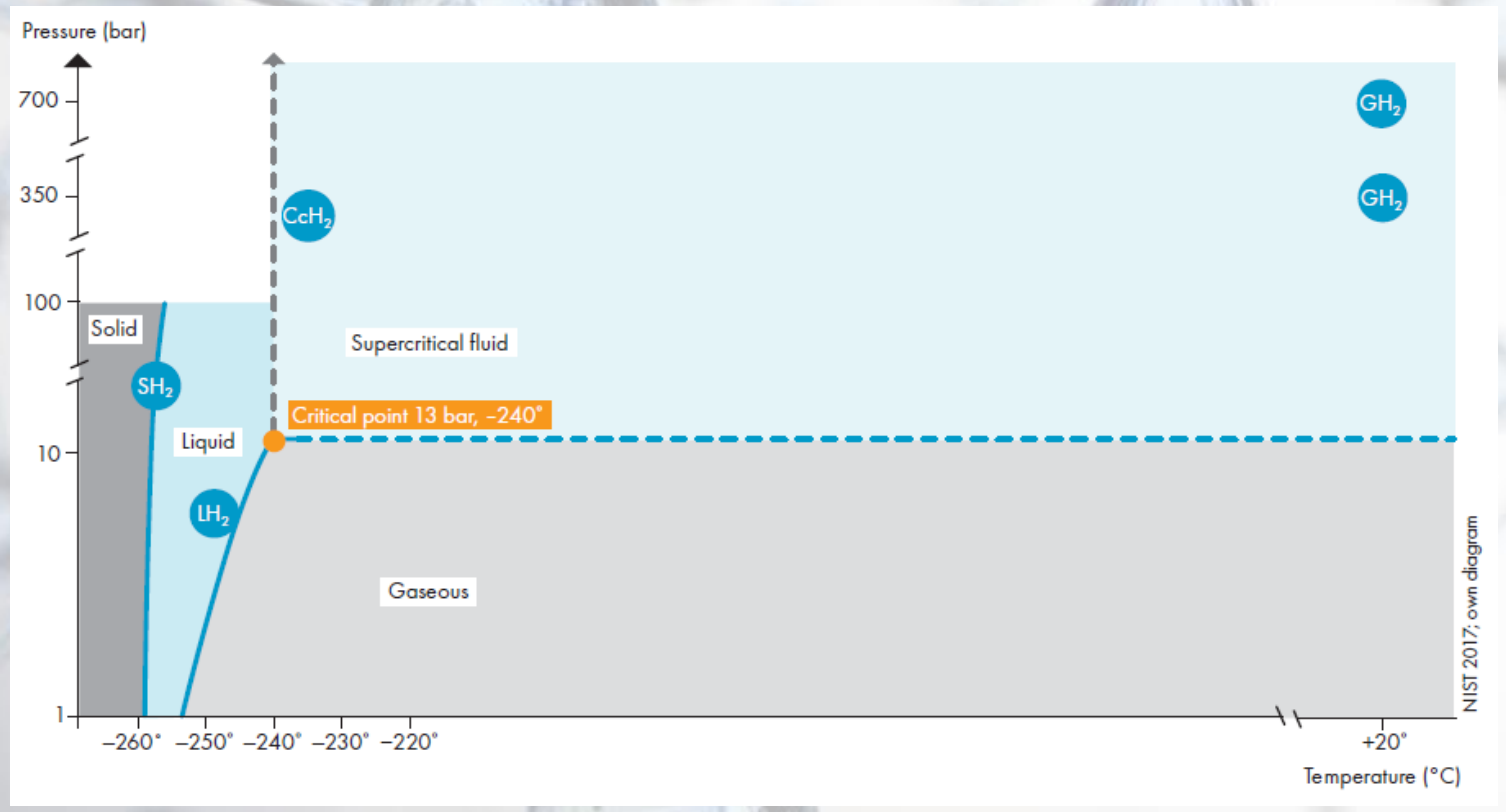
4th largest installed capacity of wind power in the world

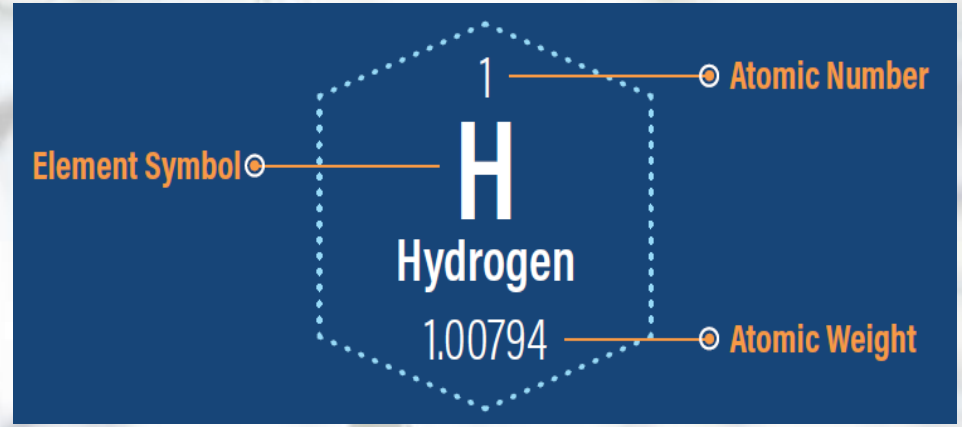
Hydrogen Properties as Energy Carrier

- Hydrogen is the most abundant element in the universe.

On Earth too, hydrogen is abundant in the form of water and as gas in the atmosphere.

Hydrogen Phase Diagram

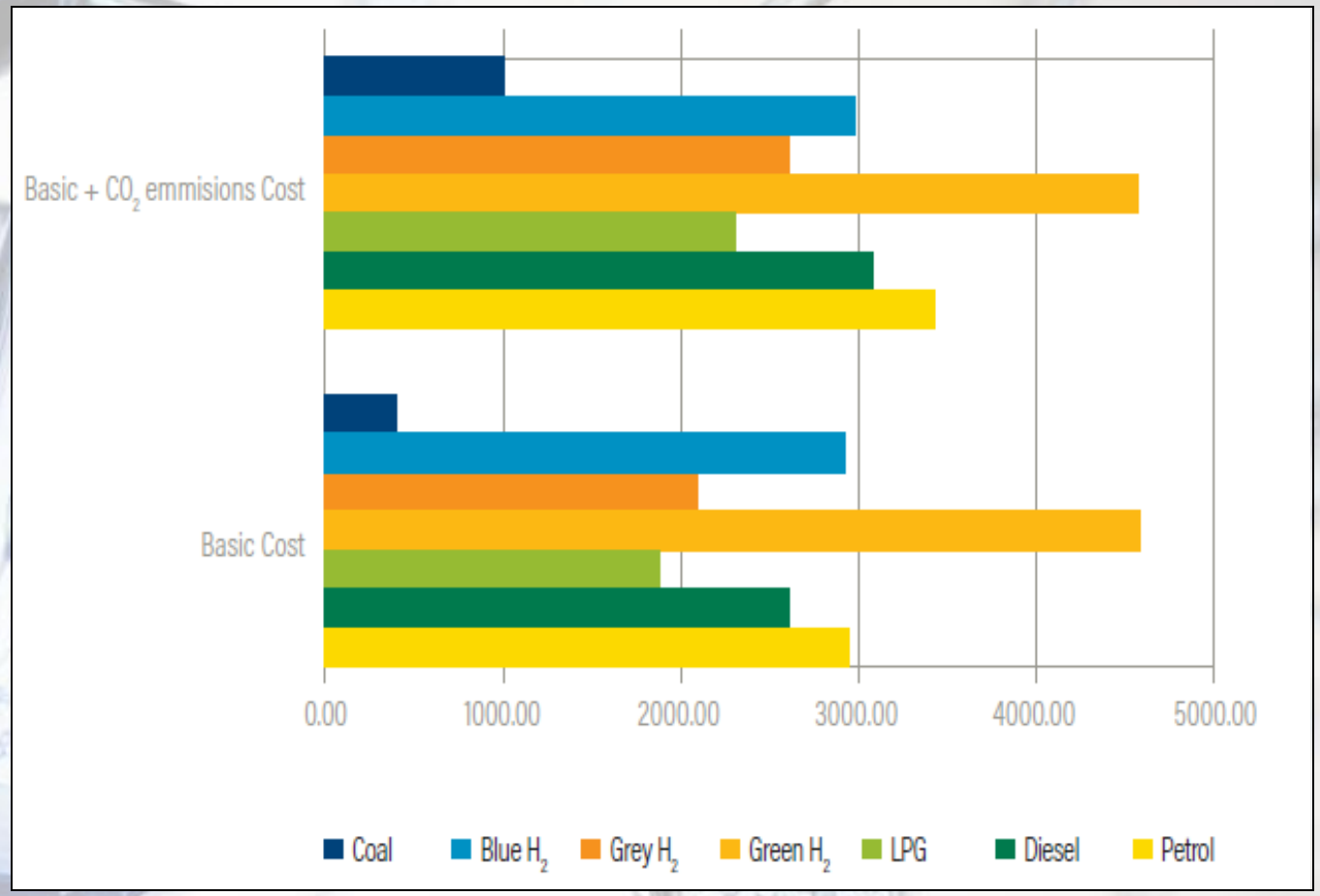




Melting Point: **1 3.81 K** (-259.34°C or -434.81°F)
Boiling Point: **2 0.28 K** (-252.87°C or -423.17°F)
Density: **0 .00008988** grams per cubic centimeter
Phase at Room Temperature: **Gas**
Element Classification: **N on-metal**
Period Number: **1**
Group Number: **1**

Costs of Various Energy Sources

- Hydrogen does not exist freely in nature, is an energy carrier that can only be produced from another energy source such as water, fossil fuels, or biomass and can be used as a source of energy or fuel.
- Hydrogen has the highest energy content as compared with other commonly used fuels by weight, about 3x as compared to gasoline. However, it also has the lowest energy content by volume, about 4x lesser than gasoline. With an average worldwide consumption of about 70 million tons, its primary use remains in petroleum refining, ammonia production, metal refining, and electronics fabrication.



Above figure depicts the basic cost of generating 1,000 MJ of energy from different fuels after accounting for the market rates of these fuels and assuming the rate of coal to be INR 10 per kg.
The cost of carbon emissions from each fuel was calculated at the rate of INR 6.45 per kg (86 USD per ton) of CO2. It was observed that in terms of energy content (1,000 MJ), hydrogen is reaching cost parity with conventional fuel. Source : WRI

Hydrogen Production Processes & Types

- The global demand for pure hydrogen is more than 70 MMT in 2019.The current demand for hydrogen is fulfilled mainly by fossil fuels, including natural gas, oil and coal. Now recently we are talking about Hydrogen production from water by using electricity from solar generation. The different processes used for producing hydrogen are thermochemical, electrolytic, direct solar water splitting, biological and nuclear as listed in table.
- Although colorless and invisible, hydrogen has been color-coded by the energy industry to differentiate it on the basis of the source or process by which it is produced.

Sr. No.	Process	Technology	Method / Source
1	Thermochemical Process (Catalyst)	Steam Methane Reformation	Natural Gas
		Coal Gasification	Coal
		Biomass Gasification	Incomplete combustion of biomass, including bio-waste, agricultural waste and municipal waste
2	Electrolytic Process (Splitting of water using electricity)	Alkaline	Aqueous solution (KOH/NaOH) as the electrolyte
		Polymer electrolytic membrane	Polysulphonated membranes are used as the proton conductor
		Solid oxide electrolysis	Solid ceramic material as electrolyte
		Anion Exchange Membrane	Solid polymer membrane made of polymer backbone and cationic groups
3	Photolytic Process (Splitting of a water molecule using sunlight)	Photoelectrochemical	Using semiconductor light absorbers
		Photobiological	Microorganisms, such as green microalgae or cyanobacteria, use sunlight
4	Biological Process (Using microbes, the organic matter is decomposed in presence of sunlight)	Microbial mass conversion	Hydrolysis and fermentation of biomass
		Photobiological	Microorganisms, such as green microalgae or cyanobacteria, use sunlight

Color	Process
	Grey: natural gas reforming without CCUS
	Brown: brown coal (lignite) as feedstock
	Blue: natural gas reforming with CCUS
	Green: electrolysis powered through renewable electricity
	Pink: electrolysis powered through nuclear energy

Electrolysis Process & Details

- Electrolysis is the breaking down of water molecules into hydrogen and oxygen using electricity and has been applied for more than 100 years. It provides a very befitting option to produce hydrogen using renewable energy. The process takes place in an electrolyzer that consists of anode and cathode electrodes separated by electrolytes. Water is used as primary input for electrolyzer technology.
- There are four types of technologies that provide readiness levels - alkaline (AE), polymer electrolyzer membrane (PEM), solid oxide (SOE) and anion exchange membrane (AEM). AE, PEM and AEM are low temperature technologies that provide higher readiness levels commercially whereas SOE is a high temperature technology. A comparative analysis between these Technologies are as given.

Alkaline Electrolysis

- Uses aqueous KOH / NaOH solution as conduting membrane
- Matured technology & commercially available
- Operates at 30–80° C temperature
- Efficiency of 63-70%

Polymer Electrolyzer Membrane

- Uses polysulphonated membrane for proton exchange & platinum, iridium oxide as electrocatalyst
- Operating as small pilot plants
- Operates at 30–80° C temperature
- Efficiency of 55-60%

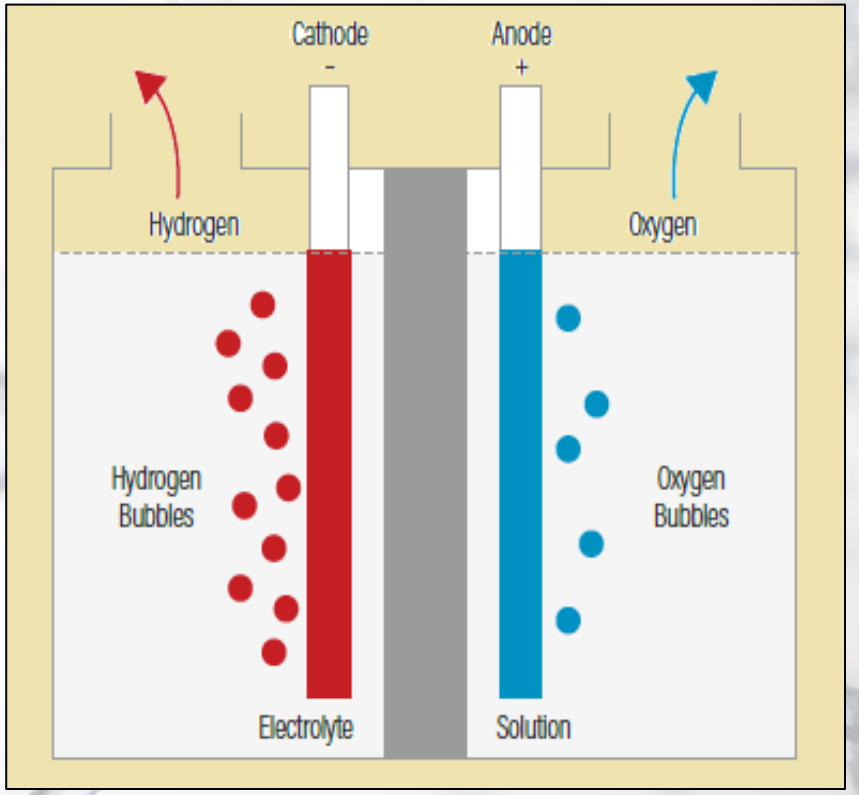
Solid Excide Electrolyzer

- Uses solid ceramic membrane
- At R&D scale now
- Operates at 500–850°C
- Efficiency of 74-80%

Anion Exchange Membrane

- Uses ionsomer membrane
- At Demonstration scale
- Operates at 50–60°C
- Efficiency of 55-69%

The diagrammatic representation of Electrolysis process is below.



Green Hydrogen Production Economics & Comparison

- There are four main stages in the hydrogen value chain: production, storage, transportation and utilization. These four states interconnect the entire hydrogen energy system. The selection of the hydrogen production process depends on the availability of feedstock / inputs, the type of energy and the end-user requirements.
- Currently, the economics of Green Hydrogen production are summarized in table.

Sr. No.	Electrolyzer Type	H_2 Purity (%)	Hydrogen Output (kgh)	Stack Lifetime (in 1000 Hrs.)	Capital cost (USD/kW)	Production cost (USD/Kg of H_2)
1.	Alkaline Electrolyzer	99.50	< 68.3	60 – 90	900 – 1850	6 – 7
2.	Polymer Electrolyte Membrane	99.99	< 3.59	20 – 60	1700 – 1850	8 – 10
3.	Solid Oxide Electrolyzer	99.90	< 3.59	< 10	> 1850	- N.A.-
4.	Anion Exchange Membrane	99.99	< 0.089	> 5	- N.A.-	- N.A.-

Green Hydrogen Storage & Transportation

- Hydrogen is a highly flammable fuel, making safety a crucial aspect in hydrogen storage, transportation and distribution technology aspects.
- For easy transportation, the volumetric density of hydrogen can be increased by compressing hydrogen and then storing it in pressurized cylinders. An alternative method to increase the density of the fluid is to liquefy the gas at a temperature of -253°C.
- However, liquefaction is an energy-intensive process and consumes around 30% of the total energy content of hydrogen. Due to heat gain and boiloff, transportation of liquid hydrogen results in energy losses.
- Road transport using pressurized containers is the normal way of transporting hydrogen but liquefaction of hydrogen for transport results in a significant increase in its energy density and allows for carrying upto 10 times more hydrogen.
- Pipelines (existing or new), although a well developed option, requires more capital expenditure and is more suited for large volumes. A simpler option is to have onsite hydrogen generation, which eliminates the cost of transportation.

Green Hydrogen Storage & Transportation – Pros & Cons

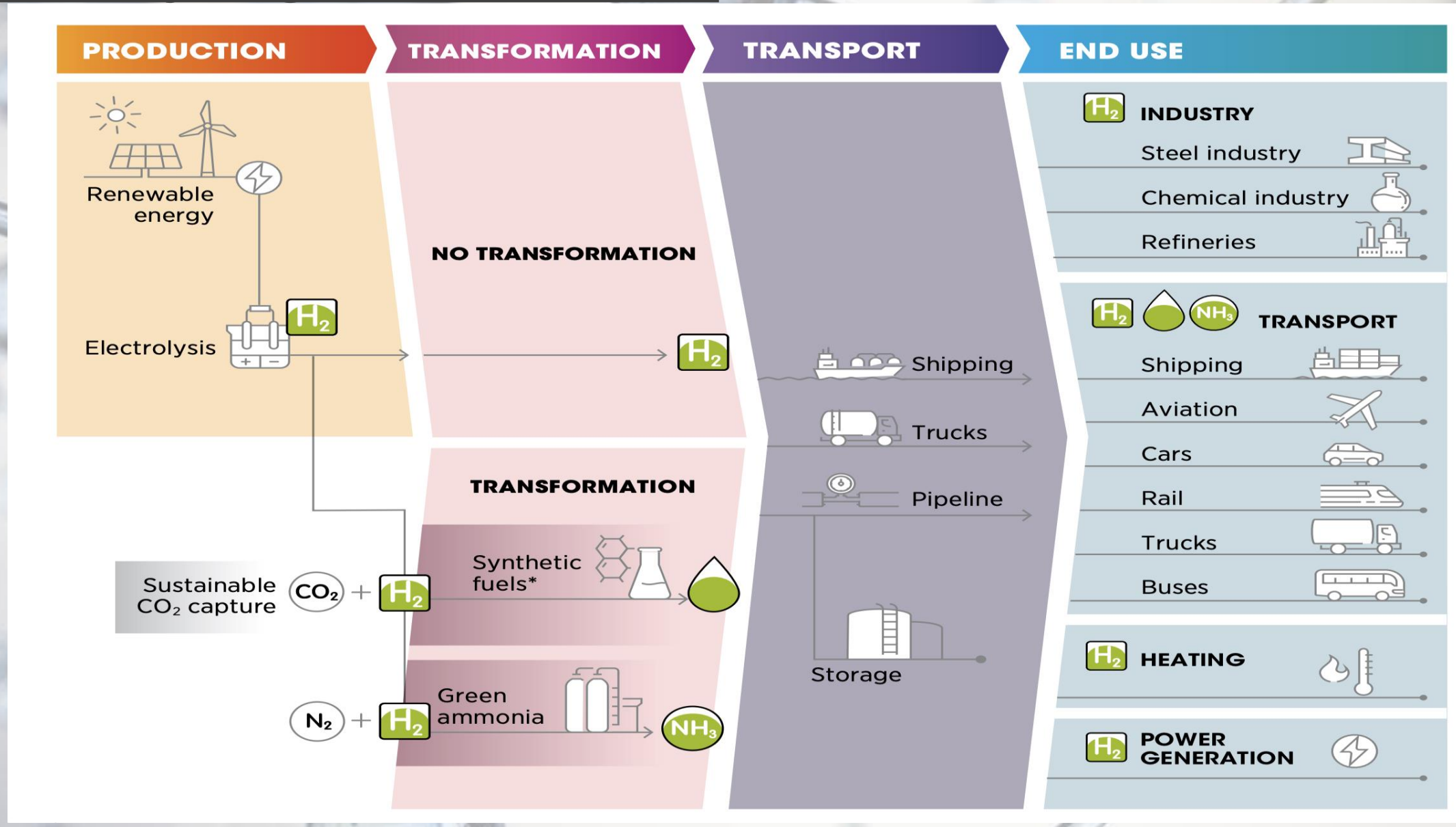
Storage Methods	Advantages	Limitations
Pressurized Storage	Matured technology, High efficiency	Specialized materials required to withstand high pressure
Cryogenic	Higher liquid density, Suitable for large quantities	High liquefaction costs, boil-off gas management and expensive materials required
Metal Hydride	Relatively high density, Modular operation	Emerging technology, not commercialized, heavier to handle

Transportation Mode	Bottlenecks	Limitations
Pressurized container or cylinders	Limited quantity can be transported	Specialized material to withstand the pressure and weight
Cryogenic	Liquefaction costs are high	Require special material to carry and to boil-off to be addressed
Pipelines	Safety issues such as leak detection, fire safety	Construction cost is high, RoW issues
Onsite production	Economical technology	Electrolyzer and electricity cost to be reduced

Green Hydrogen – Roles across Value Chain

Segments	Key subsegments	Relative importance by 2050[1]	Complementary decarbonization solutions
Transportation	▪ Large cars (fleets) and taxis ▪ Trucks and buses ▪ Light commercial vehicles ▪ Trains	39% 22% 30% 9%	▪ Battery-electric vehicles ▪ Plug-in hybrid electric vehicles ▪ Electrified trains
Heating and power for buildings	▪ Hydrogen blending for heating ▪ Pure hydrogen grids for heating	2% 16%	▪ Electrification of heating via heat pumps ▪ Energy efficiency measures ▪ Biogas/biomass
Industry energy	▪ High-grade heat	23%	▪ Demand side and energy efficiency measures ▪ Electrification ▪ Biogas/biomass ▪ Carbon capture
Industry feedstock	▪ Ultra-low-carbon hydrogen as feedstock for – Ammonia, methanol – Refining ▪ Feedstock in steelmaking (DRI) ▪ Combined with CCU in production of olefins and BTX	100% 80% 20% 30%	*For steel:* ▪ Coke from biomass ▪ CCS on blast furnace *For CCU:* ▪ Carbon storage
Power generation	▪ Power generation from hydrogen ▪ Flexible power generation from hydrogen	2% 55%	▪ Biogas ▪ Post-combustion CCS ▪ Batteries

Green Hydrogen – End Users



Unlocking the Value for Growth

Value Drivers for Growth

- Realizing potential of current Infrastructure
- Extending reach towards EGS goals
- Cohesive work front among Stake holders
- Optimize resources, Maximize throughput, Minimize losses

Stake Holders & Perspectives

Perspective:

- Meeting Obligatory commitment
- Clear knowledge and understanding of policies
- Learning & training of Employees
- Understanding, managing and minimizing Risk
- Ensuring Quality & EHS aspects
- Apt Project management
- Optimizing the resources & performance
- Reduction of plant operating cost, equipment and facility
- Enhanced investment security in facility
- Contribution towards Sustainability & carbon footprint reduction
- Facilitate incremental technology investments for favorable IRR
- Operational challenges resulting process more effective and efficient
- Create an engaging & long lasting corporate goal as well as purpose

Stake Holder's Benefits

- Gain Greater Transparency
- Understand Risks and certainty
- Ensuring Quality
- Strengthen your competitive edge
- Delivering Project on Time
- Gaining confidence for Stake Holders
- Minimise Risk and Disruptions
- Saving critical Resources
- Independent Review
- Increasing Availability & Optimizing Performance
- Safeguard Client's investment
- Strengthen Client's competitive edge

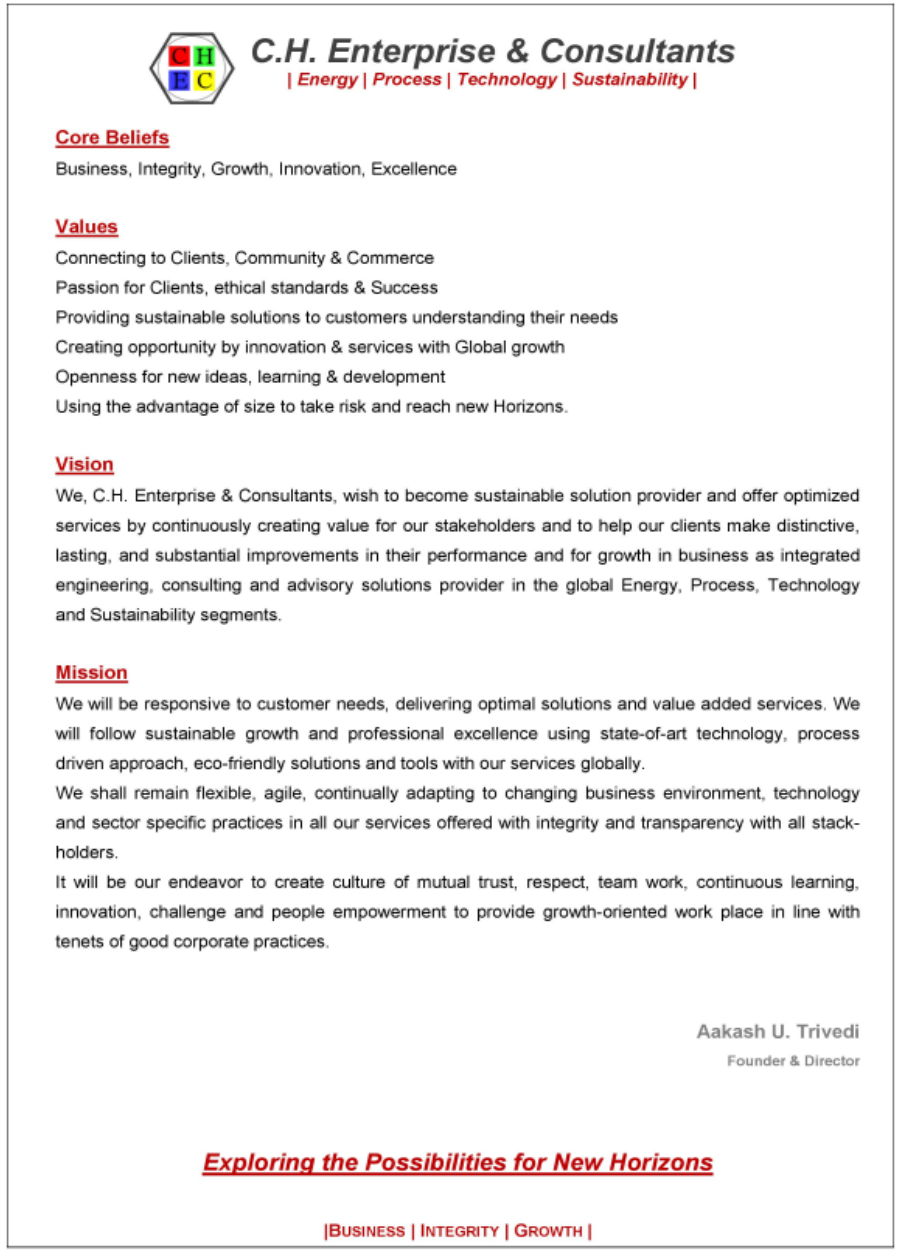
Values, Vision & Mission

Core Beliefs
Business, Integrity, Growth, Innovation, Excellence

Values
Connecting to Clients, Community & Commerce
Passion for Clients, ethical standards & Success
Providing sustainable solutions to customers understanding their needs
Creating opportunity by innovation & services with Global growth
Openness for new ideas, learning & development
Using the advantage of size to take risk and reach new Horizons.

Vision
We, C.H. Enterprise & Consultants, wish to become sustainable solution provider and offer optimized services by continuously creating value for our stakeholders and to help our clients make distinctive, lasting, and substantial improvements in their performance and for growth in business as integrated engineering, consulting and advisory solutions provider in the global Energy, Process, Technology and Sustainability segments.

Mission
We will be responsive to customer needs, delivering optimal solutions and value added services.
We will follow sustainable growth and professional excellence using state-of-art technology, process driven approach, eco-friendly solutions and tools with our services globally.
We shall remain flexible, agile, continually adapting to changing business environment, technology and sector specific practices in all our services offered with integrity and transparency with all stack- holders.
It will be our endeavor to create culture of mutual trust, respect, team work, continuous learning, innovation, challenge and people empowerment to provide growth-oriented work place in line with tenets of good corporate practices.



C.H. Enterprise & Consultants
| Energy | Process | Technology | Sustainability |

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Aakash U. Trivedi
Founder & Director

Exploring the Possibilities for New Horizons

|BUSINESS | INTEGRITY | GROWTH |

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| BUSINESS | INTEGRITY | GROWTH |

| Energy | Process | Technology | Sustainability |