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Circular Economy

India aspires to be five trillion-dollar economy by 2025 thatwould generate business and new entrepreneurs. This would also increase resource and energy consumption and waste generation. To achieve the target of five trillion-dollar economy in tune with sustainable development principles, it is necessary to ensure low carbon footprints for climate-change. Principles of circular economy is going to be the key driver to achieve this mission.

Circular systems emphasize on reuse, repair, refurbish, remanufacture and recycle, thereby minimizing wastes that reach landfills or incinerators, reducing carbon emissions and utilizing clean energy. In contrast to the linear systems that have been working on the concept to create, use and dispose, the circular system is a close-loop system where the use of created products is extended, useful parts of the old equipment are suitably used in refurbishment of same or other type of equipment or for creating a new one. Such materials reduce the need of raw materials, resources, energy (retain embedded energy) and the polluting processes. The wastes of a process or a by-product is used as raw material for the other process or there is resource recovery for manufacturing of a new product. This prevents the wastes from going to landfill sites or incinerators. Only the residual material not worth using again and again goes to landfill/incinerator. The non-toxic biological materials are returned to soil.

Circular economy can be implemented in all sectors. The “regenerative” approach of circular economy is in contrast to throw away attitude of capitalist society of “make, use and dispose”. The developing world has been observing circular strategy since long due to lack of resources and has been reusing, recycling and remaking objects with same or different use. This saves on the material and other costs.

With the environment law enforcing agencies enacting stringent environment laws, many vehicles not conforming to these will go off the roads. This provides immense opportunities for circular strategies to remake vehicles with the old parts of abandoned vehicles.

Plastic industry is another important one for circular economy. Globally, 8.3 billion tons of plastic was produced between 1950-2015. Out of 6.3 billion tons which became waste, 4.9 billion tons reached the dumpsites. With the increasing trend of plastic manufacturing, an estimated 12 billion tons of plastic will be dumped in environment by 2050. Circular strategy in the close-loop system encourages its reuse, recycle, remanufacturing and finally safe disposal. Waste plastic can be used for thermal insulation of houses. In India, major industries dealing with plastic have come together last year, to form an alliance against plastic waste. India recycles or reuses over 90 per cent of all the PET (polyethylene terephthalate plastic) manufactured in the country.

India has also shown improved electronics recycling. By signing ‘extended producer responsibility’ more than 700 electronics producers have come together to reduce e- waste.

There is a huge scope of reusing, repairing, refurbishing, remaking and recycling in the textile industry. Craze for new variety and style has pushed new generation into buying surplus clothes. The owner’s utilization time and recycling of the clothes is very low due to which natural resources of more than $ 500 billion are lost every year, according to the experts.

Economic analysis shows that three important areas, viz. cities and construction, food and agriculture, and mobility and vehicle manufacturing could bring annual benefits of Rs 40 lakh crores worth circular economy by 2050.

India’s material consumption is expected to rise from 7.5 billion tons in 2015 to 15 billion tons in 2030. India’s rate of resource extraction including mining of virgin resources is nearly three times higher than global average. In light of this resource efficiency and waste management can bring down, consumption and waste to almost nil. This will result in huge reduction in millions of tonnes of waste and CO2 emissions.

The government policy arises to enable reuse of waste and redouble recycle rate of key materials to 50% in five years. It envisions setting up a National Resource Efficiency Authority which like the Bureau of Energy Efficiency strategies for key sectors – automobiles, plastic packaging, building and construction sector, electrical and electronic sector equipment sector, solar photo-voltaic sector, and steel &aluminum to begin with.

To implement circular economy principles and circular economy strategies in organizations, the British Standards Institution (BSI) had launched the standard ”BS 8001:2017”. India is realizing the importance of having its own regulatory framework such as National Material Recycling Policy, National Policy on Resource Efficiency, Bureau of Resource Efficiency (BRE) etc. There is a need to integrate resource circularity in the Industrial Revolution (IR) 4.0 strategies.

In India, it is estimated that circular economy may provide opportunities worth $218 billion per year by 2030. According to NITI Aayog CEO Amitabh Kant, fast increasing human population will raise the total global mineral and material demand from 50 billion tonnes in 2014 to 130 billion tonnes in 2050. For sustainable development, resource efficiency and circularity is imperative.

Produce, consume and discard needs rejuvenation. Resource efficiency and waste management will need to be the key drivers of a green strategy, because it is now the only viable path, capable of creating growth, new enterprises, and a clean environment.

2020 is an essential milestone towards agenda 2030, a global commitment to achieve sustainable development by 2030.

Technologies for Hydrogen Production[1] - *Dr. J P Gupta*

Processes:

- Thermal processes: Use the energy in various feed stocks i.e. natural gas, coal and biomas to release the H2 that is the part of their molecular structure. Thermo-chemical processes use heat in combination with a closed chemical cycle to produce H2 from water. Steam reforming of natural gas is the main thermal process for hydrogen production. The process involves reaction of natural gas and steam over nickel based catalyst. The process breaks methane component of the natural gas into carbon monoxide (Cr) and H2 gas.

- Electrolytic processes: These process use electricity to split water into chemical constituents Hydrogen and Oxygen (O2) using electrolyzer.

- Photolytic Processes: These process use light energy to split water into H2 and O2.

The Table below shows the operating characteristics of the four types of electrolyses:

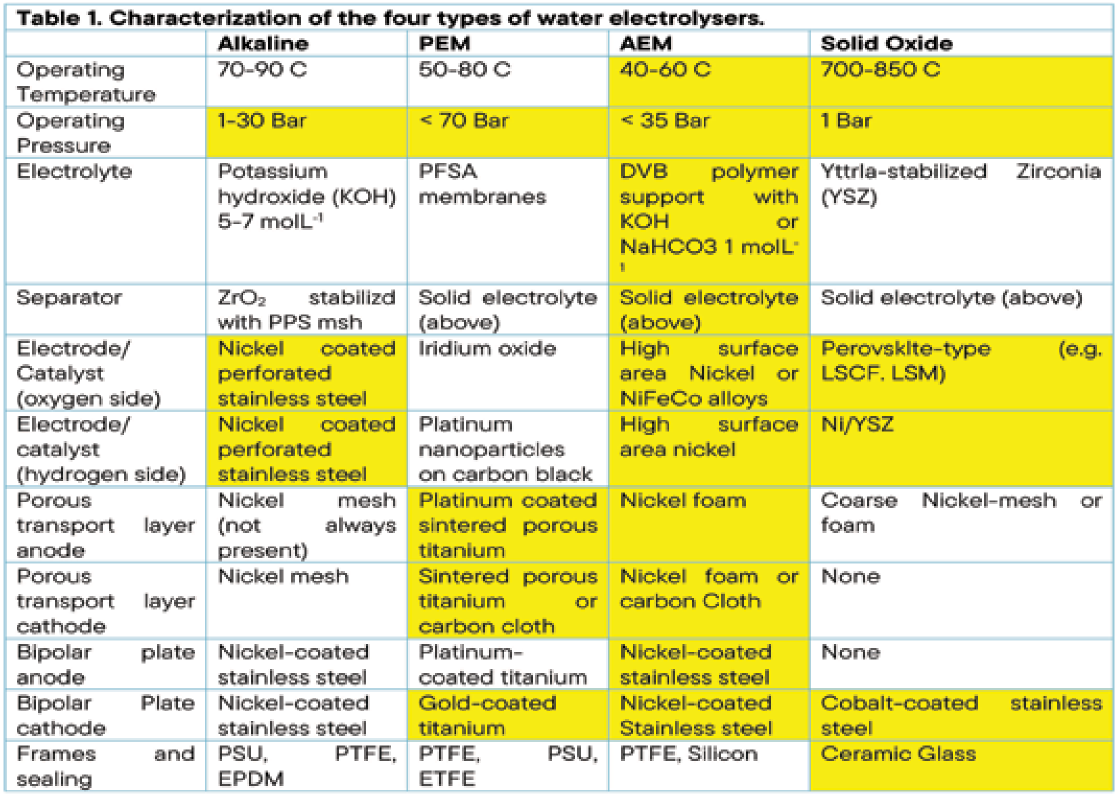
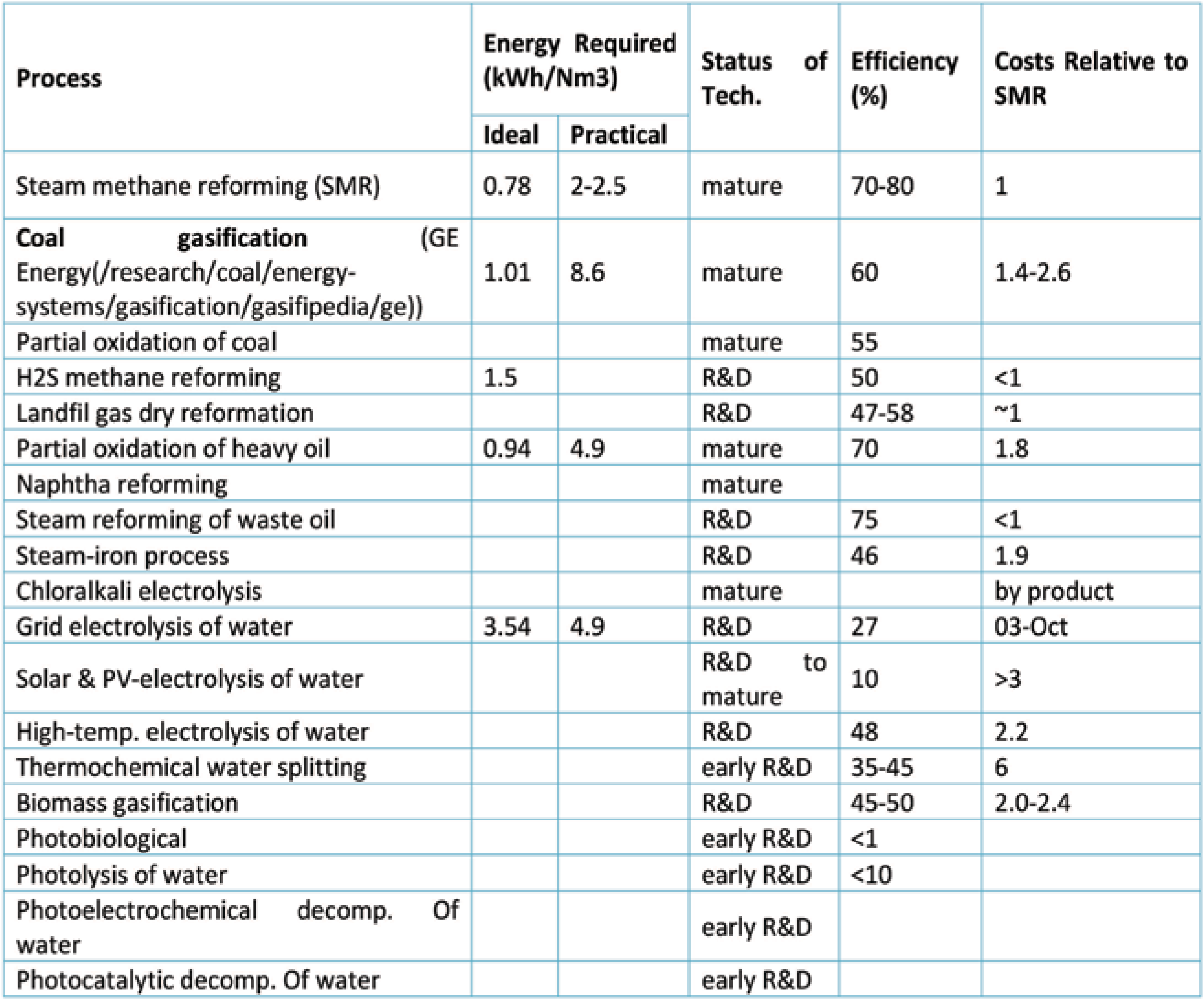


Table 1. Characterization of the four types of water electrolysers.

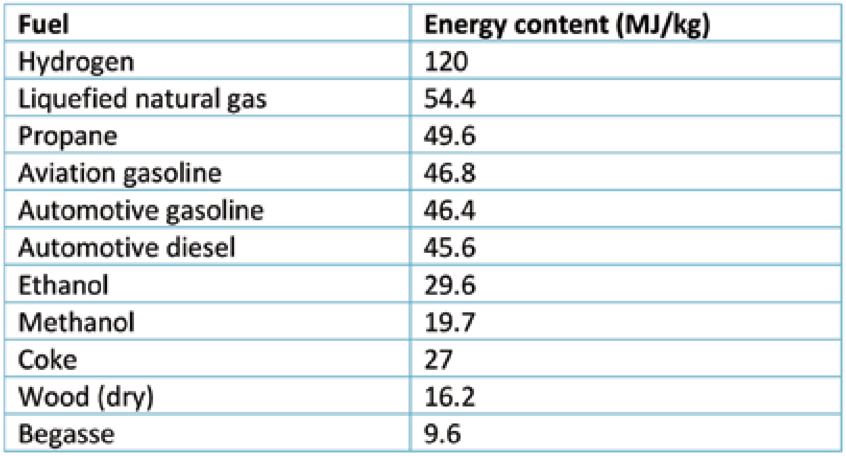
	Alkaline	**PEM**	**AEM**	**Solid Oxide**
Operating Temperature	70-90 C	50-80 C	40-60 C	700-850 C
Operating Pressure	1-30 Bar	< 70 Bar	< 35 Bar	1 Bar
Electrolyte	Potassium hydroxide (KOH) 5-7 molL^{-1}	PFSA membranes	DVB polymer support with KOH or NaHCO3 1 molL^{-1}	Yttrla-stabilized Zirconia (YSZ)
Separator	ZrO_2 stabilizd with PPS msh	Solid electrolyte (above)	Solid electrolyte (above)	Solid electrolyte (above)
Electrode/ Catalyst (oxygen side)	Nickel coated perforated stainless steel	Iridium oxide	High surface area Nickel or NiFeCo alloys	Perovsklte-type (e.g. LSCF. LSM)
Electrode/ catalyst (hydrogen side)	Nickel coated perforated stainless steel	Platinum nanoparticles on carbon black	High surface area nickel	Ni/YSZ
Porous transport layer anode	Nickel mesh (not always present)	Platinum coated sintered porous titanium	Nickel foam	Coarse Nickel-mesh or foam
Porous transport layer cathode	Nickel mesh	Sintered porous titanium or carbon cloth	Nickel foam or carbon Cloth	None
Bipolar plate anode	Nickel-coated stainless steel	Platinum-coated titanium	Nickel-coated stainless steel	None
Bipolar Plate cathode	Nickel-coated stainless steel	Gold-coated titanium	Nickel-coated Stainless steel	Cobalt-coated stainless steel
Frames and sealing	PSU, PTFE, EPDM	PTFE, PSU, ETFE	PTFE, Silicon	Ceramic Glass

Broad Cost Comparison of Various Processes:



Process	**Energy Required (kWh/Nm3)**		**Status of Tech.**	**Efficiency (%)**	**Costs Relative to SMR**
	Ideal	**Practical**			
Steam methane reforming (SMR)	0.78	2-2.5	mature	70-80	1
Coal gasification (GE Energy(/research/coal/energy-systems/gasification/gasifipedia/ge))	1.01	8.6	mature	60	1.4-2.6
Partial oxidation of coal			mature	55	
H2S methane reforming	1.5		R&D	50	<1
Landfil gas dry reformation			R&D	47-58	~1
Partial oxidation of heavy oil	0.94	4.9	mature	70	1.8
Naphtha reforming			mature		
Steam reforming of waste oil			R&D	75	<1
Steam-iron process			R&D	46	1.9
Chloralkali electrolysis			mature		by product
Grid electrolysis of water	3.54	4.9	R&D	27	03-Oct
Solar & PV-electrolysis of water			R&D to mature	10	>3
High-temp. electrolysis of water			R&D	48	2.2
Thermochemical water splitting			early R&D	35-45	6
Biomass gasification			R&D	45-50	2.0-2.4
Photobiological			early R&D	<1	
Photolysis of water			early R&D	<10	
Photoelectrochemical decomp. Of water			early R&D		
Photocatalytic decomp. Of water			early R&D		

Energy Contents of different fuels.



Fuel	Energy content (MJ/kg)
Hydrogen	120
Liquefied natural gas	54.4
Propane	49.6
Aviation gasoline	46.8
Automotive gasoline	46.4
Automotive diesel	45.6
Ethanol	29.6
Methanol	19.7
Coke	27
Wood (dry)	16.2
Begasse	9.6

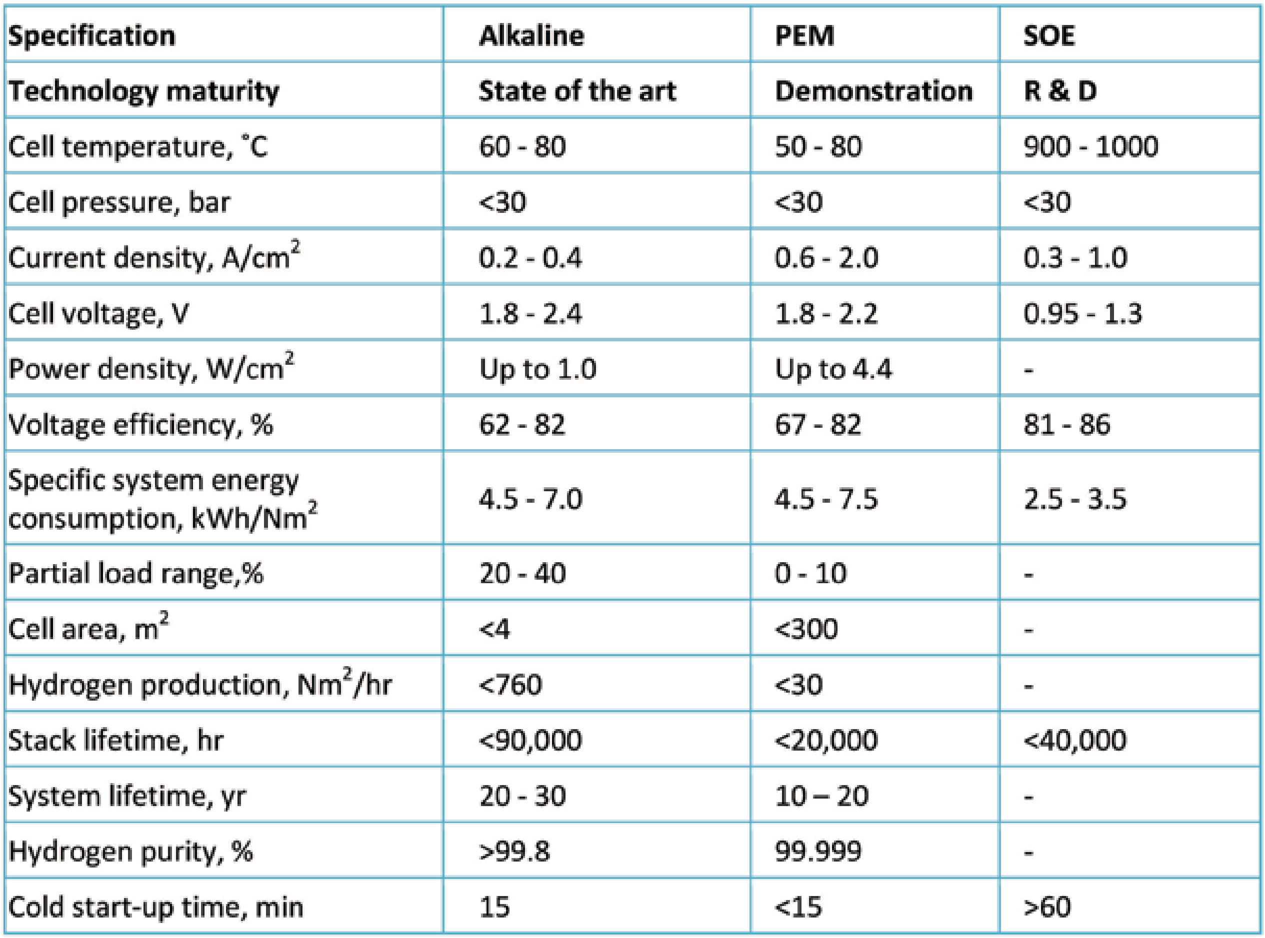
Hydrogen Production Technologies

- Water Electrolysis

  It can be defined in the simplest form by using two electrodes in water and passing the electrical current water is converted into hydrogen and oxygen. The water electrolysis method can be divided into three different types of the electrolyte alkaline, proton exchange membrane (PEM), and solid oxide electrolysers (SOE). Below Table has been listed the typical specifications of the water electrolysis technologies methods. The commercial low temperature electrolysers were developed and have efficiencies of (56% - 73%) at conditions of (70.1 - 53.4 kWh.kg−1 H_2 at 1 atm and 25°C) [93]. Alkaline electrolysis systems are the most commonly compared to other water electrolysis methods. Solid oxide electrolysis (SOE) is the most electrically efficient but still are under development. Corrosion, seals, thermal cycling, and chrome migration are the major challenges faced by the SOE technology. The Proton exchange membrane (PEM) electrolysis systems are more efficient than alkaline electrolyser. Also, the corrosion and seals issues don’t exist as (SOE), but the cost of (PEM) is too high compared with alkaline electrolysers systems. Alkaline electrolyser systems have the lowest capital cost and have the lowest efficiency so the electrical energy cost is too high. Recently, electrolysers are used for producing pure hydrogen and high pressure units have been developed [97].

The advantage of using the high pressure operation unit is to eliminate using expensive hydrogen compressors. The hydrogen production using the water electrolysis systems are showed the too high cost to generate hydrogen on large scale using the water electrolysis method. Additionally, the water electrolysis.

The typical specifications of alkaline, PEM and SOE



Specification	Alkaline	PEM	SOE
Technology maturity	**State of the art**	**Demonstration**	**R & D**
Cell temperature, ˚C	60 - 80	50 - 80	900 - 1000
Cell pressure, bar	<30	<30	<30
Current density, A/cm^2	0.2 - 0.4	0.6 - 2.0	0.3 - 1.0
Cell voltage, V	1.8 - 2.4	1.8 - 2.2	0.95 - 1.3
Power density, W/cm^2	Up to 1.0	Up to 4.4	-
Voltage efficiency, %	62 - 82	67 - 82	81 - 86
Specific system energy consumption, kWh/Nm^2	4.5 - 7.0	4.5 - 7.5	2.5 - 3.5
Partial load range,%	20 - 40	0 - 10	-
Cell area, m^2	<4	<300	-
Hydrogen production, Nm^2/hr	<760	<30	-
Stack lifetime, hr	<90,000	<20,000	<40,000
System lifetime, yr	20 - 30	10 – 20	-
Hydrogen purity, %	>99.8	99.999	-
Cold start-up time, min	15	<15	>60

systems are utilized the non-renewable power generation source to produce electricity for the water electrolysis systems [98] [99] [100] [101] [102] .

- Alkaline Electrolyser

  This type is commonly used on the large-scale systems. Alkali solutions are divided into two different electrolyte types. The first electrolyte type is potassium hydroxide (KOH) with a weight percent of (20% - 40%) [104] . Sodium hydroxide (NaOH) and sodium chloride (NaCl) have been used as the other alkaline electrolyte types. The separating diaphragm between the two electrodes is made of the asbestos material with a thickness of 3 mm and due to the usage of the asbestos materials the water electrolyser operation temperature is limited to be 80˚C. Hydrogen and hydroxide are generated at the cathode part, then the hydroxide is moved to the anode part generating oxygen. The anode and cathode part reactions can be expressed.

- Proton Exchange Membrane Electrolyser

  To overcome the corrosion has happened from the alkaline electrolysers method, the solid polymer membrane has been investigated to use in the PEM fuel cells technology. However, the deionized water with high purity has been required for the water electrolysis process. The oxidation reaction of water is happened at the anode part generating oxygen, electrons, and protons. The electrons and protons are moved to the cathode side through the PEM. The hydrogen gas is generated at the cathode part after the porotons reduced.

- Solid Oxide Electrolyser

  The solid oxide electrolyser (SOE) operation temperature can be reached at 1000˚C compared with the PEM electrolyser. These systems typically are used the thermal energy instead of a part of the electrical energy. The electrolyser efficiency is increased by increasing high temperature. Therefore, compared to alkaline and PEM processes the SOE process has a higher efficiency. In the SOE system, hydrogen is generated at the cathode part and the oxide anions are passed to the anode where oxygen will form through the solid electrolyte.

- Biomass

  Biomass energy is used to generate hydrogen fuel as a renewable energy source. Biomass energy sources such as agricultural wastes, animal wastes, municipal solid waste, etc. are used. The biomass technologies for hydrogen production can be divided into the gasification, and pyrolysis. The hydrogen production yield of the biomass process is affected with the biomass characteristics and compositions are affected with a number of process variables such as temperature, heating rate, moisture content, particle size, reactor system, etc.

- Biomass Gasification Process

The Gasification process can be commonly used in the biomass and coal gasification processes. It is commercially used in many processes and it has been based upon the partial oxidation process of the materials to get the mixture of hydrogen, carbon monoxide, methane, etc. Since the moisture has to be vaporized, the thermal efficiency of the gasification process is typically low. The recorded performance of the fluidized bed reactors is higher than the fixed bed type reactors. Syngas is produced from steam reforming process when steam or oxygen is added to the gasification process, which it can be utilized for hydrogen production in the water gas shift (WGS) or the Fischer-Tropsch reactor. Biomass is dried by using superheated steam at 900°C. The high hydrogen production yields can be achieved from the dried biomass. Based on the lower heating value, the achieved efficiencies of these reactors within range of (35% - 50%).

- Biological Hydrogen Production Process

This is another biomass method to produce hydrogen gas fuel using the biological technologies. There can be utilized the anaerobic bacteria which it is grown in the dark fermentation bioreactors or can be used algae in the light in the photo fermentative process. The main processes include the photolytic process to produce hydrogen from water using the green algae, the hydrogen production using the dark-fermentative process of anaerobic digestion, the two-stage dark/fermentative process, the photo-fermentative processes and the WGS method for hydrogen production. By using the anaerobic microorganisms the dark fermentation reaction is carried out to convert the carbohydrate to hydrogen and other final products.

Biological Hydrogen Production Process limits the low hydrogen production capacity compared with the unit capital investment. This is the major challenge of the dark fermentation method.

(Note: 1 Journal of Power and Energy Engineering, 107-154, 2019)

Hydrogen Storage*

The hydrogen consumes a large volume even after compressing it at very high pressure. Commercially available fuel cell vehicles opt for 700 bar storage pressure as hydrogen occupies a large space at low pressure. Similarly, high-pressure tanks for decentralized storage of hydrogen especially for transport applications are necessary. However, tanks capable of holding such high pressure are generally made up of carbon fiber which is a very expensive material. As the pressure requirement increases, the quantity of carbon fiber required for the tank rises along with the up-gradation of this compression system specification which can increase the initial cost of storage. Hence many researchers are now focusing on the hydrogen production methods, transportation of hydrogen, and its storage.

Liquefaction of hydrogen requires a significant energy input as the boiling point of hydrogen is very low (-253 o C) but liquid hydrogen provides comparatively a high storage density. Liquefaction consumes about 30% of hydrogen energy. The high volumetric density is the main advantage of liquid hydrogen storage.

Another means of hydrogen storage is adsorption which exhibits van der Waals bonding between hydrogen molecules and materials that store hydrogen in the solid phase. Metal hydrides and chemical hydrides exhibit these reactions and operate at low pressure.

All three storage options have their respective limitations and hence currently there is no perfect solution for hydrogen storage. Many researchers are continuously working in this field to provide a better solution for hydrogen storage and with development, it is improving day by day.

The smooth operation of large-scale and intercontinental hydrogen value chains in the future will require a much broader variety of storage options. At an export terminal, for example, hydrogen storage may be required for a short period prior to shipping. Hours of hydrogen storage are needed at vehicle refueling stations, while days to weeks of storage would help users protect against potential mismatches in hydrogen supply and demand. Much longer-term and larger storage options would be required if hydrogen were used to bridge major seasonal changes in electricity supply or heat demand, or to provide system resilience.

The most appropriate storage medium depends on the volume to be stored, the duration of storage, the required speed of discharge, and the geographic availability of different options. In general, however, geological storage is the best option for large-scale and long-term storage, while tanks are more suitable for short-term and small-scale storage.

Storage tanks

Tanks storing compressed or liquefied hydrogen have high discharge rates and efficiencies of around 99%, making them appropriate for smaller-scale applications where a local stock of fuel or feedstock needs to be readily available. Compressed hydrogen (at 700 bar pressure) has only 15% of the energy density of gasoline, so storing the equivalent amount of energy at a vehicle refueling station would require nearly seven times the space.

Ammonia has a greater energy density and so would reduce the need for such large tanks, but these advantages have to be weighed against the energy losses and equipment for conversion and reconversion when end uses require pure hydrogen.

When it comes to vehicles rather than filling stations, compressed hydrogen tanks have a higher energy density than lithium-ion batteries, and so enable a greater range in cars or trucks than is possible with battery electric vehicles. Research is continuing with the aim of finding ways to reduce the size of the tanks, which would be especially useful in densely populated areas. This includes looking at the scope for underground tanks that can tolerate 800 bar pressure and so enable greater compression of hydrogen. Hydrogen storage in solid-state materials such as metal and chemical hydrides is at an early stage of development, but could potentially enable even greater densities of hydrogen to be stored at atmospheric pressure.

Hydrogen Storage Projects Undertaken in India

Indian Oil Corporation Limited (IOCL) is also working on the development of a Type-3 High Pressure Hydrogen Cylinder in collaboration with IIT Kharagpur. The cylinder increases the energy storage density over existing cylinders. They are also working on developing material-based hydrogen storage including metal-organic frameworks (MOFs). Their research is focused on producing high energy density MOFs, which can be scaled up cost-effectively.

There are main problems for hydrogen storage such as:

- reducing weight and volume of thermal components is required;
- the cost of hydrogen storage systems is too high;

- durability of hydrogen storage systems is inadequate;
- hydrogen refueling times are too long;
- high-pressure containment for compressed gas and other high-pressure approaches limits the choice of construction materials and fabrication techniques, within weight, volume, performance, and cost constraints.

For all approaches of hydrogen storage, vessel containment that is resistant to hydrogen permeation and corrosion is required. Research into new materials of construction such as metal ceramic composites, improved resins, and engineered fibbers is needed to meet cost targets without compromising performance.Materialsto meet performance and cost requirements for hydrogen delivery and off-board storage are also needed.

At the moment, several kinds of technologies of hydrogen storage are available such as;

- The simplest is compressed H2 gas. It is possible at ambient temperature, and in- and outflow are simple. However, the density of storage is low compared to other methods.
- Liquid H2 storage is also possible:from 25% to 45% of the stored energy is required to liquefy the H2. At this method the density of hydrogen storage is very high, but hydrogen boils at about -253°C and it is necessary to maintain this low temperature (else the hydrogen will boil away), and bulky insulation is needed.
- In metal hydride storage the powdered metals absorb hydrogen under high pressures. During this process heat is produced upon insertion and with pressure release and applied heat, the process is reversed. The main problem of this method is the weight of the absorbing material – a tank's mass would be about 600 kg compared to the 80kg of a comparable compressed H2 gas tank.
- More popular at this time is carbon absorption: the newest field of hydrogen storage. At applied pressure, hydrogen will bond with porous carbon materials such as nanotubes.

High pressure hydrogen storage

The most common method of hydrogen storage is compression of the gas phase at high pressure (> 200 bars or 2850 psi). Compressed hydrogen in hydrogen tanks at 350 bar (5,000 psi) and 700 bar (10,000 psi) is used in hydrogen vehicles. There are two approaches to increase the gravimetric and volumetric storage capacities of compressed gas tanks. The first approach involves cryo-compressed tanks. This is based on the fact that, at fixed pressure and volume, gas tank volumetric capacity increases as the tank temperature decreases. Thus, by cooling a tank from room temperature to liquid nitrogen temperature (77K), its volumetric capacity increases. However, total system volumetric capacity is less than one because of the increased volume required for the cooling system. The limitation of this system is the energy needed to compression of the gas. About 20 % of the energy content of hydrogen is lost due to the storage method. The energy lost for hydrogen storage can be reduced by the development of new class of lightweight composite cylinders. Moreover, the main problem consisting with conventional materials for high pressure hydrogen tank is embrittlement of cylinder material, during the numerous charging/discharging cycles.

Liquefaction

The energy density of hydrogen can be improved by storing hydrogen in a liquid state. This technology developed during the early space age, as liquid hydrogen was brought along on the space vessels but nowadays it is used on the on-board fuel cells. It is also possible to combine liquid hydrogen with a metal hydride, like Fe-Ti, and this way minimize hydrogen losses due to boil-off.

In this storage method, first gas phase is compressed at high pressure than liquefy at cryogenic temperature in liquid hydrogen tank (LH2). The condition of low temperature is maintained by using liquid helium cylinder. Hydrogen does not liquefy until -253°C (20 degrees above absolute zero) such much energy must be employed to achieve this temperature. However, issues are remaining with LH2 tanks due to the hydrogen boil-off, the energy required for hydrogen liquefaction, volume, weight, and tank cost is also very high. About 40 % of the energy content of hydrogen can be lost due to the storage methods. Safety is also another issue with the handling of liquid hydrogen as does the car's tank integrity, when storing, pressurizing and cooling the element to such extreme temperatures.

Solid state hydrogen storage

As mentioned above, certainly some practical problems, which cannot be circumvented, like safety concerns (for high pressure containment), and boil-off issues (for liquid storage), both are challenging for hydrogen storage. There is a third potential solution for hydrogen storage such as (i) metal hydrides and (ii) hydrogen adsorption in metal-organic frameworks (MOFs) and carbon-based systems.

In these systems, hydrogen molecules are stored in the mesoporous materials by physisorption (characteristic of weak van der Waals forces). In the case of physisorption, the hydrogen capacity of a material is proportional to its specific surface area.The storage by adsorption is attractive because it has the potential to lower the overall system pressure for an equivalent amount of hydrogen, yielding safer operating conditions. The advantages of these methods are that the volumetric and cryogenic constraints are abandoned. In recent decades, many types of hydrogen storage materials have been developed and investigated, which include hydrogen storage alloys, metal nitrides and imides, ammonia borane, etc.

Currently, porous materials such as zeolites, MOFs, carbon nanotubes (CNTs), and graphene also gained much more interestdue to the high gravimetric density of such materials.

Hydrogen storage in metal hydrides

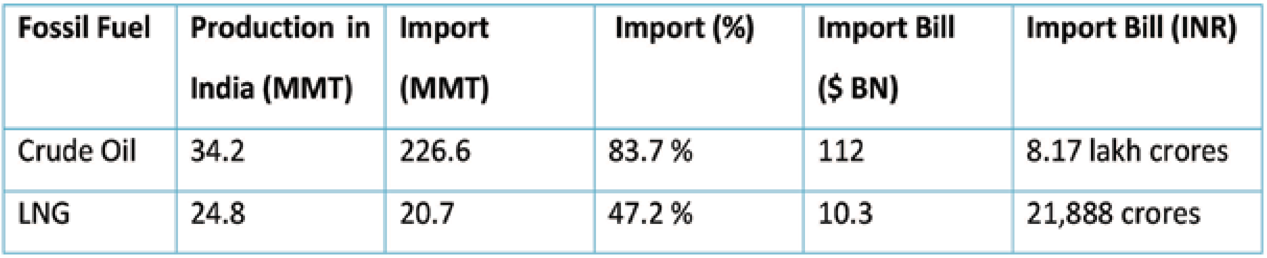
Initially, metal alloys, such as LaNi5, TiFe and MgNi were proposed as storage tanks since by chemical hydrogenation they form metal hydrides. Later, hydrogen can be released by dehydrogenation of metal hydrides with light elements (binary hydrides and complex hydrides) because of their large gravimetric H2 densities at high temperature. Regarding vehicle applications, metal hydrides (MHs) can be distinguished into high or low temperature materials. This depends on the temperature at which hydrogen absorption or desorption is taking place. Normally, in MHs hydrogen uptake and release kinetics is considered as above or below of 150 °C, respectively. La-based and Ti-based alloys are examples of some low temperature materials with their main drawback as they provide very low gravimetric capacity (<2 wt %).

The analysis of above LiAlH4 (LAH) shows that the gravimetric weight ratio of hydrogen is 10.6 wt%; thereby LAH seems a potential hydrogen storage medium for future fuel cell powered vehicles. But, in practice the hydrogen storage capacity is reduced to 7.96 wt% due to the formation of LiH + Al species as the final product. Due to this, a substantial research effort has been devoted to accelerating the decomposition kinetics by catalytic doping in the MHs. The high hydrogen content, as well as the discovery of reversible hydrogen storage is reported in Ti-doped NaAlH4. In order to take advantage of the total hydrogen capacity, the intermediate compound LiH must be dehydrogenated as well. Due to its high thermodynamic stability this requires temperatures higher than 400 °C which is not considered feasible for transportation purposes. Another problem related to hydrogen storage is the recycling back to LiAlH4 due to its relatively low stability, requires an extremely high hydrogen pressure in excess of 10000 bar.

** Hydrogen Storage for Energy Application written by Rahul Krishna, Elby Titus, Maryam Salimian, Olena Okhay, Sivakumar Rajendran, Ananth Rajkumar, J.M.G. Sousa, A.L.C. Ferreira, Joao Campos Gil and Jose Gracio, published on September 5th, 2012.*

Transition from Fossil Fuel - *Dr. J P Gupta*

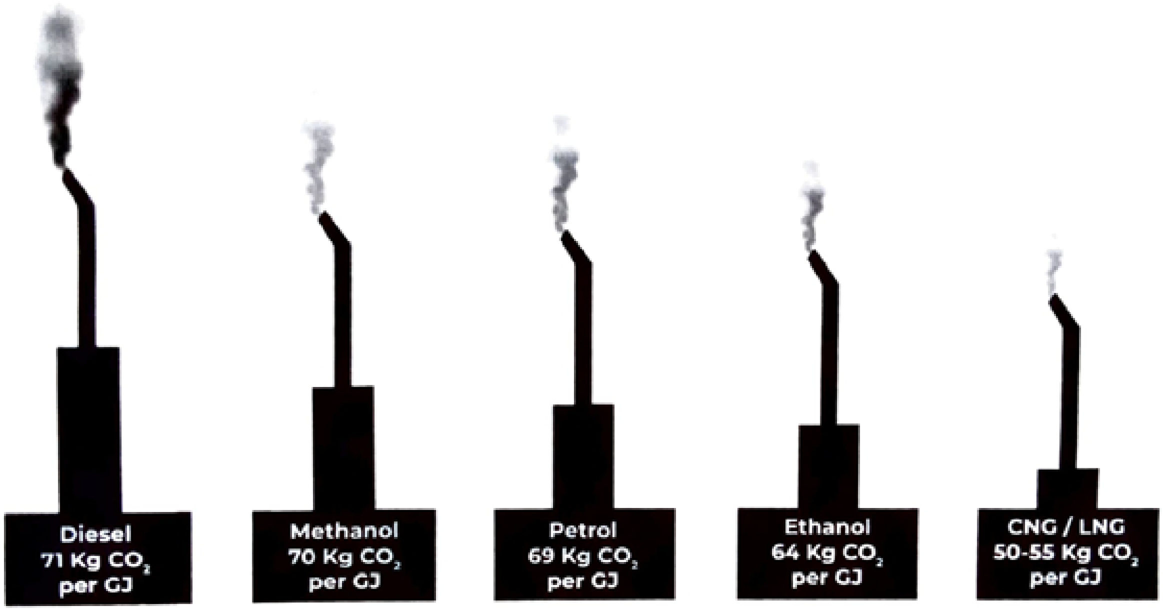
India has a large growing population and economy, but comparatively has limited availability of fossil fuels to fulfill its energy demands. The key point to consider here is the ever-increasing fuel demand and its dependency on imported crude oil for domestic needs. India's annual energy import cost is in excess of USD 119.2 billion in 2021. More than 82% of this cost is consumed in importing crude oil and natural gas.



Fossil Fuel	Production in India (MMT)	Import (MMT)	Import (%)	Import Bill ($ BN)	Import Bill (INR)
Crude Oil	34.2	226.6	83.7 %	112	8.17 lakh crores
LNG	24.8	20.7	47.2 %	10.3	21,888 crores

Source: Ready reckoner snapshot of India's oil and Gas data 2018-19.

CO_2 Emission Comparison



Source: U.S. Energy Information Administration

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As per the International Energy Agency, India will be importing 90% of its consumption by 2040. To reduce the environmental pollution and petroleum imports in India, there is a need to look for an alternate source of clean energy to meet the requirement.
We may look at solar PV and wind which have revolutionized India's green energy sector in the past decade. Diversification of electricity sources by integrating renewable energy in its grid is helping India in achieving the Paris agreement targets. The country has pledged to achieve 40% installed capacity from renewable energy sources by 2030 and reduce emissions intensity by 33-35% below 2005 levels in its nationally determined commitments to the 2015 Paris agreement.

Green Hydrogen – The National Agenda

Prime Minister in his Independence Day speech (15, August2021) has announced five key initiatives, the first being Mission Hydrogen. He outlined a vision of becoming a global leader and enabling a substantial domestic hydrogen economy. Hydrogen has the promise of transforming India from an energy-deficient to an energy-rich country. It can even make India a net exporter of energy. In February 2022, India made a big splash in the hydrogen ecosystem by announcing its Green Hydrogen Policy. The policy takes ahead the vision articulated by Prime Minister Narendra Modi, to make India the global hub for the production and export of Green Hydrogen. The policy is based on a number of incentives for investors to use this new age fuel and gradually move away from traditional sources of energy.

Hydrogen is considered one of the most sustainable fuels of the future. When hydrogen is burned, we get water vapour, with no residue or climate-harming impact. The challenge has been to make "green hydrogen", which was the thrust of the Prime Minister's proclamation. For it, a lot of energy for the electrolysis of water is needed. Unless this electricity is produced with a zero-carbon footprint (i.e., with solar or wind), it defeats the key aspect of 'green' hydrogen. All other modes that do not use electrolysis to break a molecule of water are methods where hydrogen is produced as a by-product, or through a carbon burning process. The success of a massive breakthrough for scalable hydrogen production must be seen in confluence with factors like declining costs, financial incentives and carbon taxes, as happened for the breakthrough of other renewables. It seems like a global breakthrough is about to happened at this very moment. Thankfully, India is blessed with a clear minded Prime Minister, all-year sunshine and a large coastline. About 5,000 trillion kWh per year of energy is transferred from the sun to India's land area with most parts receiving 4-7 kWh per sq. m per day. In India, an average of 300 sunny days a year, can effectively be harnessed by solar photovoltaics' power, to provide huge scalability. This showcase the very high potential for production of Green Hydrogen energy in India. Solar-to-hydrogen also solve an intermittence challenge, as hydrogen has the potential to reduce/substitute the need for battery storage.

Opportunities for Green Hydrogen

Based on India's current progress in the renewable energy sector, it is clear that green hydrogen will make a greater impact on India's overall energy sector. Green hydrogen will help to provide a sustainable solution for the Indian industrial sector. India has fewer reserves of natural gas and green hydrogen production from renewables can make a difference in this scenario. Under the 'Make in India' program, India has the opportunity to start the production of electrolyzers and fuel cells which will allow capturing a large share in this market worldwide. As compared to other parts of the world, India has lowest cost of electricity from the solar photovoltaic systems, this generated power in the future will be helpful to scale up green hydrogen production. Water consumption by electrolyzers will be an issue of concern. Electrolyzers consume about 9 liters of water to produce 1 kg of hydrogen. In this scenario, seawater electrolysis (being availability of large coastline in India) will be of great interest that requires further development and research work. The existing hydrogen infrastructure needs to be strengthened for the larger acceptance of fuel cell vehicles. For further developments, hydrogen refuelling stations are required to be created and will be play promising role.

The concept of Green hydrogen economy brings many opportunities for India to become energy independent. For the last decade, India is constantly focusing on growing its renewable energy capacity by taking advantage of its geography. Since hydrogen is expected to be an integral part of the energy system of the future, at an overall level, it seems logical to proceed in the planning with scaling of renewable energy in connection with scaling of hydrogen production. India can take the advantage of its renewable energy scenario and can scale up its hydrogen production facilities. The mass production offers India an opportunity to export green hydrogen to other nations in the long term, after meeting its own needs to replace fossil fuels. Green Hydrogen when used with fuel cells can help India significantly reduce its petroleum imports and environmental pollution.

Today green hydrogen is viewed as a very much promising energy carrier for achieving net-zero emission targets as it does not emit GHG upon combustion. Its inherent chemical characteristics, multiple end-uses, and harmony with other fuels and energy carriers make it a strong contribution to electrification, battery storage systems, carbon, capture, utilization, and storage (CCUS), bioenergy, etc.

At present, hydrogen is being primarily produced with the help of fossil fuels for use in the chemical, steel, and refinery industry. Today, it is possible to produce hydrogen with the help of renewable energy-based electricity. The 'net-zeroness' of hydrogen depends on the method of production. Steam Methane Reforming (SMR) incurs a measurable amount of emissions when used for producing hydrogen (Hydrogen produced with such process is called grey hydrogen).

Green hydrogen (made from water and green electricity using an electrolyzer) is considered the next big movement toward sustainable development. It has found relevance in today's energy policy narrative, given its ability to decarbonize 'hard-to-abate' industries. Hard-to-abate sectors (like the steel industry) require a significant higher investment into green technology compared to the existing cost of carbon-based technologies, in the short term.

Hydrogen needs to be considered as complementary to its alternatives rather than contemplating it as an ultimate and stand-alone solution as it comes with its own constraints. The present storage and transportation technologies are expected to be mature and cost-effective by 2030. Hence, the production and near-real-time utilization of hydrogen at the same location can be promoted to safeguard investments against undesirable sunk costs.

Production of green hydrogen requires water and renewable electricity as input to the electrolyzer. The availability of sufficient water streams is critical as it is a valuable and limited resource having multiple application areas. Desalination plants can be set up to process wastewater or seawater for electrolysis to avoid possible water usage conflicts. Freshwater from such desalination plants can also be provided to the local population if the plants are set up in water scares regions. Green hydrogen as an energy sector can become a reality in India if the large availability of renewable and water resources is used optimally.

India's Efforts about the hydrogen economy

India's ambitious plans of installing 450 GW of renewable energy capacity will fuel its drive to become the global hub of green hydrogen manufacturing.

CNBC-TV18 has reported from sources that a Rs 15,000-crore production-linked incentive (PLI) scheme was being worked on to push for electrolyser manufacturing in India. The scheme is expected to run for a period of five years, starting from FY24 with possible certain tax benefits. The ultimate aim of the government is to bring down the cost of green hydrogen to $1 per kg and have five million metric tons per annum (MMTPA) green hydrogen capacity by 2030 in India.

India's largest company Reliance Industries Limited and its Chairman Mukesh Ambani has announced that the green Energy Giga Complex will have an electrolyser factory for green hydrogen production, and a fuel cell factory. He hopes that India can bring down hydrogen costs massively in the future. RIL hopes to become a net-zero emissions company by 2035, and a Rs 75,000-crore investment in green energy is a large part of the plan.

"Green hydrogen is the best and cleanest source of energy, which can play a fundamental role in the world's decarbonisation plans. Efforts are on globally to make green hydrogen the most affordable fuel option by bringing down its cost to initially under $2 per kg. Let me assure you all that Reliance will aggressively pursue this target and achieve it well before the turn of this decade. And India has always set and achieved even more audacious goals. Am sure that India can set an even more aggressive target of achieving under $1 per kg within a decade. This will make India the first country globally to achieve $1 per 1 kilogram in 1 decade – the 1-1-1 target for green hydrogen," he said.

Way forward

Renewable energy in India provides the opportunity to produce green hydrogen and to develop hydrogen infrastructure.To achieve a quick and safe adoption, many challenges still need to be solved. These challenges include hydrogen production cost, storage, transportation, policies, regulations, public awareness, etc. These can be resolved with Chain of world class Indian R & D Institution and with International Cooperation. The world is slowly moving towards the adoption of a Hydrogen economy and India is also taking important initiatives. Indian organizations, including both government and public are investing in the research of hydrogen technologies. Many ongoing research and demonstration projects are very important to develop hydrogen and fuel cell technology economically. The progress in this development will play a key role in the commercialization of the technology.

As Indian businesses invest in research and development across the entire green hydrogen value chain, the lack of a homegrown research workforce will become a bottleneck. Addressing this challenge will not only require serious investment in universities to scale up their research and research training programs but also strong incentives for collaboration between academia, corporate labs and public research institutions. When universities are an integral part of the national research enterprise, they produce human capital aligned with national economic needs which has a long-term multiplier effect in sustaining innovation.

As the Indian Industries are to make Key strides toward decarbonization, the entire industrial sector needs to be brought under the decarbonization umbrella. They will need strong political backing, steady investment and receptiveness for innovation and change. Industrial decarbonization will transform India to a sustainable future.

No country needs green hydrogen more than India – to reduce life-threatening air pollution in its cities, to escape the debilitating financial burden of energy imports, and to decarbonize its rapidly growing economy. No country has a more urgent need to fast-track the green hydrogen economy and lead the way than India.