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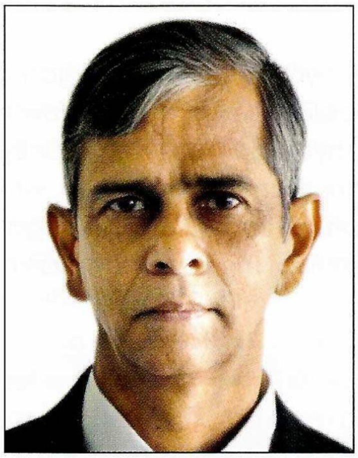
SPECIAL ISSUE

GREEN HYDROGEN –THE WAY FORWARD



by Shankar Ghosh
A Shell - N - Tube Presentation

The primary and basic objective of making green hydrogen is to improve our environment so that our children can live in a healthier world.

Emissions from gasoline and diesel vehicles—such as nitrogen oxides, hydrocarbons, and particulate matter—are a major source of this pollution. Hydrogen-powered fuel cell electric vehicles emit none of these harmful substances—only water (H2O) and warm air. India hopes its green hydrogen mission will make it a globally competitive producer and consumer by 2030. It could then be well placed to move towards becoming a carbon net zero economy.

Hydrogen is not an energy producer rather more correctly it is an energy carrier.

The production of hydrogen in general and green hydrogen in particular requires more energy than other fuels. Safety issues also played a part is discouraging hydrogen use. hydrogen is a highly volatile and flammable element and extensive safety measures are therefore required to prevent leakage and explosions.

Green hydrogen, blue hydrogen, brown hydrogen and even yellow hydrogen, turquoise hydrogen and pink hydrogen. They're essentially colour codes, or nicknames, used within the energy industry to differentiate between the types of hydrogen. Hydrogen is a highly inflammable substance and explosive in nature; it cannot be easily transported from one place to another and it can be generated by the hydrolysis of water but it is a very expensive process. After discussions with multiple stakeholders, the Ministry of New & Renewable Energy has decided to define Green Hydrogen as having a well-to-gate emission (i.e., including water treatment, electrolysis, gas purification, drying and compression of hydrogen) of not more than 2 kg CO2 equivalent / kg H2. renewable electricity needed to power the electrolyser unit. This renders production of green hydrogen more expensive than blue hydrogen, regardless of the cost of the electrolyser. A low cost of electricity is therefore a necessary condition to produce competitive green hydrogen.

Historically a dark horse, green hydrogen energy has received renewed attention among global policy-makers and energy experts as a potential driver of net zero emissions. This is in large part because of significant advances in enabling technologies along with government subsidies and industrial policies supporting its research and development (e.g. more than €5 billion approved by the European Commission and $9.5 billion in the US Inflation Reduction Act).

Emissions-free green hydrogen uses clean electricity from renewable energy sources, including solar, wind, geothermal and hydropower, to separate hydrogen from water in a process known as electrolysis. According to *The Economist*, the element is not a primary source of energy like fossil fuels, but an energy carrier like electricity. The article also notes that: "There is no natural source of hydrogen, and most of it is bound up in molecules like fossil fuels, biomass, and water."

What is green Hydrogen?

- Green hydrogen is hydrogen generated by renewable energy or from low-carbon power. Green hydrogen has significantly lower carbon emissions than grey hydrogen, which is produced by steam reforming of natural gas, which makes up the bulk of the hydrogen market.

- One use is in the chemical industry for manufacturing ammonia and fertilisers. While its second main use is in the petrochemical industry to produce petroleum products.

- Green hydrogen is hydrogen produced by splitting water by electrolysis. This produces only hydrogen and oxygen. We can use the hydrogen and vent the oxygen to the atmosphere with no negative impact.

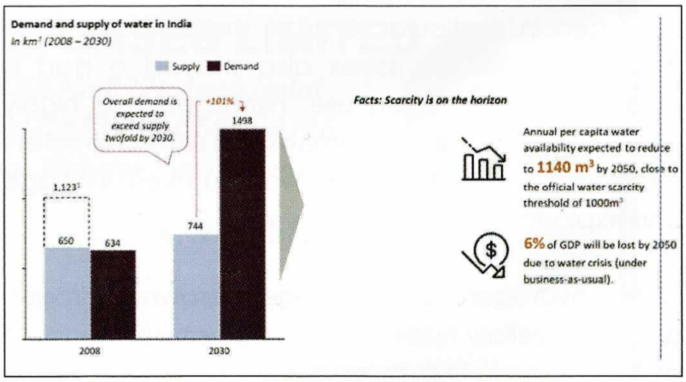
- China consumes and produces more hydrogen than any other country – its current annual usage is more than 24 million tonnes.

- Generation of green hydrogen aims to remove the greenhouse gas emissions from the production of hydrogen by manufacturing it using electrolysis, powered by renewable energy. The rapid growth in production of green hydrogen is seen by many as essential for leading economies to achieve zero carbon emissions by 2050.

According to estimates, in order to replace the dirty hydrogen used now in refineries, fertiliser, and chemical plants, almost double the electricity produced by every wind turbine and solar panel worldwide would be required, and that's before green hydrogen is used for anything else, such as steelmaking, transport or heating . Therefore, additional hydrogen uses beyond the applications where it is strictly necessary will only increase the required annual pace of renewable capacity deployment, which will make the decarbonisation task more challenging.

It has also been projected that with an expected requirement of 35 Mt by 2050 (assuming 25% export capacity), India would require a tentative capacity in the range of 192 GW to 224 GW of electrolysers by 2050, assuming all of it is green hydrogen . Given that the global capacity of electrolysers just crossed 300 MW in 2021, this signifies that India itself would require an electrolyser capacity of 640 to 750 times the current global capacity, by 2050. For India to achieve this, it would require 110-130% of its current total electricity generation (2020-21) by 2050, creating an immediate need for a road map for meeting the rapid growth in demand for electricity, especially from renewables . Furthermore, as of June 2022, just 7.8GW of electrolytic hydrogen projects have been announced, while announced electrolyser manufacturing plants amount to just 4GW/year by 2030.

One key challenge in the Indian context is water availability, as 1kg of renewable hydrogen produced via electrolysis requires roughly 10 litres of water, and India is amongst the most water-stressed countries in the world . One estimate suggests that India would require ~50 billion litres of demineralized water supply to meet its target. Solutions such as desalination have been suggested, but this will increase the physical footprint of the infrastructure required, while also potentially adding to the competition for land use and the impact on biodiversity, and also creating challenges and limitations in the location of electrolysers therefore, the green hydrogen hubs proposed in the mission must have synergy between



being water-rich, renewable energy-rich, and having proximity to demand centres to be commercially viable. These factors will also aid in determining the need for additional storage and transportation/distribution infrastructure while adding to the overall costs.

Another factor to be considered is that hydrogen leaks easily, and liquid hydrogen reacts explosively with air requiring additional infrastructure for safe handling and operations. There are scientific claims asserting that if there are 10% leaks during its production, transportation, storage, or use, the benefits of using green hydrogen over fossil fuels would be completely wiped out.

These are concerning claims to say the least, and warrant more research, technology and data looking into the plausible erosion of climate benefits of such projects. Further, any introduction of a hydrogen blend concentration in existing gas grids would also require extensive study, testing, and modifications to pipeline integrity monitoring and maintenance practices.

A sustainable green hydrogen economy thus hinges upon the creation of a supply chain, starting from the manufacture of electrolysers to the production of green hydrogen, using renewable source generated electricity; while also keeping green hydrogen cost competitive as compared to other alternatives. The levelized cost of green hydrogen production and storage (LCOH) is currently ~ INR 400/kg which will have to be drastically brought down in the near future for the hydrogen vision to become a feasible reality. With implicit subsidy support and a government-backed R&D push, the plan is to target lower costs of renewable power generation and to bring down the costs of electrolysers to make the production of green hydrogen cost-competitive. In reality how this is implemented and achieved will be a different ballgame altogether as the nation attempts to balance its socio-economic needs and decarbonization ambitions. Another consideration is that would converting green hydrogen from its original form to another such as ammonia, liquid fuel, etc be the most efficient utilisation of resources across the value chain?

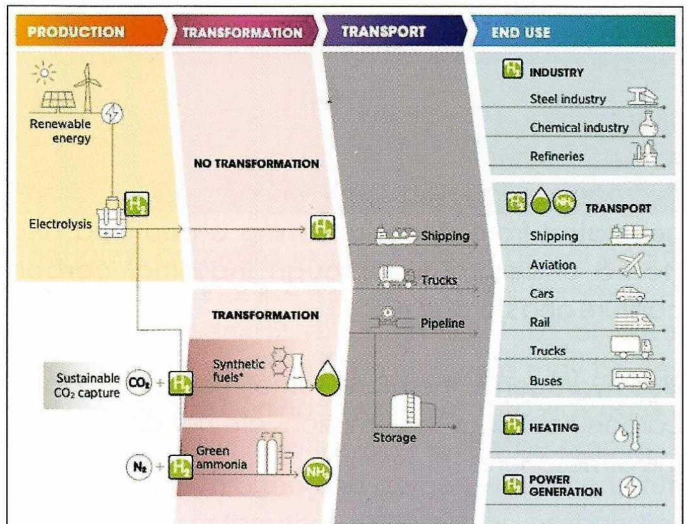
Green hydrogen has been hailed as a clean energy source for the future. But the gas itself is invisible – so why are so many colourful descriptions used when referring to it?

It all comes down to the way it is produced. Hydrogen emits only water when burned. But creating it can be carbon intensive.

So various ways to lessen this impact have been developed – and scientists assign colours to the different types to distinguish between them.

Depending on production methods, hydrogen can be grey, blue or green – and sometimes even pink, yellow or turquoise – although naming conventions can vary across countries and over time.

But green hydrogen is the only type produced in a climate-neutral manner, meaning it could play a vital role in global efforts to reduce emissions to net zero by 2050.

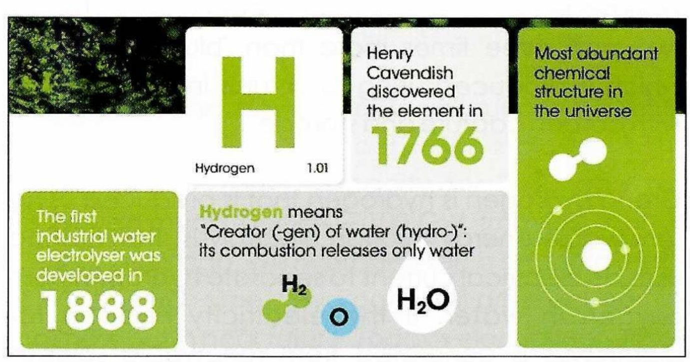


Source: IRENA

* The term synthetic fuels refers here to a range of hydrogen-based fuels produced through chemical processes with a carbon source (CO and CO_2 captured from emission streams, biogenic sources or directly from the air). They include methanol, jet fuels, methane and other hydrocarbons. The main advantage of these fuels is that they can be used to replace their fossil fuel-based counterparts and in many cases be used as direct replacements – that is, as drop-in fuels. Synthetic fuels produce carbon emissions when combusted, but if their production process consumes the same amount of CO_2, in principle it allows them to have net-zero carbon emissions.

Hydrogen can be produced from a range of resources including fossil fuels, nuclear energy, biomass and renewable energy sources. This can be done via a number of processes.

The resulting gas can be burned or used as a carrier to provide energy. And, if generated using renewables, it can be a clean alternative to burning fossil fuels.



Black, brown and grey hydrogen

Grey hydrogen is the most common form and is generated from natural gas, or methane, through a process called "steam reforming".

This process generates just a smaller amount of emissions than black or brown hydrogen, which uses black (bituminous) or brown (lignite) coal in the hydrogen-making process.

Black or brown hydrogen is the most environmentally damaging as both the CO2 and carbon monoxide generated during the process are not recaptured.

Blue hydrogen

Hydrogen is labelled blue whenever the carbon generated from steam reforming is captured and stored underground through industrial carbon capture and storage (CSS).

Blue hydrogen is, therefore, sometimes referred to as carbon neutral as the emissions are not dispersed in the atmosphere

Scaling up electrolysers to meet the 1.5oC climate goal.

As global economies aim to become carbon neutral, competitive hydrogen produced with renewables has emerged as a key component of the energy mix. Falling renewable power costs and improving electrolyser technologies could make "green" hydrogen cost competitive by 2030. Green hydrogen can help to achieve net-zero carbon dioxide (CO2) emissions in energy-intensive, hard-to-decarbonise sectors like steel, chemicals, long-haul transport, shipping and aviation. But production costs must be cut to make it economical for countries worldwide. Green hydrogen currently costs between two and three times more than "blue" hydrogen, which is produced using fossil fuels in combination with carbon capture and storage.

Green hydrogen is hydrogen that is produced using renewable energy through electrolysis. This method uses an electrical current to separate hydrogen from oxygen in water. If the electricity needed for electrolysis is generated from renewable sources such as solar or wind, the production of hydrogen in this way emits no greenhouse gasses.

Will green hydrogen form the core of India's clean energy mix? Experts are optimistic about the potential of this 'fuel of the future'. Like all fuels, hydrogen when burnt produces energy. But the by-product of burning hydrogen is water, making it the most environmentally friendly fuel.

This 'green' approach to producing hydrogen is good for sustainability. But it drives up costs, which could obviously hamper India's plan to ramp up the production of green hydrogen. Add to that, only a handful of Indian companies manufacture electrolysers, which are used to generate green hydrogen.

Now, according to The Energy and Resources Institute (TERI), the cost of green hydrogen production is $5-$6 per kg. At this rate, it is not easy for industries like steel, fertilizer and long-range shipping to adopt this fuel. For that, we need green hydrogen prices to come down to at least $2 per kg. Reliance chairman Mukesh Ambani has proposed that India should aim to bring down prices to $1 per kg. But this reduction in prices will not be possible unless we start manufacturing electrolysers on a much larger scale in India.

The most common technique is to extract hydrogen from water, which is two parts hydrogen and one part oxygen (hence H2O).

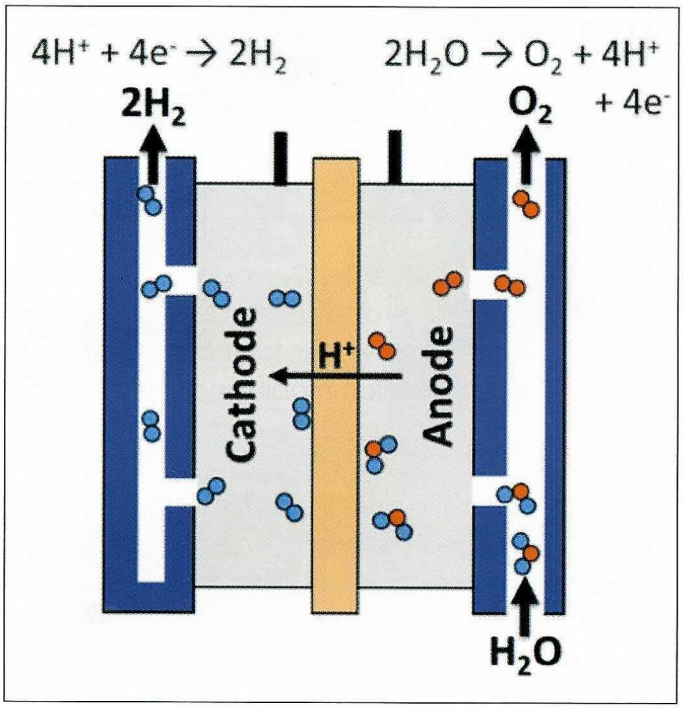
Hydrogen atoms form hydrogen molecules (H2) and oxygen molecules pair up too. Each can then be bottled up (more on that later).

If the electricity is generated from renewable sources such as solar or wind, production of hydrogen in this way emits no greenhouse gasses.

This is how we come to all the different shades of hydrogen:

- brown hydrogen is produced using coal where the emissions are released to the air
- grey hydrogen is produced from natural gas where the associated emissions are released to the air

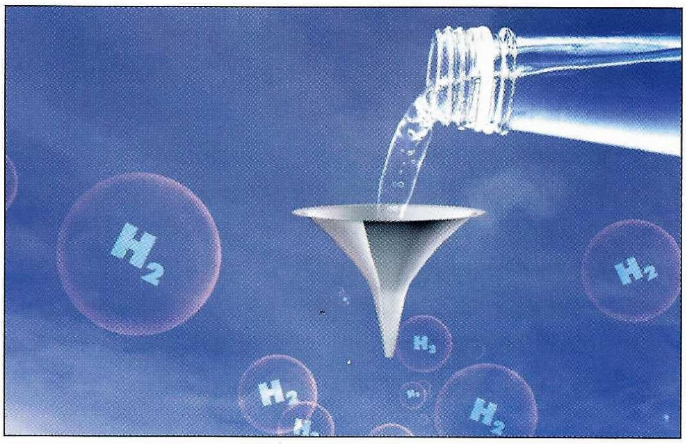
- blue hydrogen is produced from natural gas, where the emissions are captured using carbon capture and storage green hydrogen is produced from electrolysis powered by renewable electricity.



The technical analysis found that currently, the largest electrolyzer unit sold produces only 380,000 kg H2/year. There are two limitations for electrolyzers of this size. If the system were to be used for forecourt production, fueling approximately 1,900 cars, 2.3 MW of electricity would be required. This electricity demand would likely preclude the purchase of cheaper industrial electricity in the forecourt scenario, thus raising the price of hydrogen. If the system were to be used in a large hydrogen generation plant, the limited hydrogen production capacity means that a significant number of electrolyzer units would be required. For example, a 500,000 kg/day hydrogen generation plant using nuclear power and electrolysis would require 500 of the largest electrolyzer units available today. In this scenario, electrolyzers 10 to 100 times the size of today's units could be utilized.

At current electrolyzer efficiencies, in order to produce hydrogen at lower than $3.00/kg, electricity costs must be lower than 4 and 5.5 cents per kWh. For an ideal system operating at 100% efficiency, electricity costs must be less then 7.5 cents per kWh to produce hydrogen at lower than $3.00/kg. This analysis demonstrates that regardless of any additional cost elements, electricity costs will be a major price contributor.

GREEN HYDROGEN IN INDIA



The latest buzzword in the world of global energy aspirations sounds like the title of a blockbuster Sci-Fi movie — Green H2 -1-1-1 ($1 for 1 kg of green hydrogen in 1 decade). The buzzword may be new but the science behind it was dreamt up way back in the 19th century. "Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable," Jules Verne wrote in his 1875 novel, The Mysterious Island.

The ball was set rolling by Prime Minister Narendra Modi when he unveiled the 25-year roadmap for hydrogen development in his address on India's 75th Independence Day and announced the National Hydrogen Mission to meet the larger goal of self-reliance in energy production by the 100th Independence Day in 2047. "The thing that is going to help India with a quantum leap in terms of climate is green hydrogen. We have to make India a global hub for green hydrogen production and export," he said.

Some years ago, government had launched a similar mission for solar power under which India is chasing 500 gigawatt (GW) capacity by 2030 and has achieved much success —100 GW, from less than 30 GW six years ago. Will hydrogen see a similar takeoff? It will, but with time. "Hydrogen will drive economies not now but in near future. Today's electrolysers (used to separate hydrogen from water using cathode, anode and membrane) consume 40-50 units of electricity to split water and generate 30-35 units. Energy consumed is more than energy produced.

India can produce green hydrogen from 15-20 GW installed capacity by 2030. For that, it will need to invest $4-5 billion in electrolysers, according to the India Hydrogen Alliance (IH2A), a grouping of industry stakeholders.

Last week, Indian Oil Corporation (IOC), Larsen & Toubro (L&T) and ReNew Power announced a joint venture to develop green hydrogen. Additionally, IOC and L&T also said that they would join hands to manufacture and sell electrolysers, used in the production of green hydrogen.

Jorhat Pump Station

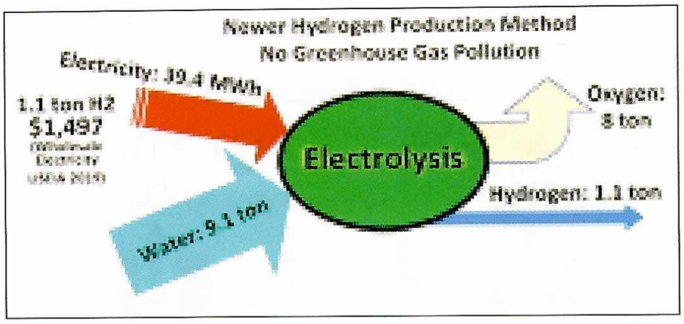
Oil India Limited (OIL) has taken the first significant step towards Green Hydrogen Economy in India with the commissioning of India's First 99.999% pure Green Hydrogen pilot plant, with an installed capacity of 10 kg per day at its Jorhat Pump Station in Assam today. The plant produces Green Hydrogen from the electricity generated by the existing 500kW Solar plant using a 100 kW Anion Exchange Membrane (AEM) Electrolyser array. The use of AEM technology is being used for the first time in India.

This plant is expected to increase its production of green hydrogen from 10 kg per day to 30 kg per day in future. The company has initiated a detailed study in collaboration with IIT Guwahati on blending of Green Hydrogen with Natural Gas and its effect on the existing infrastructure of OIL. The company also plans to study use cases for commercial applications of the blended fuel.

Green hydrogen is safer than conventional fuels

To evaluate hydrogen's safety, it must be compared to that of other conventional fuels like gasoline, propane, and diesel. While no fuel is 100 percent safe, green hydrogen has been shown to be safer than conventional fuels in a multitude of aspects.

Risks are related to electrolysers which are used in the production of green hydrogen. Other exposures include freezing water in the stack, fracture of pressurised pipes or compartments,



Many fuels are flammable. Compared to gasoline, natural gas, and propane, hydrogen is more flammable in the air. However, low concentrations of hydrogen have similar flammability potential as other fuels.

Mixtures of hydrogen and air can be highly explosive. Never smoke near a place where hydrogen is generated or being used. Remove all possible sources of flame and sparks. Hydrogen should only be generated and used in a well ventilated out door area.

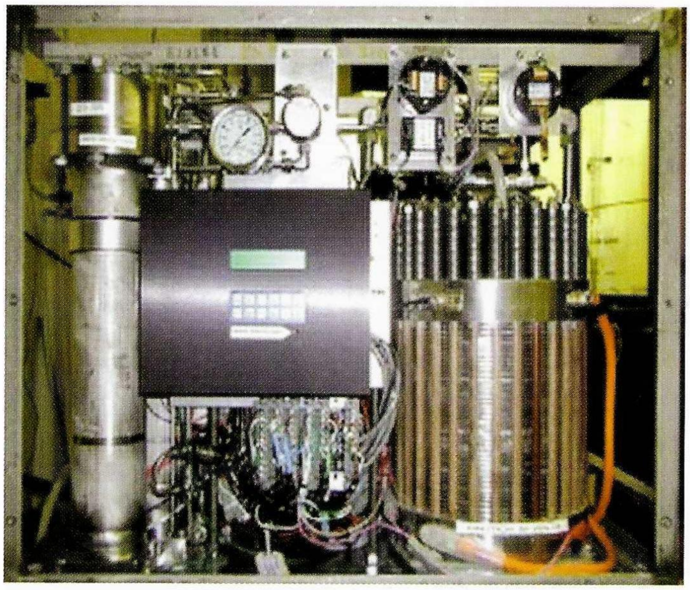
The major safety issue is losing containment of hydrogen; as a gas it is stored under high pressure that could injure nearby personnel and as a cryogen it could cause injuries such as frostbite. The released gaseous or cryogenic hydrogen poses a combustion hazard.

Face shields are generally required when operating any hydrogen system under pressure and connecting or disconnecting lines or components to protect against pressure-driven debris.

Hydrogen used in the fuel cells is a very flammable gas and can cause fires and explosions if it is not handled properly. Hydrogen is a colorless, odorless, and tasteless gas. Natural gas and propane are also odorless, but a sulfur-containing (Mercaptan) odorant is added to these gases so that a leak can be detected.

In enclosed locations with normal temperatures, spilled liquid hydrogen will create enormous gas pressures, tearing apart vessels without safety valves. The two prime dangers from fuel cell and hydrogen-powered vehicles are the danger of electrical shock and the flammability of the fuel.

A "hydrogen explosion"occurs when air includes more than 5% in density of oxygen, and more than 4% in density of hydrogen, they then ignite with a resulting explosion. If the temperature is more than 500°C, it will ignite spontaneously and explode.



Green hydrogen pilot project targeting fuel dispensation at 700 bar

GH2 Solar, a unit of Noida-based Uneecops Technologies, is working with a research organization on a green hydrogen pilot project for stationary and transport applications. The project will include the production, storage, distribution and dispensation of hydrogen, with a fuel-dispensation target of 700 bar.

"The project will use PEM electrolyzer and produce 10 normal cubic meters of green hydrogen per hour. A 50 kW electrolyzer will be installed," Anchal Tyagi, Uneecops Solar's green hydrogen chief, told pv magazine. "It will be powered by a solar plant that will be co-located with the green hydrogen plant.

'Global demand for hydrogen electrolysers in 2030 will be about six times higher than available supply'

More than 400GW of electrolysers will be required by the end of the decade, but only 70GW will be manufactured by then "Before we even include known projects in the Middle East, Australia and Scandinavia in ammonia, fuel and Power-to-X, we reach potential demand of 400GW of electrolysis by 2030... our model only indicates 70GW of supply by 2030."

Recharge believes that announced green hydrogen projects in the Middle East and Australia alone add up to 80-100GW by the end of this decade.

REPowerEU's plans for 20 million tonnes of green hydrogen by 2030 would require 120-200GW of electrolysers alone.

A global supply crunch of electrolysers needed to produce green hydrogen and a lack of domestic manufacturers to make them pose a major challenge to India's ambitious targets to use the zero-carbon fuel, a government official told Reuters.

India, which unveiled the first phase of its hydrogen policy on Thursday, plans to manufacture 5 million tonnes of green hydrogen per year by 2030, half of the European Union's 2030 target of 10 million tonnes.

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