January–March 2022

ENERGY FUTURE

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COVER STORY

GREEN HYDROGEN TO PLAY KEY ROLE IN COMBATING CLIMATE CHANGE

VIEWPOINT

ACHIEVING INDIA'S CLIMATE CHANGE GOALS

FEATURE

HARNESSING THE POTENTIAL OF 'GREEN HYDROGEN' IN INDIA

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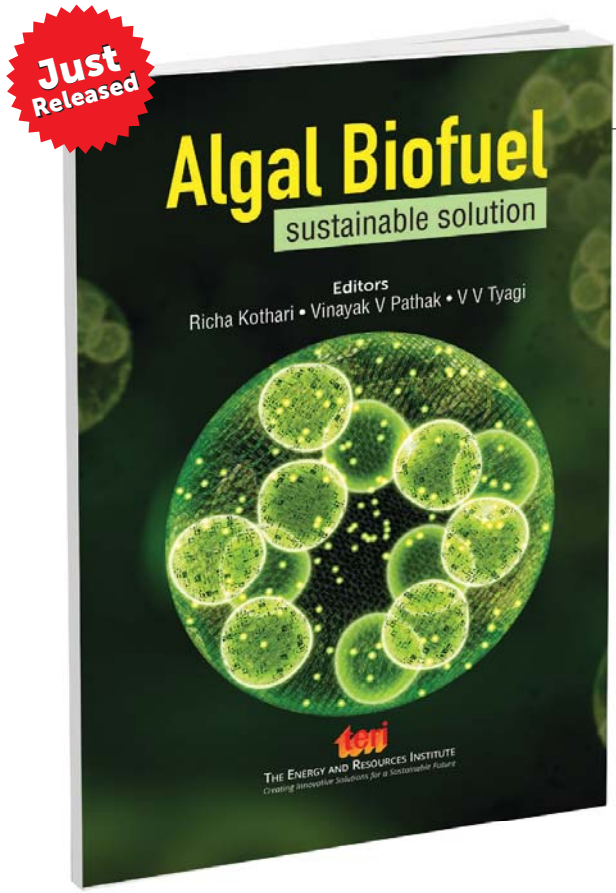
SUSTAINABLE ENERGY SOLUTIONS FROM BIO SOURCES



Major topics covered

- Algal biomass harvesting for biofuel production
- Biogas as bioenergy option
- Application of algal biomass as a feedstock
- Bioethanol production from lignocellulosic/ algal biomass
- Crop residues as a potential substrate for bioenergy production
- Biodiesel production from non-edible oilseeds

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Algal Biofuel: sustainable solution explores a wide spectrum of bioenergy sources, including their applications. It provides latest information in the field of bioenergy technologies and their future prospect including lipid content. It discusses governance of biofuel at global and national levels and the potential of biofuel to meet the rising energy demand. The book focuses towards the strategies to ensure the availability of algal biomass, effective cultivation and harvesting techniques. The strategies to enhance the algal lipid synthesis and its conversion for biodiesel production have been also elaborated.

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Editorial

Green hydrogen is a clean source of energy as it only emits water vapour and leaves no residue in the air, unlike coal and oil. Hydrogen has the propensity to end our dependency on fossil fuels as the world intends to meet its climate goals by limiting the global rise in temperature.

With the launch of the Green Hydrogen Mission, India is preparing to achieve its ambitious targets on the energy independence and climate. Green hydrogen plays a key role in the development of clean energy and decarbonization systems in the country. India also aims to reduce its total carbon emissions and achieve net zero in the decades to come. For meeting India's climate goals, there is now a focus on developing green hydrogen in the country for minimizing greenhouse gas emissions, while also promoting self-sufficiency. For this, harnessing its plentiful renewable resources that are available locally is essential. Presently, the main resources of renewable energy in India are wind, solar, hydro, and biomass. In the current context of green hydrogen, these resources of renewable energy have also become significant. Wind and solar resources are making strides in India. Incidentally, both wind and solar resources are of intermittent nature. This matter has been addressed to some extent by the MNRE's policy on wind-solar hybrid power systems with the provision of energy storage. Large-scale development of reliable power supply from wind and solar sources, and also biomass and hydro, will help in the production of green hydrogen in a big way.

Our cover story in this issue mentions some good initiatives that will encourage companies to adopt green hydrogen production in India. For instance, the first biomass-based green hydrogen production commercial plant is coming-up in the Khandwa district of Madhya Pradesh. This plant will produce one tonne of hydrogen daily, from 30 tonnes of biomass feedstock. The hydrogen will be produced in a thermally accelerated anaerobic digester reactor by gasification, that is, by supplying steam, heat and oxygen but without combustion. Similarly, in another initiative, NTPC Ltd. is exploring the potential of large-scale, off-grid hydrogen energy storage and micro-grid projects at strategic locations throughout the country. It has selected the Guest House of Simhadri Thermal Power Project, Vishakhapatnam, for off-grid supply of green hydrogen based micro-grid electrical power. It is the first green energy storage project in India.

Overall, R&D efforts should concentrate on development of a consistent supply chain for hydrogen and availability of appropriate storage systems for demonstration projects, with an objective to obtain operational feedback. Relevant start-ups could be supported in this endeavour. R&D efforts need to be speeded-up to: minimize the production cost of hydrogen, indigenization, maximization of efficiency and develop technology to suit the Indian environment. Globally, various targets, mandates and policy initiatives supporting hydrogen in different sectors are under implementation. Policy has a pivotal role to play in resolving the issue of supply creation and demand generation. In the absence of adequate demand, production cannot be scaled up and the costs will not decline, consequently impacting its uptake. Recent announcement by the Government of India on the launch of the first phase of the National Hydrogen Mission, in 2022, is a welcome step in this direction. India can achieve rapid cost reduction in technologies by moving towards deployment-led support. Collaborations between public and private players for scaling up the hydrogen ecosystem and reducing the risk of initial deployment are needed. Several companies have also announced ambitious targets and initiatives. India is at an inflection point of developing an economically competitive, low carbon hydrogen sector. In December 2020, TERI published a detailed assessment of the potential role that hydrogen can play across the Indian economy—covering transport, industry and power. The first feature article in this issue captures some of the major outcomes and recommendations emerging from the same.

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Girish Sethi

Girish Sethi
Senior Director – Energy Program, TERI

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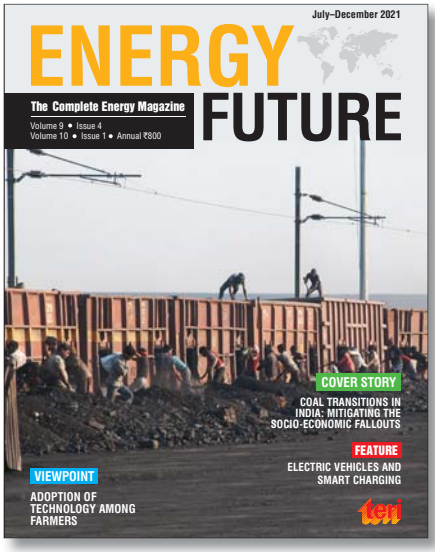

New Message

teripress@teri.res.in

Letter to the Editor

The December 2021 issue of Energy Future is quite apposite in my view. I agree with the authors that India's transition from coal to renewable and cleaner options will mark a massive shift in our industries, economy as well as the job market. While limiting - and ultimately stopping - the use of coal will reduce emissions from fossil fuelled vehicles, and thereby prevent climate change, we also need to be mindful of the socio- economic fallouts of this transition. Particularly, the transition of the skilled labour force and how we can use or better our existing skill-capacities should be the focus of this transition. This, in my opinion, will allow the people to more readily participate in the adoption of cleaner power, while simultaneously ensuring our economic growth.

Harsh Garewal,
Guwahati, Assam

Send

Saved

"We can already see how fast the EV sector is growing, with new and innovative technology releasing ever so often. This is why I enjoyed the feature article on Electric Vehicles and Smart Charging the most. It has highly informative as the author, Shweta Kalia, covered the basics of smart charging control strategies. The article efficiently defined important concepts like, centralized and distributed control strategies, real-time pricing, ToU tariff, CPP, etc. The table analysing and comparing city-wise EV policies and schemes was an innovative and efficient way of providing effective information for readers like me. I would also like to mention the article on 'End-Use Power Dmenad Estimation in Residential Sector' by Saswata Chaudhury. It underlined the need for efficiency improvements in residential energy consumption."

Snehal Gupta
Ahemdabad, Gujrat

Thank you very much for your encouragement. The editorial team of Energy Future will ensure that the magazine caters to your information and knowledge needs. We welcome your suggestions and comments to further improve our content and presentation.

Email: teripress@teri.res.in

Editor
Energy Future

"I liked of the issue overall talked about innovative emerging technologies across various sectors. It covered major industries and the issue involved. Particularly insightful for me was the Energy Insights section of this issue. The article titled 'Ablest Faecal Sludge Management' really brought to light the largely overlooked issue of mismanagement of faecal sludge and how hazardous the same can be. The authors' critical examination and comparison of the present technologies was highly informative. Upon further reading-up on my own I found out about Maharashtrian cities, Wai and Sinnar, that are leading examples of successful implementation of scheduled desludging service. This was through the introduction of scheduled desludging through a public private partnership model. Coverage like this article helps raise awareness to on-ground issues, which in-turn leads to real change."

Kriti Gupta
Pune, Maharashtra

"I liked reading the feature article that talked about some of the most viable solutions for improving irrigation services in the agriculture sector. We all know the important role that the agricultural sector plays in both supporting our food-security needs as well as our GDP. As highlighted by the authors, its economic contribution is significant, especially for rural livelihoods. In this case, over-utilization and adverse environmental consequences as a result – these act as twin problems with double the consequences. Thus, improving access to irrigation services will not just ensure better profitability for the farmers, along with water security, but also align with broadening the scope of India's renewable power. This article highlighted how we can do just the same and do it well."

Neha Verma
Lucknow, Uttar Pradesh

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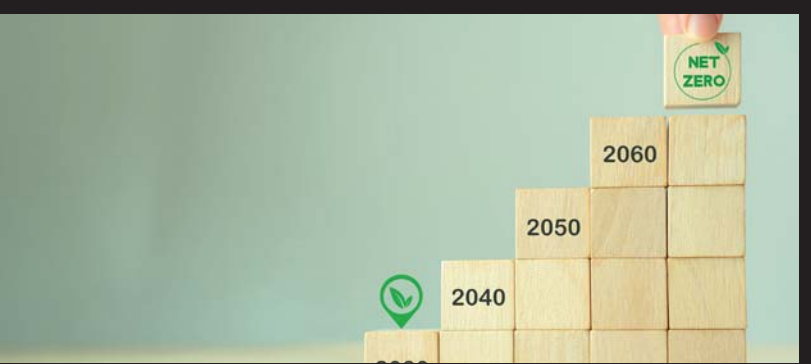


NTPC TOP BIOMASS USER IN INDIA, CONSUMES 58,000 MT: POWER MINISTRY

State-run power giant NTPC has emerged as the top biomass user, having co-fired about 58,000 MT (metric tonne) of biomass, while tendering a total of 10.7 million metric tonnes (MMT) over short-term and long-term basis, the Power Ministry said. As on date, approximately 59,000 MT of biomass has been co-fired in thermal power plants in the country, while tenders for 12 MMT are at different stages of process for short-term and long-term duration, the Ministry said in a statement. "The biomass co-fired in the NCR region stands at 21,000 MT and tenders floated in the region are about 5.50 MMT. Contracts have already been awarded for more than 11 lakh MT of biomass pellets," it added. The agro-residue/

biomass earlier considered as a waste product has now begun to produce zero-carbon electricity for the citizens of the country. In turn, farmers are getting additional income by selling the stubble/biomass for conversion into torrefied/non-torrefied biomass pellets. EF

Source: https://www.business-standard.com/

GOVERNMENT LAYS ROADMAP FOR TRANSITION TO GREEN ENERGY

In accordance with Hon'ble Prime Minister's announcement at COP26, the Ministry of New and Renewable Energy (MNRE) is committed to achieving 500 GW of installed electricity capacity from non-fossil fuel sources by 2030. The MNRE has constituted a committee for preparing a roadmap to achieve 500 GW of non-fossil fuel-based energy capacity by 2030. The committee includes representations from important agencies dealing with renewable energy and electricity. A total of 152.90 GW of renewable energy capacity projects (including large hydro) have been installed in the country as on February 28, 2022, which includes 50.78 GW from solar power, 40.13 GW from wind power, 10.63 GW from biopower, 4.84 GW from small hydro power, and 46.52 GW from large hydro power. Further, projects of 72.61 GW capacity are under various stages of implementation and 21.11 GW capacity are under various stages of bidding. EF

Source: https://pib.gov.in/

TATA POWER COMMISSIONS 100-MW SOLAR PLANTS IN UTTAR PRADESH

Tata Power has said that its subsidiary, Tata Power Renewable Energy, has commissioned 100 megawatt (MW) of solar projects in Uttar Pradesh. As much as 50 MW of the plants have been built in Prayagraj, while the remaining capacity has been set up in Banda. The solar plants are expected to generate more than 221.3 million units of electricity every year. "The commissioning of solar PV projects in Uttar Pradesh's Prayagraj and Banda has strengthened our position as a leading renewable energy company, and we will continue to contribute to the country's sustainable energy growth," Praveer Sinha, CEO and MD, Tata Power, said. Tata Power currently has a solar portfolio of 2123 MW across the country and its wind power capacity stands at 932 MW. It also has 1854 MW of renewable energy capacity under implementation. EF

Source: https://www.financialexpress.com/

INDIA AND DENMARK AGREE TO WORK TOGETHER ON GREEN HYDROGEN

India and Denmark have agreed to initiate joint research and development on green fuels including green hydrogen, during the Joint S&T Committee meeting on January 14, 2022.

The Joint Committee discussed national strategic priorities and developments in Science, Technology, and Innovation of both countries with a special focus on green solutions of the future—strategy for investments in green research, technology, and innovation at the virtual meeting.

The committee emphasized on development of bilateral collaboration on mission-driven research, innovation, and technology development, including climate and green transition, energy, water, waste, food, and so on as agreed by the two Prime Ministers

while adopting the Green Strategic Partnership – Action Plan 2020–2025. They agreed to organize 3–4 webinars for partnership development and stressed on promoting call for proposals in green fuels, including green hydrogen. The Joint Committee also reviewed the progress of the ongoing projects of last two joint calls being implemented in the areas of energy research; water; cyber-physical systems, and bioresources & secondary agriculture. EF

Source: https://dst.gov.in/

CSIR-CMERI'S SOLAR TREE BREAKS GUINNESS WORLD RECORD

Revolutionizing the intertwined fields of agriculture and sustainable energy, the Council for Scientific and Industrial Research's Central Mechanical Engineering Research Institute (CSIR-CMERI) have broken the Guinness World Record for the world's largest solar panel. The solar tree, which has been installed at the CSIR-CMERI Centre of Excellence for Farm Machinery in Ludhiana, has a solar photovoltaics panel surface area of 309.83 m^2. The surface area of the last solar tree developed by CSIR-CMER was 67 m^2. With 75% power generation in India dependent on diesel, switching to renewable energy, primarily solar, is the need of the hour. On how it all started, CSIR-CMERI, Durgapur, Director Professor Harish Hirani said, "We started with six solar trees ranging from 3 kW to 11.5 kW, which together generated around 50 kW power. We then worked on the material and fabrication cost and started developing a single 50 kW solar tree." EF

Source: https://www.hindustantimes.com/

IREDA INKS MOU WITH CIPET FOR SOLARIZATION OF CIPET ACADEMIC CAMPUSES

On March 11, 2022, Indian Renewable Energy Development Agency Ltd. (IREDA) signed a Memorandum of Understanding (MoU) with the Central Institute of Petrochemicals Engineering & Technology (CIPET), to provide its techno-financial expertise for solarization of CIPET campuses. The two organizations are under the Ministry of New and Renewable Energy and the Ministry of Chemicals and Fertilizers, respectively. The MoU was signed by Shri Pradip Kumar Das, Chairman & Managing Director (CMD), IREDA and Prof. (Dr) Shishir Sinha, Director General, CIPET in the presence of senior officials. Under the MoU, IREDA will help CIPET to solarize its numerous academic campuses by installing solar PV or rooftop solar projects. The project is most likely to begin at CIPET's Varanasi, Ayodhya (Uttar Pradesh) and Bidar (Karnataka) campuses. CIPET will be able to lower its electricity expenditure and reduce its carbon footprint by installing solar power plants at its academic campuses. EF

Source: https://pib.gov.in/

MAHANADI COALFIELDS LIMITED BECOMES LARGEST COAL PRODUCING COMPANY IN INDIA

The Mahanadi Coalfields Limited (MCL), a unit of the CIL, has crossed 157 million tonne (MT) in coal production in the financial year of 2021–22, to become the leading coal producing company in the country, a release said. On March 12, 2022, the company produced 7.62 lakh tonne of dry fuel, which is the highest in a day during the current financial year reaching 157.7 MT with a growth of around 16% over the last financial year, the company release said. MCL has to play a bigger role in ensuring energy security to the nation, said the CMD in his congratulatory message to all the employees. Surpassing all previous records, MCL has despatched over 166 MT dry fuel to the consumers, registering 22% growth over a previous financial year while it has also removed 195 MCuM (million cubic metre) of over burden registering 19% growth over the last financial year, the release added. EF

Source: https://www.business-standard.com/

INDIA ADDS RECORD 1700 MW ROOFTOP SOLAR CAPACITY IN 2021: MERCOM

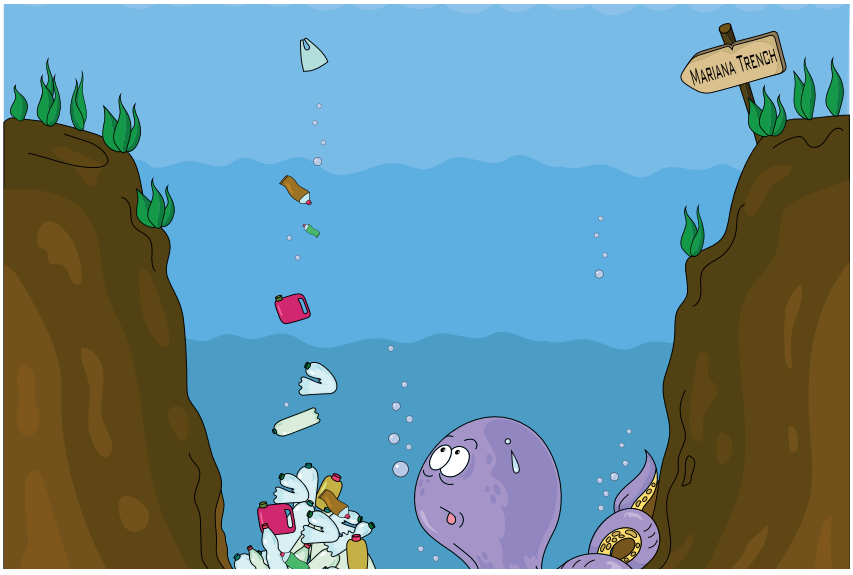
India installed a record 1700 megawatt (MW) of rooftop solar capacity in 2021, registering a 136% year-on-year rise, according to a Mercom India Research report. The country had added 719 MW of rooftop solar capacity in 2020, the research firm said in its latest report on March 9, 2022. India added a record 1.7 GW of rooftop solar capacity in 2021, the highest ever in a year. In 2021, the residential and commercial segments accounted for 35% and 33% of installed rooftop solar capacity, respectively. Industrial rooftop solar installations constituted 26%, and the remaining 6% was from the government segment. "The rooftop solar market in India had its best year, largely due to the pent-up demand from 2020, which experienced a severe decline due to the COVID-19 pandemic. Certainty around net metering regulation helped along with the demand from consumers across all segments, be it residential, commercial, and industrial," said Raj Prabhu, CEO of Mercom Capital Group. EF

Source: https://www.business-standard.com/

175 COUNTRIES AGREE TO FIRST-OF-ITS-KIND PLASTIC WASTE TREATY

The world has taken its biggest step yet to curb the plastic pollution crisis. The United Nations said recently that representatives of 175 countries have agreed to develop a first-of-its-kind global treaty to restrict plastic waste. The resolution followed negotiations at the fifth session of the UN Environment Assembly in Nairobi, Kenya. The treaty aims to tackle one of the most pressing environmental issues the world faces. The sheer pervasiveness of plastic waste has been widely recognized in recent years, with plastic debris identified everywhere from Arctic snow to the bottom of the Mariana Trench, the deepest point in the ocean. EF

Source: https://www.hindustantimes.com/



STUDY FINDS HOW MOUNTAIN STREAMS CAN SIGNAL CLIMATE CHANGE

Scientists at the University of California have found a new tool that can better assess an important but overlooked indicator of global warming, which is a variety of bugs, worms and snails living in high mountain streams. The study was published in the journal, *Ecological Monographs*. Water-based invertebrates are especially vulnerable when the climate swings from historic droughts to massive floods. Because they serve as food for other forms of alpine life, such as birds, bats, frogs and fish, ecologists worry about the insects' ability to thrive. Understanding how these small creatures are affected by climate change requires understanding where we ought to find them. As a step towards protecting them, the team applied a new theory for predicting biodiversity in high mountain streams. EF

Source: https://www.hindustantimes.com/

OCEANS ARE HOTTER, HIGHER AND MORE ACIDIC, CLIMATE REPORT WARNS

The world's oceans in 2021 grew to their warmest and most acidic levels on record, while melting ice sheets helped push sea levels to new heights, the World Meteorological Organization (WMO) said. Oceans saw the most striking extremes as the WMO detailed a range of turmoil wrought by climate change in its annual "State of the Global Climate" report. The WMO report follows on the latest United Nations climate assessment, which warned that humanity must drastically cut its greenhouse gas emissions or face increasingly catastrophic changes to the world's climate. EF

Source: https://www.thehindu.com/

DEFORESTATION, CLIMATE CHANGE MAKING OUTDOOR WORK UNSAFE

A double-blow of forest destruction and climate change has caused temperatures to soar in many tropical locations, making outdoor work unsafe for millions of workers, according to a study published recently. Between 2003 and 2018, the study found, about 4.9 million people lost at least half an hour per day of working conditions at a temperature recognized as safe.

"Tropical locations are already on the edge of being too hot and humid to safely work because of climate change," said Luke Parsons, lead author on the paper published in the journal *One Earth*. Parsons' research further found that 91,000 people lost more than two hours of safe working temperatures per day—the overwhelming majority of them in Asia. EF

Source: https://economictimes.indiatimes.com

PARTICLE GEL COULD SOLVE LOW HEAT PRODUCTION EFFICIENCY

Geothermal energy comes from heated water or steam within the earth and provides a renewable source of energy to heat buildings and generate electricity. But many geothermal reservoirs also have an inherent problem—geological fractures that allow water to divert into other areas, cooling the water and the surrounding rock and limiting the efficiency of heat extraction from underground reservoirs. Researchers at Missouri University of Science and Technology are working on a solution. "We're developing cost-effective polymer gels that can be injected into geothermal reservoirs to control the diversion problem," says Dr Baojun Bai, professor of Geosciences and Geological and Petroleum Engineering at Missouri S&T. "The particle gels can partially or fully block the geological fractures so that when water is injected into the reservoirs, it travels to other areas of hot rock, carrying more heat and improving geothermal recovery efficiency." EF

Source: https://www.worldenergynews.com/

FIRST FLOATING TIDAL POWER DELIVERED TO NOVA SCOTIA GRID

Nova Scotia has allocated circa 30 MW of capacity via demonstration permits and berths at FORCE (Fundy Ocean Research Center for Energy) for developers to demonstrate their energy generation prowess. "Achieving 'first power' to the grid from our new platform in Grand Passage signals a real inflection point for our business," said Jason Hayman, CEO, Sustainable Marine. "It crystalizes the journey we've been on, following almost a decade of rigorous research, development and testing. The project has enabled Sustainable Marine to gradually acquire skills and resources to deliver turnkey projects, including a multipurpose construction vessel called the Tidal Pioneer, and a suite of next-generation, remotely operated subsea installation machines supporting our novel Swift Anchors technology."

"Sustainable Marine Energy achieved a first in Canadian tidal energy history, delivering power from a floating platform in Grand Passage to Nova Scotia's electricity grid," said Nova Scotia Premier Tim Houston. "This project and others are positioning Nova Scotia as a global player in the tidal energy sector and are creating green technologies, green jobs, a cleaner environment and a predictable, renewable source of electricity for Nova Scotians." EF

Source: https://www.worldenergynews.com/

IEA LAUNCHES A ROADMAP FOR MOLDOVA ON SYSTEM INTEGRATION OF RENEWABLES

The electricity system in Moldova is characterized by its reliance on imports, which supplied 69% of demand in 2020. Renewable electricity accounted for just over 12% of domestic generation, though there remains over 27 GW of potential renewable generation capacity via wind, solar, biomass, and hydro. To provide Moldovan policymakers at all levels with a vision towards a clean, secure and modern electricity system, the International Energy Agency launched a policy roadmap on System Integration of Renewables for Moldova. The Roadmap was presented along with the Ministry of Infrastructure and Regional Development, featuring input from the European Bank for Reconstruction and Development, Hitachi, and WindEurope. It was

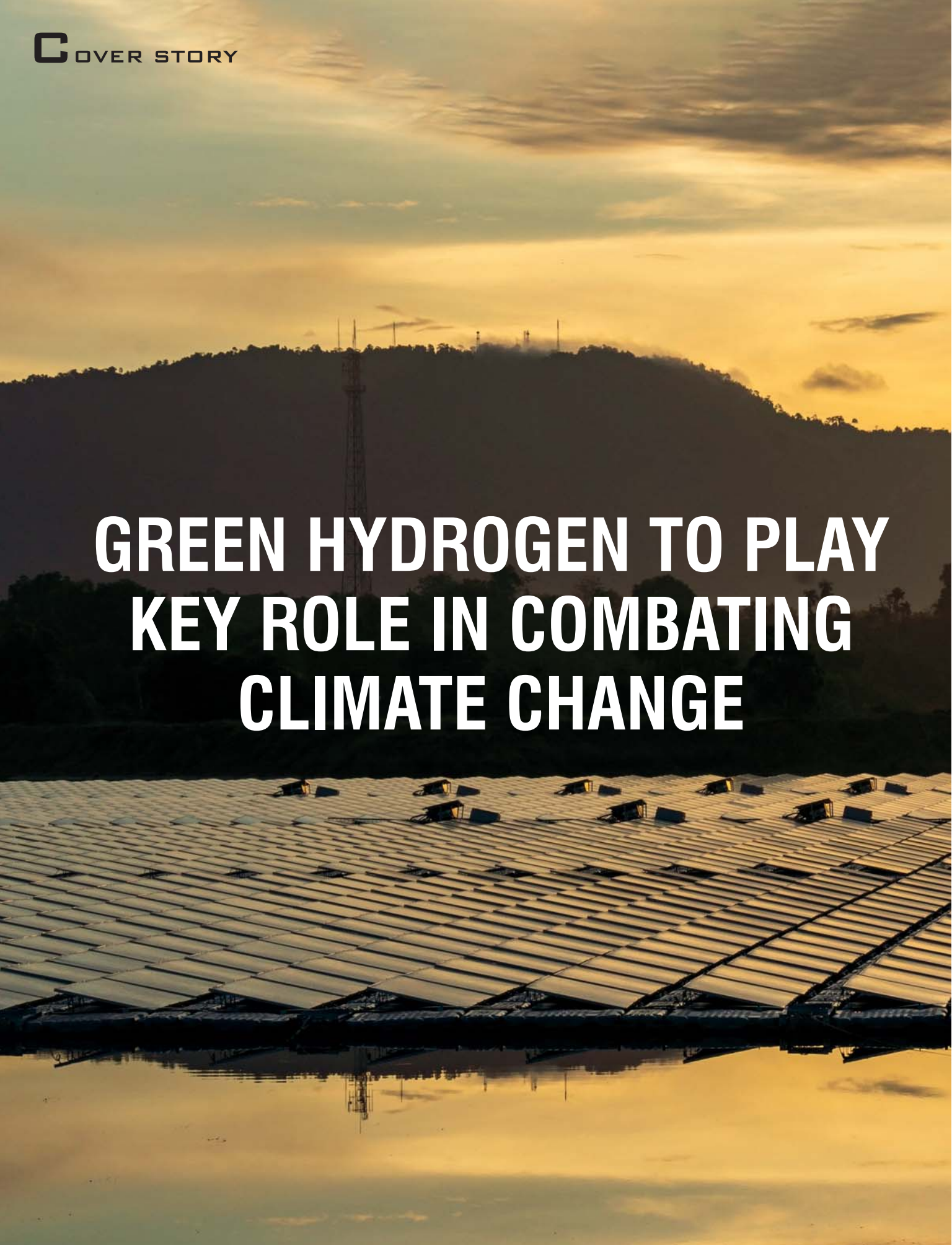
developed as part of the IEA's work through the EU4Energy Programme. The Roadmap examines tangible steps the government can take to enhance the power system and facilitate investment in renewables, removing barriers to deployment and establishing flexible electricity markets with strengthened regional coordination. EF

Source: https://www.iea.org/

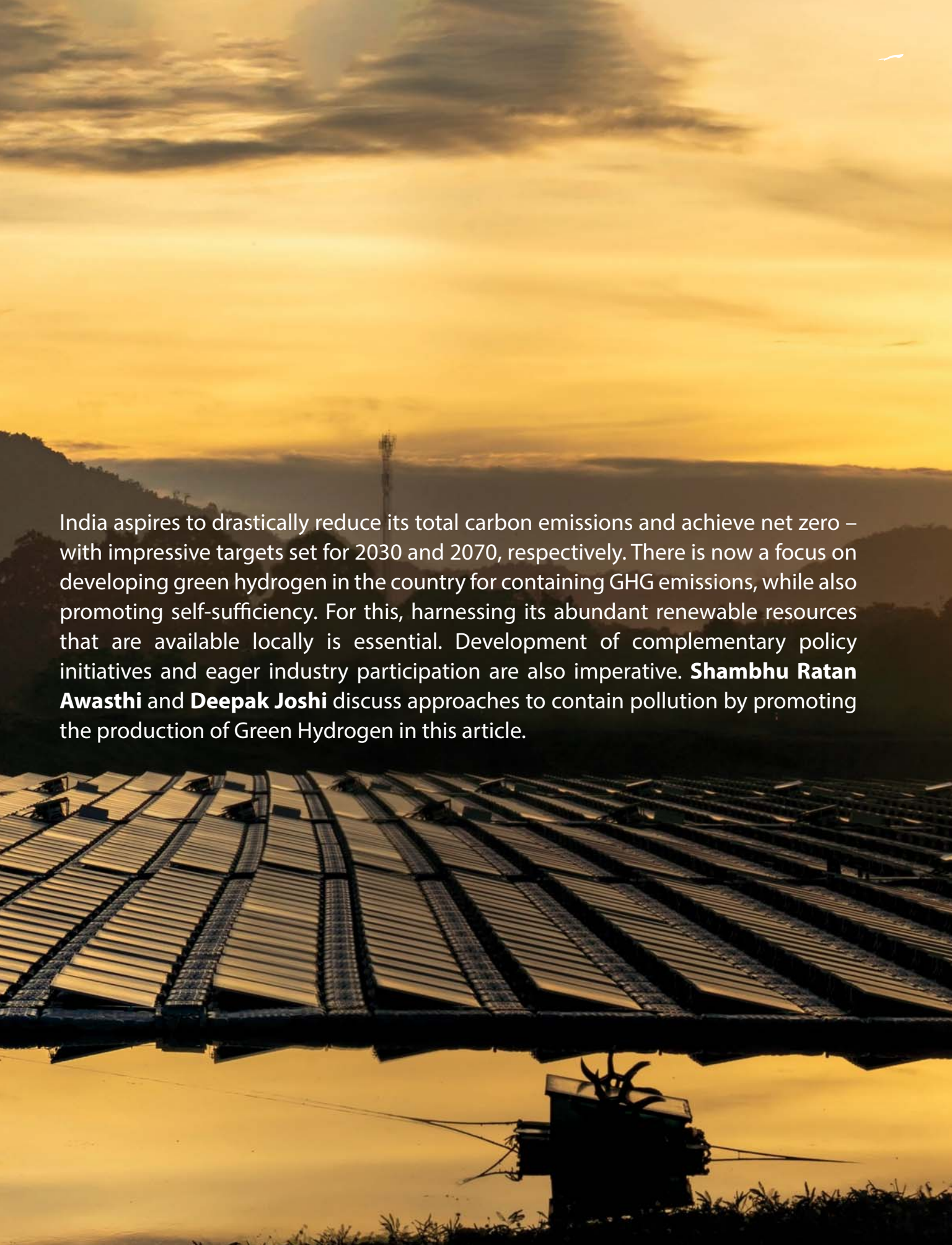
BRAZIL'S TRUCKING SECTOR HAS OPPORTUNITIES TO FURTHER IMPROVE ENERGY EFFICIENCY AND CUT EMISSIONS

Brazil's freight sector has numerous opportunities to use energy more efficiently, reduce carbon emissions and improve air quality by taking steps such as replacing older trucks, improving fuel economy and investing in rail and roads, according to a joint study by the IEA and Brazil's Energy Research Office EPE. This year's *Atlas of Energy Efficiency* includes a special focus on the road freight sector, providing an overview of how the sector has developed over the past two decades, how policies have influenced energy consumption and emissions, and where opportunities lie for further progress. Brazil has some of the largest trucks in the world, with heavy trucks playing a critical role in hauling agricultural commodities and accounting for 60% of total freight energy use in the country. Over the past two decades, the efficiency of Brazil's trucks has improved thanks to policies to spur innovation in the auto industry, modernize roads, restrict emissions, and advance alternative fuels. EF

Source: https://www.iea.org/



GREEN HYDROGEN TO PLAY KEY ROLE IN COMBATING CLIMATE CHANGE



India aspires to drastically reduce its total carbon emissions and achieve net zero – with impressive targets set for 2030 and 2070, respectively. There is now a focus on developing green hydrogen in the country for containing GHG emissions, while also promoting self-sufficiency. For this, harnessing its abundant renewable resources that are available locally is essential. Development of complementary policy initiatives and eager industry participation are also imperative. **Shambhu Ratan Awasthi** and **Deepak Joshi** discuss approaches to contain pollution by promoting the production of Green Hydrogen in this article.

Modern developments started at the beginning of the 19th century and gained momentum by the middle of the century. Because of technological advancements, fossil fuel-based power generation unit capacity started increasing and has crossed 1000 MW.

All types of transport vehicles (road, rail, water, and air) used fossil fuels – namely petrol, diesel, coal, and natural gas. The use of these fuels is likely to continue for a few decades during the energy transition phase.

At that point of time, hydrogen was also used for the production of ammonia for fertilizers, refineries, steel industries, etc. Since then, hydrogen continues to be produced from fossil fuels, mainly natural gas.

Sometime, in the latter half of the 20th century, concerns were raised on the issue of global warming resulting in climate uncertainty. Now, it has been globally accepted that emission of greenhouse gases due to burning of fossil fuels is the main culprit for global warming.

Global R&D efforts started searching for harmless or less harmful sources of energy. Finally, a unanimous opinion was formed that hydrogen offers a way to combat global warming, with a rider that it should be green hydrogen, i.e., produced from renewable energy. R&D efforts are being intensified globally and the world is gearing-up for green hydrogen-based policies and projects.

In line with global concerns, at the COP26 summit in Glasgow, in November 2021, the Prime Minister of India, Narendra Modi, pledged to cut India's total projected carbon emission by 1 billion tonnes till 2030, reduce the carbon intensity of the nation's economy to less than 45% by the end of this decade and achieve net-zero carbon emissions by 2070.

This article presents India's policy initiatives, industry participation, etc., towards a green hydrogen economy – with an emphasis to make the best use of locally available renewable energy resources for production of green hydrogen and development of the necessary infrastructure. The present and emerging global and Indian scenario are also briefly included, as well as the barriers to be overcome in the energy transition to green hydrogen.

Indian Scenario

The main resources of renewable energy in India are wind, solar, hydro, and biomass. India has a long coastal boundary of about 6100 km on the mainland and there is huge unexploited potential in offshore wind and ocean energy. In the present context of green hydrogen, these resources of renewable energy have also become significant. Wind and solar resources are making strides in India and several other countries. Incidentally, both wind and solar resources are of intermittent nature. This matter has been addressed to some extent by MNRE's policy on wind-solar hybrid power systems with the provision of energy storage. Large-scale development of reliable power supply from wind and solar sources, and also biomass and hydro, will help in the

production of green hydrogen in a big way.

The additional hydropower generation in rainy season can be utilized for production of hydrogen instead of reducing/stopping power generation from hydropower plants. In fact, during rainy season, the coal-based thermal power plants are shut down for annual maintenance, thus, extra hydropower during this season can be used as a substitute. Similarly, power from run-off river type power plants can be utilized, i.e., whenever additional water is available, it can be utilized in the production of hydrogen. It will help to reduce pondage capacity of future run-off river/canal fall power plants and will also improve its economic viability.

India's economy is agriculture based. The renewable energy resources generally available are solar and agriculture/animal/forest/industry/municipal wastes and may be in some cases wind and/or hydro. In order to achieve self-sufficiency in hydrogen and oxygen – a byproduct of electrolysis process – power generation at district level using locally available renewable energy resources (including biomass) is necessary. In fact, solar energy is stored indirectly in the plants and trees and is available as a source of renewable energy in the form of agriculture/cattle/forest wastes. It is an inevitable byproduct of farming and forestry. As per the available data, the food grain production in 2021-22 is estimated to exceed 300 million tonnes. The annual agricultural waste amounts to 350 million tonnes which is spread all over the country. If this and other wastes are utilized for power generation, then localized harm to environment would be much less, as compared to the present localized, large-scale harm caused by fossil fuel-based centralized power generation.

It needs to be understood that organic wastes, mainly carbon when burnt, emits CO_2 and other greenhouse gases. The atomic masses of hydrogen, carbon, and oxygen are 1, 12, and 16, respectively. Thus, in the burning process, 12 grams of carbon consumes 32 grams of oxygen.

Now, let us consider the electrolysis process to produce hydrogen as given by the following equation, in which electrical energy is supplied to split water molecule into hydrogen and oxygen:

$$2H_2O = 2H_2 + O_2 \quad (1)$$

In the electrolysis process of splitting of a water molecule, while producing 4 grams of hydrogen, there is a simultaneous production of 32 grams of oxygen too. The 12 grams of carbon consumes 32 grams of oxygen. The production of 12 grams of green hydrogen produces 96 grams of oxygen. In other words, the production of green hydrogen by electrolysis of water can help to sustain carbon (present in the wastes) combustion up to 3 times the mass of green hydrogen produced.

Welcome Initiatives

A few welcome initiatives that will encourage companies to adopt green hydrogen production and use are given as follows:

1. The material originating from a living organism is called biomass (Figure 1). Biomass-based power generation will enhance income and employment in rural areas. For this, a hydrogen literacy drive will help to convince the villagers to contribute in local power generation instead of burning the agriculture waste, say *parali,* in the field; which also adversely affects the fertility of soil. It will also promote organic farming which is desirable for public health and will also reduce the requirement of chemical fertilizers and water for irrigation.
   - The first biomass-based green hydrogen production commercial plant is coming up in the Khandwa district of Madhya Pradesh. This plant will produce one tonne of hydrogen daily, from 30 tonne of biomass feedstock. The hydrogen will be produced in a thermally accelerated anaerobic digester reactor by gasification, i.e., by supplying steam, heat and oxygen but without combustion. It also produces biochar and methane. At the cost of INR 24 Crore, the plant is being installed by M/s Watomo Energies Ltd in association with M/s Biezel Green Energy, with financial participation of interested farmers. In this totally indigenous technology-based endeavor, biochar and methane will be the byproducts which will also add to the income.
2. A thought that needs attention – large reservoir of hydropower projects may be very useful to produce green hydrogen as the

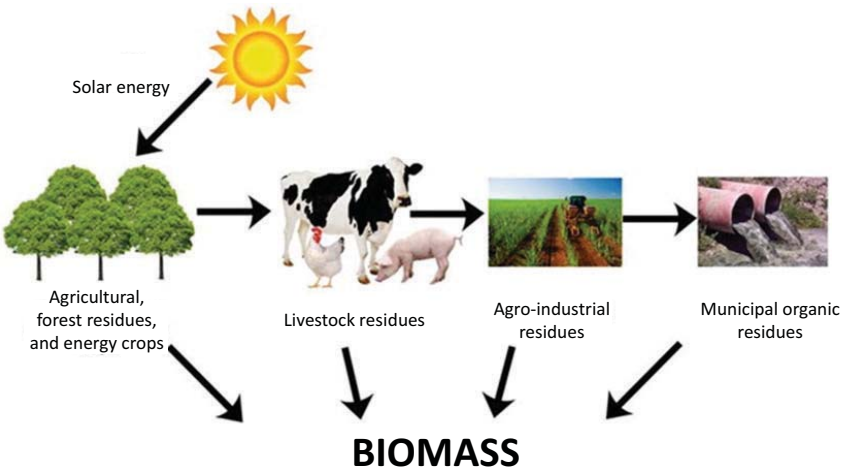


Figure 1: Feedstock for biomass-based hydrogen production plant [1]

basic requisites are already available at such projects. The large surface of reservoirs can be used to install floating solar power plants. The generation of additional power from a hydropower plant is generally possible during rainy season, when availability of solar power is low and uncertain. Thus, solar and hydropower resources are complementary to some extent.

NTPC Ltd. is exploring the potential of large-scale, off-grid hydrogen energy storage, and micro-grid projects at strategic locations throughout the country. It has selected the Guest House of Simhardi Thermal Power Project, Vishakhapatnam, for off-grid supply of green hydrogen-based micro-grid electrical power. It is the first green energy storage project in India. The renewable energy will be supplied to the electrolyzers (solid-state, high temperature solid oxide) from a nearby floating solar farm to produce green hydrogen (Figure 2). The hydrogen will be stored in tanks and will be fed to the hydrogen fuel cells to generate and supply electric power to NTPC's Guest House. The project is scheduled to become operational in 2022. The 50 kW solid oxide fuel cells are based on the technologies of M/s Bloom Energy, California.

3. India has a long coastline and hence the coastal districts have attractive options to produce hydrogen from sea water; by using the new material developed by IIT Madras (Figure 3). The material developed (Halide perovskite: Cs_2PtI_6) is photovoltaic and remains stable in water.

Figure 2: Floating solar park to produce green hydrogen [2]

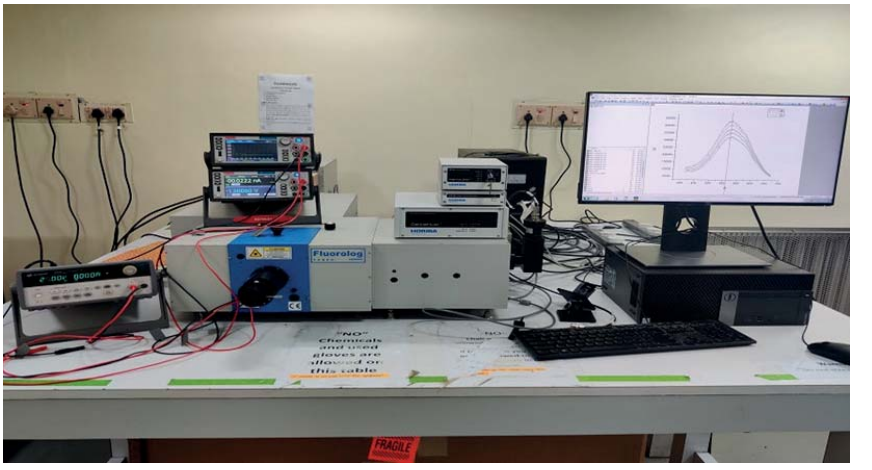


Figure 3: IIT-Madras develops a device to produce 'clean' hydrogen from seawater [3]

Demonstration projects provide useful exposure to O&M staff, which helps in identifying the areas of improvement. The visit by academic and research institutions, students, research scholars, etc., will help to popularize a new approach for green hydrogen. Similarly, introducing cars and buses based on fuel-cell technology in selected areas may be considered as a part of popularizing the campaign.

R&D efforts should concentrate on development of a consistent supply chain for hydrogen and ensuring availability of appropriate storage systems for demonstration projects, with an objective to obtain operational feedback. Relevant start-ups could be supported in this endeavor. R&D efforts need to be speeded-up to: minimize the production cost of hydrogen, indigenization, maximization of efficiency and develop technology to suit the Indian environment in – electrolyzers, fuel cells, metallurgy for piping to transport pure hydrogen, refueling stations, liquid hydrogen storage and transportation and so on.

The possibility of using existing infrastructure available for fossil fuels needs to be explored for the various aspects mentioned above.

Enthusiasm of Indian Industries

Several companies in public and private sectors are gearing up to contribute to the green hydrogen revolution in India. A few examples are as under: [4]

Reliance Industries Ltd, the largest private sector oil and gas company in the country, plans to become a net carbon-zero firm by 2035. It aims to replace transportation fuels with clean electricity and hydrogen. It has set a target to achieve 100 GW installed renewable power capacity by 2030. Reliance plans to manufacture electrolyzers in partnership with M/s Stiesdal A/S, Denmark and has also set a target to produce hydrogen at 'under US$1/kg within a decade'.

Adani New Industries Ltd plans accelerated investment to become the cheapest green hydrogen producer in the world. It has signed an MoU with M/s Ballard Power Systems, Canada – a global leader in fuel cells – to explore the possibility of commercial manufacturing of hydrogen fuel cells in transport and industry sectors.

GAIL, a PSU, has ordered one of India's largest 10 MW electrolyzers to produce 4.5 tonnes of green hydrogen daily. The plant scheduled for commissioning by end 2023 will be installed in its Vijaipur complex in Guna, MP. GAIL has already started blending of 2% hydrogen in natural gas and supplying to Avantika Gas Limited, a city gas distribution company operating in Indore, MP.

NTPC plans to produce green hydrogen on a commercial scale through its upcoming 4750 MW renewable energy park at the Rann of Kutch. The company has revised and doubled its target to achieve 60 GW of renewable capacity by 2032. Presently, NTPC is running a pilot project, the Vindhyachal thermal power project, with a 5 MW electrolyzer (presently the largest capacity in India). The cost of hydrogen in this project is estimated to be around US$2.8-3.0 per kg. NTPC has awarded a contract to Amara Raja Power Systems to install India's first green hydrogen fueling station in Leh, Ladakh at 3600m above mean sea level and temperatures ranging from -14° to 20° C. It will ply 5 hydrogen buses at Leh as a step towards an emission free transport in and around Leh.

Engineering giant, L&T, has announced to set up a green hydrogen plant at its Hazira complex and a few more at its other sites. It has signed an MoU with HydrogenPro AS, Norway, for the manufacture of Megawatt-scale alkaline water eletrolyzers. L&T plans to invest INR 5000 Crore to become a net-zero emitter by 2040. About 90% of this would be from renewable energy, green hydrogen and biodiesel, whereas the remaining 10% would be offset by creating carbon sinks.

The Indian Oil Corporation Limited (IOC), a PSU, is setting up green hydrogen electrolyser plants at its Mathura and Panipat oil refineries. IOC has set a target to produce 5% of its total hydrogen by 2027-28 and 10% by 2029-30 at its refineries starting with the Mathura and Panipat oil refineries. IOC will install a 5 KTA (40 MW) green hydrogen plant at its Mathura Refinery and a 2 KTA (16 MW) plant at the Panipat Refinery and it will wheel renewable power from its wind farms in Rajasthan.

IOC has also planned a standalone green hydrogen production unit in Kochi, that will draw power from the 40 MW solar power plant operational at the Kochi International Airport. It is planned to run hydrogen buses between Cochin airport and Trivandrum.

Bharat Petroleum Corporation Ltd. is going to work on alkaline electrolyzer technology for production of green hydrogen in collaboration with Bhabha Atomic Research Centre. The green hydrogen from this project would be used mainly in refineries.

Other companies, such as ReNew Power, ACME Group, JSW Group, etc., are finalizing their plans to enter the green-hydrogen ecosystem as well.

Global Scenario

The first green hydrogen production project was commissioned in the Netherlands, in 2019, where renewable energy is supplied from a 1 MW solar power plant. The project was developed by the Gasunie New Energy and Gasunie EnergyStock, Netherlands.

China has unveiled a medium- and long-term plan for the development of hydrogen energy (2021-2035). It successfully deployed fuel cell-operated vehicles and hydrogen refueling stations during the 2022 Winter Olympics. This clean transportation comprised more than 1000 fuel cell vehicles and hydrogen refueling stations in Beijing and Zhangjiakou. China plans to produce annually 100,000-200,000 tonne of green hydrogen to reduce emission of carbon dioxide by 1-2 million tonnes per year. [5]

World's largest hydrogen fuel cell-based power plant is the Shinincheon Bitdream in Incheon, South Korea. The plant was commissioned in 2021 with an installed power capacity of 78.96 MW and annual generation of 700 GWh of electrical energy. It will supply

electricity to 2.5 lakh households and in addition 44,000 households will be heated. The plant will annually absorb 24,000 tonnes of fine dust due to water/vapour (exhaust of fuel cells) and purify the air for 7 lakh habitats in the surrounding area.

Green Hydrogen International has unveiled its plans to build a 60 GW green hydrogen production facility near the Piedras Pintas salt dome in Texas to power aeroplanes and outer space rockets. Its layout is shown in Figure 4. It is claimed to be the largest of its kind in the world.

Thyssenkrupp Steel of Germany, the largest steel manufacturer of Europe, will stop burning coke in blast furnaces; instead, it will shift to green hydrogen (to be supplied by M/s STEAG).

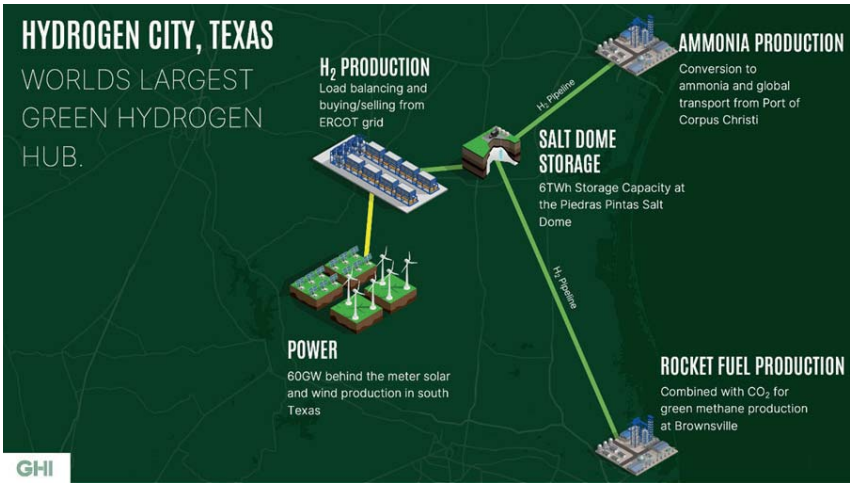


Figure 4: Planned to feed farms, planes, and rockets [6]

However, before finalizing the project, a feasibility study for an electrolysis plant with 520 MW capacity is being carried out. The project is scheduled to be commissioned by 2025.

In Korea, Samsung and Hyundai – in collaboration with the Global Green Growth Institute, are planning a green hydrogen/ammonia production project. The development of the green hydrogen project at Sarulla, Indonesia, costing $1.2 billion would get a geothermal electric power plant in North Sumatra, Indonesia. The objective is to supply green hydrogen, which is to be used as green fuel in the cement and steel industries in the Sei Mangkei Industrial Zone, about 250 km to the north of Sarulla plant.

Saudi Arabia is exploring ways to become the top producer and exporter of blue and green hydrogen in the world. It has set ambitious clean hydrogen production targets of producing 2.9 million tonnes annually by 2030 and 4 million tonnes per year by 2035. The world's largest

green hydrogen production facility is being setup at a planned city 'Neon'.

France, Japan, Australia, Norway, Germany, Portugal, Spain, Chile, Finland, Canada, India, as well as the European Union, have issued their policies to stimulate the production of green hydrogen.

Challenges Ahead

The challenges in energy transition to hydrogen are summarized below:

» High cost (4-6 $/kg) is a major barrier in the adoption of green hydrogen. It will have to be brought down to a level comparable with that of gray hydrogen (1-2 $/kg) by policy support and economies of scale.

» A huge demand for green hydrogen will have to be created. Presently, the demand for green hydrogen in the future is unclear.

» There is a lack of infrastructure for production, storage (as pressurized gas or cryogenic liquid or in metal hydrides), transportation and distribution of hydrogen. However, till such time, existing natural gas pipelines can be used by blending hydrogen within safe permissible limit after some minor modifications, as necessary. R&D is also in progress to make use of existing CNG pipelines by applying protective synthetic liners inside to make them leak proof and suitable for transporting pure hydrogen. If it turns out to be successful as well as affordable, then some CNG pipelines may be used for the transportation/ distribution of hydrogen.

» Lack of well-established, efficient, and economical technologies in the industry sector, mainly fertilizer, oil refinery, steel plant, etc., to replace fossil fuel-generated gray hydrogen with green hydrogen.

» Safety becomes a forerunner when the use of hydrogen spreads to general public in transport and domestic sectors. At present, safety measures are mainly confined to industries using hydrogen; there are no established standards/guidelines for safe usage of hydrogen by general public.

Indian Initiatives

India had realized the potential of hydrogen as a future fuel quite early on and the Ministry of New and Renewable Energy had released the *Hydrogen and Fuel Cell Roadmap* in 2006.

On 15 August 2021, the Prime Minister of India emphasized the need for energy independence. He announced the National Hydrogen Mission and declared India's plan to become a global hub for green hydrogen production. [7]

Green Hydrogen Policy 2022

The policy, notified by the Ministry of Power on 17 February 2022, is

Figure 5: Highlights of the green hydrogen and ammonia policy [8]

designed to promote the production of green hydrogen and green ammonia by easing the processes of purchase of renewable energy, storage and transmission/distribution for the manufacturers. The highlights of the policy are shown in Figure 5.

India plans to produce 5 million tonnes of green hydrogen by 2030 for which separate dedicated manufacturing zones will be setup. The incentives have been notified in the first part of India's National Hydrogen Policy, whereas the second part of the policy is awaited.

Conclusion

As discussed, green hydrogen requires green energy and our country is enormously endowed with such energy. Recently, the drilling work on India's first 'geothermal' project, a continuous source of renewable energy, has started in Puga Valley, Leh, Ladakh at 4400 m above sea level. The project is being executed by ONGC and Iceland. It will utilize the heat inside the earth at a depth of 500 m. In this demonstration project, a 1 MW electric power plant will be installed. The excess energy can be well utilized for production of green hydrogen.

A sharp fall in the generation cost of solar and wind power in India has been witnessed in the last few years, especially after the introduction of tariff-based competitive bidding.

Similar to the creation of demand for LED bulbs, there is an intense need to create a huge demand for green hydrogen which will substantially lower its production cost due to the economies of scale.

The R&D efforts to facilitate operation, or to find solutions for storage and transport, or to reduce the cost of production of hydrogen, are mostly in progress at various renowned institutions such as IISc, IITs, research organizations, industries, etc. The findings of such research will help to narrow down the technological gaps, procedural gaps, and metallurgical gaps and help achieve the green hydrogen goals.

Hydrogen, the lightest basic element on the earth has the heaviest possibilities in the fight against climate change. EF

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Shambhu Ratan Awasthi is the former General Manager of BHEL and Deepak Joshi is MPGENCO's former Chief Engineer.

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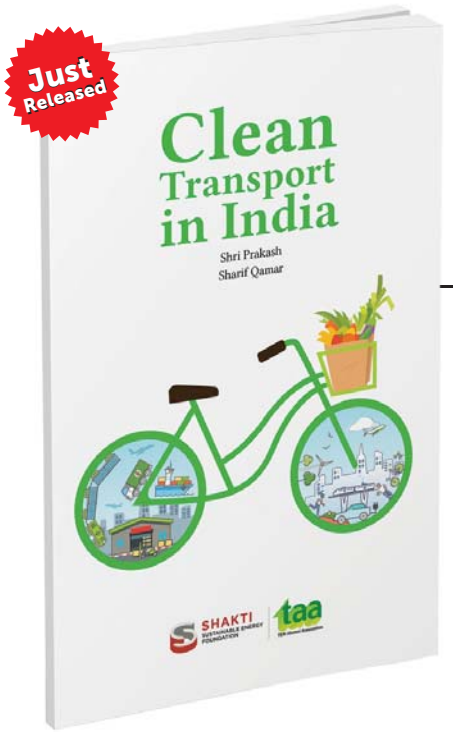
THE PATHWAY TO SUSTAINABLE TRANSPORT



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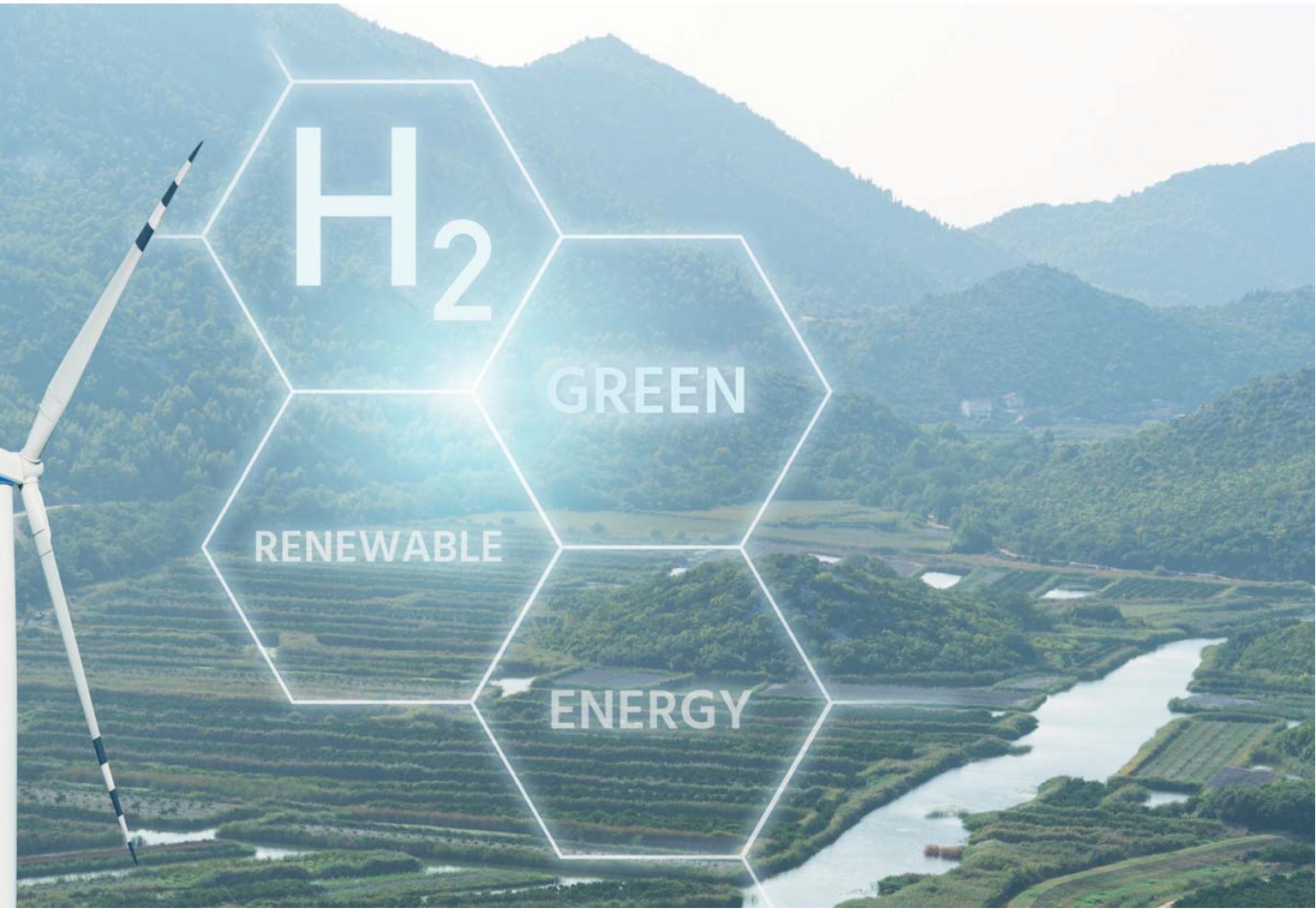

HARNESSING THE POTENTIAL OF 'GREEN HYDROGEN' IN INDIA

With the launch of the Global Hydrogen Mission, India is preparing to achieve its ambitious targets on energy independence and climate. Green hydrogen plays a key role in the development of clean energy and decarbonization systems in the country. In this context, TERI, under its Energy Transitions Commission India work programme, released a report on '*The Potential Role of Hydrogen in India*'. In this article, **Renjith G** and **Shruti Dayal** capture some of the major outcomes and recommendations emerging from the same.

The role of green hydrogen in India's energy system is becoming mainstream. Numerous developments are coming together for green hydrogen to play a substantial role, such as the growing demand in several end-use sectors, like industry, supply-side innovation in production technologies, enabling technological developments, and growing policy interest in driving deep decarbonization of energy systems. In 2016, India's total GHG emissions were 2531 $MtCO_2e$; electricity production accounted for 40% of the country's total GHG emissions, followed by manufacturing industries and construction (18.68%) and the transport sector (13%).[1] In this context, green hydrogen, produced through renewable electricity and electrolyzers, has significant potential to displace fossil fuel imports, improve energy security and decarbonize energy supply. This is expected to be a significant step in meeting the energy independence and climate goals of the country.

India's policymakers and industry stakeholders are actively working to develop the green hydrogen ecosystem. During India's 75th Independence Day Speech, the Hon'ble Prime Minister announced the launch of the National Hydrogen Mission (NHM). The objective of the Mission is to make India a global hub for the production and export of green hydrogen. It is expected to cover all aspects of hydrogen technology: generation, storage, R&D, and pilot projects. The government has also proposed the introduction of Green Hydrogen Purchase Obligations for the fertilizer and refinery sectors. In February 2022, the Ministry of Power launched the first phase of the Green Hydrogen Mission, which included supply-side measures to boost the production of green hydrogen and ammonia.

Several industry stakeholders are also taking measures to develop India's green hydrogen ecosystem by setting targets and undertaking projects. Some of these include - NTPC, IOCL, Reliance Industries, Adani Group, etc.

Hydrogen is, however, not a panacea. Its suitability depends on the specific characteristics of each sub-sector. Therefore, its use needs to be prioritized in sectors where it is not feasible to directly electrify or no other zero-carbon alternatives exist. In December 2020, TERI, under its Energy Transitions Commission India work programme, released the report '*The Potential Role of Hydrogen in India*'. This report provides a first-of-its-kind assessment on the potential of hydrogen in some key sectors for India, facilitating policymakers and businesses in planning for a low carbon future. In this article, we capture some of the key outcomes and recommendations emerging from this analysis.

Hydrogen Demand

Today, hydrogen is primarily used in the refinery and fertilizer industry. In 2020, India's hydrogen consumption was approximately 6 Mt. As per TERI's analysis, this demand could increase by four and half times, reaching approximately 28 Mt by 2050. The anticipated growth in fertilizer and refining products' demand is expected to drive the green hydrogen demand in these sectors. Further, the need for decarbonization, reducing import dependency on coking coal, and natural gas could enable its penetration in new sectors such as steel. The role of hydrogen in the transport sector could be limited to the heavy-duty and long-distance segments – where battery storage faces limitations. In the power sector, hydrogen has the potential to become a long-term storage vector in a highly variable renewable electricity system that helps in seasonal balancing needs.

Potential of 'Green' Hydrogen

Most hydrogen in India is produced using reforming of fossil fuels, especially imported natural gas. India has an advantage when it comes to green hydrogen. The country has huge potential for generating cheap renewable electricity. According to National Institute of Solar Energy (NISE) and National Institute of Wind Energy (NIWE), there is an estimated potential of 749 GW of solar[2] and 695 GW[3] of onshore wind (@120 metres AGL) installed capacity. These factors make India particularly well-suited to green hydrogen production in the long run.

As per the analysis, green hydrogen is projected to become competitive with grey hydrogen produced using fossil fuels by 2030, if not before. By 2030, the costs of green hydrogen production are likely to fall approximately to INR 150/kg, influenced by factors such as, the decline in the costs of 'round the clock' electricity and electrolyzers, increases in electrolyzer efficiencies. Our estimates suggest that, currently, the costs of green hydrogen production are between INR 400/kg and INR 300/kg, compared to INR 140–180/kg from natural gas reformation.

Hydrogen Supply Chain – Transportation and Storage

In India, the renewable potential is scattered across the regions. Hence, the possible options are either to transmit the electricity generated to user location or to produce green hydrogen and transport it. The storage and transportation of hydrogen is costly and involves safety issue, thereby making it a major challenge. Globally, most hydrogen is produced and consumed on-site; the rest is transported using trucks or pipelines. Given its small molecular size and properties, hydrogen is prone to leakage and embrittlement, and is also highly flammable. Pipelines

1 India's Third Biennial Update Report to The United Nations Framework Convention on Climate Change. Accessed from - https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

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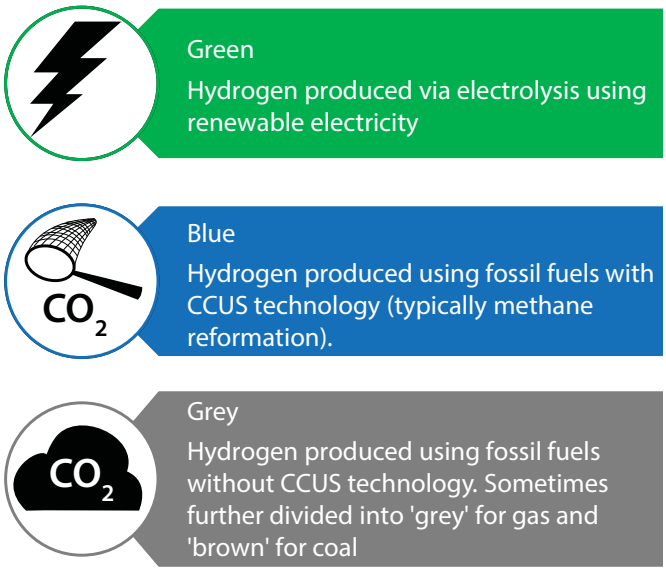

Figure 1: Hydrogen production routes

Source: *Hall, W., Spencer, T., Renjith, G., and Dayal, S. "The Potential Role of Hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy." New Delhi: The Energy and Resources Institute 2022.*

need to be designed with higher specifications to minimize leakage and embrittlement. High initial capital costs and technical concerns (related to retrofitting existing pipelines) could present challenges to the use of pipelines transmission. Alternatively, hydrogen can be transported in the form of ammonia, methanol, and Liquid Organic Hydrogen Carriers (LOHCs). Although easier to transport, if not used directly, these fuels would need to be processed further to release hydrogen, before final consumption. This would involve more energy and thus greater costs, which would need to be balanced with cheap transportation to be cost-effective. At lower volumes, transporting hydrogen via trucks is also a viable option.

To meet the green hydrogen demand for users, hydrogen storage will also be required. Hydrogen can be stored physically as a gas or liquid. Globally, salt caverns are the cheapest form of hydrogen storage. However, it is unlikely that India has sufficient suitable salt deposits for this to be an option. The next cost-effective options are either rock cavern storage or reusing depleted hydrocarbon reservoirs. Further analysis is required to understand their potential in geographically relevant locations for India. The most expensive but commonly used hydrogen storage method is high-pressure steel tanks. These above-ground storage tanks have a few limitations compared to other geological options and could be a suitable option for hydrogen storage for India.

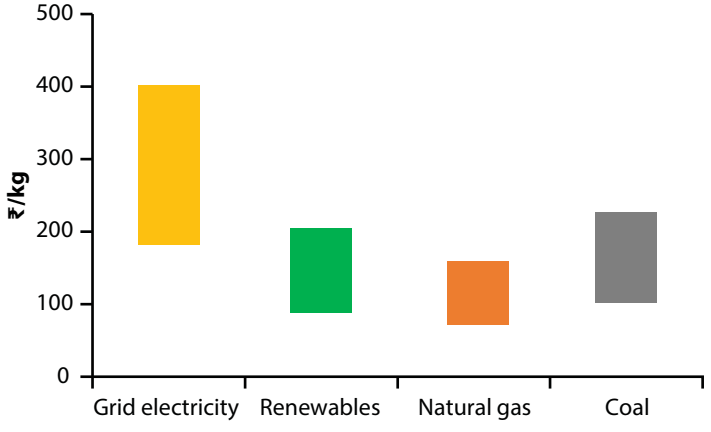

Figure 2: Levelized costs of hydrogen from various sources, 2030 range

Source: *(Hall, W. et al. 2022)*

Iron and Steel

India is currently the world's second-largest steel producer and third-largest steel consumer. Low-emission primary steel-making technologies will be required to ensure that the steel sector can reduce emissions to near-zero levels by the mid-century or 2060. Steel demand is estimated to increase rapidly by 2050 (around 350 Mt) – to meet India's growing infrastructure development requirements. Two leading technologies that have the greatest potential for India are smelting reduction with Carbon Capture Use and Storage (CCUS) and hydrogen-based direct reduction. The cost of steel production from conventional routes in India ranges from around INR 22,200/t of crude steel, to around INR 37,000/t, respectively. Our analysis finds that, as costs of green hydrogen decline reaching INR 74/kg by 2050, hydrogen direct reduction could start to compete with alternate options. The steel sector could then represent the single largest sector for emerging hydrogen demand by 2050, requiring around 9 Mt of green hydrogen each year. Another possible route could be the smelting reduction route with CCUS. However, there is significant uncertainty around the use of CCUS technologies in India and further analysis on the same is needed.

Industry

Ammonia

The Indian fertilizer industry is amongst the most efficient in the world, due to a near-complete shift to natural gas-based processes in the 1980s and 1990s

and additional technology upgrades. Decarbonizing the production of ammonia in the fertilizer industry would require producing hydrogen from green or blue sources, as the hydrogen production constitutes the bulk of CO_2 emissions in the process. Along with the growing ammonia fertilizer demand in the country, overall hydrogen demand is projected to increase from just over 3 Mt today to around 7.5 Mt by 2050. A significant portion of the demand could be met through green or blue hydrogen production pathways.

Refineries

In refineries, some hydrogen is already produced as a byproduct during the refining process. In most cases, this is insufficient to meet the total requirement. Hydrogen is mainly used to process crude oil into value-added products and for removing sulphur content. Policies such as the Bharat Stage Emission Standards – 6 (BSVI), that mandate a lower amount of sulphur in transportation fuels, are expected to increase the hydrogen requirement in this sector. We project that the total hydrogen demand will increase to approximately 5 Mt in 2050 from 2.6 Mt in 2020, further depending on the pace of road transport sector decarbonization.

Transport

In India, owing to the large population, the demand for transport activity is huge and drives the energy demand today. Approximately, 60% of the petroleum products' consumption today is in the transport sector. According to a TERI analysis, by 2050, road passenger activity is set to increase atleast three times from 8500 Billion Passenger Kilometres (BPKM) in 2016, while road freight activity is expected to increase to nearly eight times from 1900 Billion Tonne Kilometres (BTKM) in 2016. Foreseeing the growing importance of energy transition in this sector, the Indian government has already introduced several policies and regulations to develop the electric vehicle (EV) manufacture ecosystem, to foster the charging ecosystem development and accelerate EV adoption among the population. As per the study, EVs will start making economic sense in almost all segments by 2030 or before except in long-haul, heavy-duty buses and freight segments. This will be driven by lower costs of battery, improved charging time, and greater availability of infrastructure which increases its attractiveness. However, in long-haul, heavy-duty bus and freight segments, where its activity is expected to grow exponentially, hydrogen fuel cell vehicles could dominate over EVs. This is due to the decline in the cost of green hydrogen, fuel cells, and on-board hydrogen storage technology, relatively high gravimetric energy density and lower charging times compared to battery storage option. Figure 3 shows the Total Cost of Ownership (TCO) analysis for freight segments across different options. As hydrogen fuel cell vehicles make economic sense across the bus and heavy-duty truck segments, we estimate that the hydrogen demand will increase to 5-8 Mt by 2050, depending

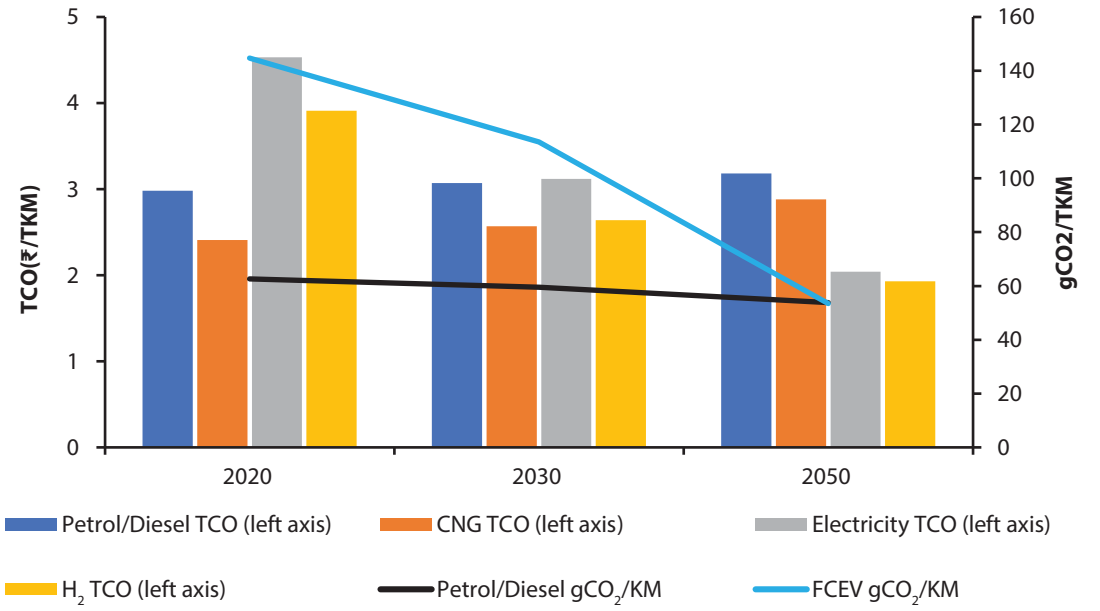

Figure 3: Modelled results for TCO/TKM for heavy-duty trucks and carbon intensity (gCO_2/TKM)

Source: *(Hall, W. et al. 2022)*

on the penetration scenario and EV evolution.

Hydrogen as a Seasonal Balancing Option for Power Sector

The discussion around the decarbonization of the Indian power sector began a while ago. India has also set ambitious targets to install renewable capacity, 175 GW by 2022 and 450 GW by 2030, which is greatly in line with climate commitments. Such large-scale renewable electricity generation is expected to come with high variability, intermittency and seasonality. Zero-carbon flexible generating options to manage the daily and seasonal imbalance would be vital. Though, battery storage is becoming cost competitive, it can only provide short duration energy storage. Meanwhile, the role of green hydrogen as a long-term storage vector is receiving due importance for supporting the seasonal demand fluctuations. Our analysis shows that this could only happen if the renewables take a higher share (in the order of 70%-80%) in the total energy generation mix. Thus, we see this as a long-term technology option for India, with a limited potential compared to others.

Figure 4 provides an overview of the projected hydrogen demand across various sectors.

Way Forward

The proposed launch of the National Hydrogen Mission will be a significant step for India in developing its hydrogen ecosystem. Announcements by industry on the development of green hydrogen technologies will also help jumpstart the hydrogen value chain. This is an opportunity to grow an economically competitive, low carbon hydrogen sector and also reduce energy imports, whilst drastically reducing emissions. To ensure that India remains ahead of

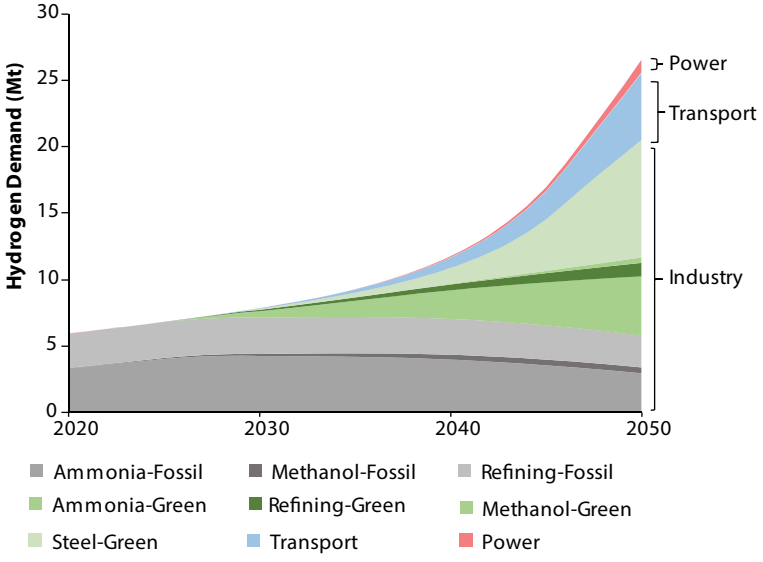

Figure 4: Hydrogen demand projection in the Low-Carbon scenario, 2020-2050

Source*: (Hall, W. et al. 2022)*

the curve on clean energy technology development, our report makes the following suggestions:

Greater Cross-Sectoral Coordination

To maximize the benefits of hydrogen technologies, a cross-sectoral approach will be required, that understands the case for shared infrastructure, aggregate energy system impacts and overlapping ministerial responsibilities. The development of hydrogen technologies and end-use cases falls under the remit of several different ministries. Therefore, a separate institutional setup could help coordinate activity between concerned ministries.

Shift from R&D to Commercialization Support

There should be a greater focus on demonstrating hydrogen technologies. Since caustic soda produces green hydrogen using electrolysis as a byproduct, the caustic soda industry could help expand India's nascent electrolyzer manufacturing industry. This would require the development of public-private partnerships to de-risk initial deployment. By moving to deployment-led support, India can achieve rapid cost reductions in key hydrogen technologies. Such activity would also align with the 'Make in India' and 'Atmanirbhar Bharat' initiatives.

Introduce Carbon Markets

To accelerate the switch to low carbon technologies, the introduction of carbon markets could be explored. The development of a domestic carbon market (similar to the Emissions Trading System in Europe), will be an important tool to help accelerate the switch to low carbon technologies.

Create Markets through Mandates and Standards

Measures to support the creation of demand for green hydrogen will also be needed. These could be in the form of green product standards – allowing consumers to differentiate between products made using environmentally sustainable methods. Producers could charge a premium to account for the higher initial costs. The Confederation of Indian Industry (CII) is already developing such standards under their 'GreenPro' initiative (CII, 2019).[4]

Targeted Industry Activity

Private sector companies also have a vital role to play. Establishing international collaborations with leading technology providers can support the rapid deployment of hydrogen technologies in the near term. Coordinating existing private sector R&D activity through consortia

[4] Confederation of Indian Industry (CII). (2019). *GreenPro*. Retrieved from https://ciigreenpro.com/

could solve similar problems, or develop demonstration projects, which require multiple companies along a supply chain or within a cluster.

A System-Wide Approach to Reduce Costs

Aggregating demand through a cluster-based approach is the best way to reduce costs and build an optimal system. This also helps to better design the system and ensure high utilization rates. A geospatial analysis would be helpful to study the potential of such locations and to map the overlapping renewables' sources available.

Financing Support for Pilot Projects

Getting access to international finance is the primary requirement that helps in driving the global decarbonization initiatives for developing countries. In the current context, this becomes paramount as the pandemic has shaken the economy and put uncertainty in its growth trajectory. However, this should not be a limitation for decarbonization initiatives as the world is in a climate change peril. In case of the development of such a capital-intensive hydrogen ecosystem, global financial support and access to more climate funds are extremely important.

Conclusion

Hydrogen has become mainstream in the decarbonization agenda across countries. Globally, various targets, mandates and policy initiatives supporting hydrogen in different sectors are under implementation. Policy has a pivotal role to play in resolving the issue of supply creation and demand generation. In the absence of adequate demand, production cannot be scaled up and the costs will not decline, consequently impacting its uptake. Recent announcement by the Government of India on the launch of the first phase of the National Hydrogen Mission, in 2022, is a welcome step in this direction. India can achieve rapid cost reduction in technologies by moving towards deployment-led support. Collaborations between public and private players for scaling up the hydrogen ecosystem and reducing the risk of initial deployment are needed. Several companies have also announced ambitious targets and initiatives. India is at an inflection point of developing an economically competitive, low carbon hydrogen sector.

In December 2020, TERI published a detailed assessment of the potential role that hydrogen can play across the Indian economy – covering transport, industry, and power.

Working on '*the Potential Role of Hydrogen in India*' report would not have been possible without the financial support from the Children's Investment Fund Foundation (CIFF). EF

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WIN-WIN BENEFITS OF CO-FIRING

Co-firing coal and biomass can reduce air pollution and help farmers

India has been using coal to produce power since the late 1800s, with a few hydropower plants in the hilly regions around the same time. Grid-connected biomass power, on the other hand, was introduced only in the 1990s as per the country's clean energy mandate.

However, coal shortages began worrying the government, along with their costly imports. An unprecedented coal shortage in September-October 2021 resulted in power cuts across the country and intense competition among state power utilities to secure enough energy from the grid, to keep their industry and cities functioning. Power demand, too, was on the increase, going hand in hand with development.

These factors led to the exploration of fuel alternatives and a huge energy efficiency drive in the country among the residential, commercial and industrial sectors, along with other initiatives.

Biomass co-firing was an offshoot of the fuel alternative theory. It comprises adding biomass as a partial substitute fuel in high-efficiency coal boilers – that have been traditionally designed to burn coal. What tipped the balance towards co-firing biomass with coal was stubble burning in the fields of Punjab, Haryana, Uttar Pradesh, Rajasthan and Madhya

Pradesh, leading to substantial air pollution in Delhi-NCR (national capital region) in the months of October and November every year. The media took up this cause, until the government was forced to take action.

Pollution Woes

As per survey reports, the availability of biomass in India is estimated at about 750 million metric tons per year. Around 30% of the available biomass quantity is surplus and it is estimated that at least half of it is responsible for stubble burning every year.

Farmers, over the years, have been faced with labour shortage and excess production (rice and wheat) aided by mechanization, which has only added to the stubble load. They are left with no viable option, but to burn the agriculture waste, which increases air pollution.

This farm residue though, can be converted into biomass pellets, which can then be supplied to power plants for biomass co-firing as per the Centre for Science and Environment (CSE). The latter quoted the power ministry's data to say that about 0.25 Mt of biomass pellets are needed to produce one GW capacity, at the rate of 7% co-firing. Thus, for 100 GW capacity, nearly 25-30 Mt of biomass pellets will be required. This is a huge opportunity for farmers to increase their income while cutting down on air pollution as well.

In order to further promote the use of biomass pellets – made primarily of agro residue – in coal-based thermal power plants, the Ministry of Power (MoP) modified its 2017 policy in October 2021, making the initiative mandatory and in force for a period of 25 years, or till the useful life of the power plant. Though, based on feedback received, the Central Electricity Authority of India or CEA Thermal Engineering and Technology Development (TE&TD) Division eventually issued guidelines for exemption/relaxation from mandatory co-firing of biomass by thermal power plants on 4th February 2022; to be decided on a case-to-case basis by a special committee.

Besides air pollution from stubble burning, emissions from thermal power plants give out carbon dioxide and release heavy amounts of SOx, NOx, particulate matter and mercury, among other pollutants in the form of coal ash (also called fly ash).

Areas around power plants report piling ash, in the form of slurry in ash ponds and in the dry form in open fields. Several studies have confirmed contamination of drinking water in areas around Maharashtra and near the NCR. Scientists say that long-term exposure to fly ash in the air can lead to serious pulmonary illnesses and even cancer.

Despite the National Green Tribunal (NGT) ordering the Central Pollution Control Board (CPCB) to ensure that all thermal power plants in India make 100% ash utilization, almost 50% of the power plants are yet to comply with this order. Many plants do not even have a 50% annual ash utilization rate.

As per '*State of India's Environment Report 2021*', about 64% (132 GW) coal power capacity has been added in the last decade. So, annual fly ash generation rose from 123 Mt to 217 Mt during that period.

Various research studies do state that co-firing biomass with coal does generate less fly ash and definitely reduces air pollution – via direct emissions as well as reduction of stubble burning emissions.

Pros and Cons

Co-firing biomass and coal helps to minimize greenhouse gases, because it reduces net CO_2, CH_4, SO_x and often NO_x emissions, compared to coal combustion. The existing coal power plants can be retrofitted quickly and cost-effectively. The boiler efficiency drops only little or not at all, after adjustment to the new fuel mixture. Also, a big advantage is the existing network of coal power plants in India; thus, new plants are not required.

The use of biomass also helps eliminate direct burning of straw in open fields. The flexibility of fuels reduces the electricity consumption of stored coal and increases the amount of renewable energy generated. This leads to win-win benefits for several stakeholders, especially given that government-owned NTPC—which operates majority of the coal power plants in India—has a target of achieving 60 GW capacity from renewable energy sources by 2032.

Types of Co-Firing

There are three different concepts for co-firing biomass in coal boilers:

Direct co-firing: The biomass and coal are burned in the same furnace. This method is most commonly used, because it is the easiest to implement and most cost-effective. It is being followed in India so far as well.

Indirect co-firing: Here, the solid biomass is converted to a clean fuel gas, using a biomass gasifier. The gas can be burnt in the same furnace as the coal. This principle is less researched than direct co-firing.

Parallel co-firing: Here, a completely separate biomass boiler for increasing the steam parameters, like pressure or temperature, is installed in the steam system of the coal power plant. This allows the use of a higher amount of biomass.

Policy

To accelerate the co-firing initiative, the MoP issued a policy dated 17 November 2017, on biomass utilization for power generation. In this policy, it had advised all fluidized bed and pulverized coal units of power generation utilities, public or private, to use 5-10% blend of biomass pellets made primarily of agro residue, along with coal, after assessing the technical feasibility, viz. safety aspects, etc.

In another important development for power producers using biomass, the Central Electricity Regulatory Commission (CERC) issued its *Terms and Conditions of Tariff Regulations, 2019*, notified in March 2019, for estimation of power generation using biomass at coal-fired plants. This became relevant after an advisory from the CEA in late 2018, to all public and private power generating utilities to endeavor to use

5-10% biomass pellets primarily made of agro residue, along with coal. Then followed the clarification of Ministry of New and Renewable Energy (MNRE) in September 2019, that placed the power generated from co-firing of biomass in coal-based thermal power plants as renewable energy. MNRE also made power from biomass eligible for meeting non-solar Renewable Purchase Obligations (RPO).

CERC also took note of the requests by the Captive Power Producers Association to make any proposed methodology applicable to captive power plants too.

The SAMARTH Scheme

On 1 February 2022, Union Finance Minister, Nirmala Sitharaman announced the launch of the *Sustainable Agrarian Mission on Use of Agro Residue in Thermal Power Plants (SAMARTH)* scheme to promote the co-firing initiative. In her budget speech, the minister said: "5-7% biomass pellets will be used in thermal power plants, resulting in CO_2 saving of 38 MMT annually. This will also provide extra income to farmers, give job opportunities to locals and help avoid stubble burning in agricultural fields."

As per a press release by the Ministry of Power on 26 July 2022[1], till the end of FY 2020-21, only seven power plants in the country had co-fired biomass pellets. Though on the biomass pellet procurement side, more than 40 plants have floated several new tenders. Around 248.16 lakh MT of biomass tenders are at various stages of the tendering process – of which around 120 lakh MT are under award, while orders have been placed for 13 lakh MT.

The SAMARTH Mission has been continuously organizing offline and online training and awareness programs for farmers, pellet manufacturers, and power plant officials, with the assistance of the National Power Training Institute (NPTI). In the FY 2021-22, ten programs were held over six months, mostly in the NCR. This year the plan is to cover all major states where surplus biomass is available, such as Chhattisgarh, Gujarat, Tamil Nadu, Maharashtra, and Uttar Pradesh.

The press release also confirms that about 80,525 MT of biomass has been co-fired in 35 thermal power plants in the country, with a cumulative capacity of 55,335 MW till 24 July 2022. While 14 of these plants are NTPC's, 21 power plants are from the state and private sector as well. These initiatives have reduced the CO_2 footprint in thermal power generation by 100,000 MT.

Challenges Ahead

Intermediate fuel processing is an issue, flagged an official of Maharashtra State Power Generation Company, since the quantity of biomass required by large thermal power plants is double of coal.

1 https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1845043

The difference in gross calorific value of coal and biomass is also a concern. Handling and storage infrastructure is needed for such large quantities of biomass.

Availability of biomass and its high, volatile price are other constraints. This factor though needs to be looked into, as one would think farmers would prefer to sell their biomass than burn it.

If not carefully designed, co-firing involves some risks, like increased plant outages, corrosion and ash deposition issues, possible interference with the operation of the boiler, etc.

NTPC had to overcome several hurdles to install the technology in 13 of its power stations. Infrastructure for unloading and storage of biomass had to be created, and slight modifications in software and hardware as well as standard operating procedures were made. The retrofitting allowed the company to co-fire a maximum of 10% biomass.

Several states with large coal-based installed capacities, such as Telangana State Power Generation Corporation Limited with 3772 MW, Karnataka Power Corporation with 8738 MW, Tamil Nadu Generation and Distribution Corporation (18,732 MW), Andhra Pradesh Power Generation Corporation (4559 MW) and Kerala State Electricity Board (2832 MW), have not yet moved forward with respect to co-firing. Some of them seem to be awaiting support from the government on clear guidelines and funds for the pelletization supply process. Better fuel-processing support at the backend will be needed to roll out this scheme successfully.

The China Experience

There are ample examples of successful biomass co-firing in coal power plants in Europe and the US. China too has introduced various policies and initiatives in its five-year plans to promote biomass-coal co-firing, such as the "Notice on Construction of Pilot Projects for Technical Transformation of Coal-biomass Co-firing Power Generation" issued by the Chinese National Energy Administration (NEA) and the Ministry of Ecology and Environment in 2018.

China is the world's top carbon emitter and a large agricultural country with abundant biomass resources; the utilization of agricultural wastes in existing coal-fired power plants was an attractive option to alleviate environmental pollution and reduce consumption of fossil fuels. With government efforts to encourage the development of renewable energy, investment in biomass power generation grew rapidly and several agricultural/forestry waste power generation projects were set up a few years ago.

As per research conducted in 2020[2], there were 84 pilot projects in total, with a total investment of 133.86 million yuan. If all 84 pilot projects were successfully carried out, the total annual biomass consumption would be 13.27 Mt, of which 7.51 Mt of agricultural and forestry biomass would be consumed, whereas 4.23 Mt of urban sludge and 1.53 Mt of municipal waste would be treated.

About 8.3 billion kWh of biomass power could be increased every year to replace 2.62 Mt of coal and reduce 7.33 Mt of CO_2 emissions. The on-grid price could be reduced by 0.05–0.1 yuan/kWh. However, by the end of 2017, the installed capacity of agricultural and forestry biomass power generation was only 7.1 million kW and accounted for only 0.6% of all power generation, which was far from meeting the Chinese targets.

The unit capacity of the co-firing power plants in China is usually between 50 MW and 800 MW (refer Table 1) with both direct and indirect co-firing. The thermal efficiency of biomass co-firing with pulverized coal boiler technology reaches 92%, and the power generation efficiency reaches 45%. Chinese research reports state that coal-biomass co-firing power generation technology has better technical and economic advantages than pure biomass-fired power generation technology.

Some of the challenges they are facing though relate to cost, unstable biomass supply, negative effects on boilers, and difficulties in government supervision.

Win-Win Benefits

Besides reducing emissions, research has demonstrated that when implemented at relatively low biomass to coal ratios, there are significant reductions in energy consumption and solid waste generation during co-firing.

[2] https://www.etipbioenergy.eu/value-chains/conversion-technologies/conventional-technologies/biomass-co-firing; www.mdpi.com/journal/sustainability

Summary of Typical Domestic and Foreign Application of Coal-Biomass Co-firing Power Generation Units

Power Plant Commissioning/Year	Capacity of Coal-Fired Unit		Biomass Fuel	Co-Combustion Ratio of Heat	Technical Characteristics
Shiliguan power plant/2005	400 t/h high temperature and high pressure boiler	Direct co-firing	Wheat-straw, corn stalk	18.6% (Design), 5%~8% (Reality)	Independent burning system of BWE company in Denmark to achieve co-combustion, and the fuel entering the boiler needs to be pretreated
Baoli No. 2 Power Generation Co., Ltd /2010	300 MW boiler	Direct co-firing	Straw, molding biomass	6.76% - 21.90%	Through a set of pulverizing system, biomass fuel is burned separately
Datang Changshan thermal power plant/2018	660 MW	Indirect co-firing	Straw, rice husk, waste	3%	Using micro positive pressure of circulating fluidized bed (CFB) and gasifier system to gasify the original burner
Huadian Xiangyang power plant/2018	600 MW	Indirect co-firing	50% rice husk, straw, 50% biomass briquette	1.8%	CFB negative pressure gasifier System
Changyuan Jingmen power plant/2016	640 MW	Indirect co-firing	Rice husk, straw	1.7%	Biomass CFB gasification unit
Finnish Kymijari power plant/1998	167 MW/240 MW	Indirect co-firing	Wood-based biomass, waste recycling fuel	15%-30%	Atmospheric air gasification, FW (foster wheeler) CFB vaporizer

Sources say the use of biomass co-firing technology generates renewable energy that can be cost competitive with solar and wind power.

The government is considering financing of agro residue collection and processing equipment to incentivize biomass co-firing for plants and farmers. Even though there may be costs involved with slight technical changes to the boilers, and for biomass pellets (as per NTPC, a tonne of pellets costs around INR 7000) costing more than coal, there will also be an increase in the power consumption and heat rate in the plant. CERC may allow NTPC to pass on these costs to the consumer, if required.

Conclusion

The Indian government has been extensively promoting the use of biomass in power plants by way of advertisement campaigns, awareness missions and extensive training programs. Aggressive promotion in Haryana, Punjab and Uttar Pradesh has begun showing results. Though, it is still imperative to increase farmers' awareness through radio, TV networks and other social media, besides facilitating the collection of biomass to ensure stable supply.

Another step that may help is to encourage cooperation between coal-biomass co-firing power plants and universities to introduce high-level talent and provide financial support for research, develop and optimize calculation methods for biomass power generation and establish different monitoring systems for biomass power generation in different coal-biomass co-firing types.

Establishing a biomass information platform to connect farmers, coal-biomass co-firing power plants and other biomass-related stakeholders, and exchanging information with each other, is the need of the hour. The biomass supply, collection, storage, transportation and purchase system needs to be standardized throughout the country.

State supervision is vital; being a new program, it will need handholding from the government and private sector, with scope for encouraging feedback to take steps for improvement at every stage. EF

Anita Khuller has over 24 years of experience in technical writing, new business development, communications, and capacity building in South and Southeast Asia, in the clean energy, waste, environment, infrastructure, rural development and education areas.

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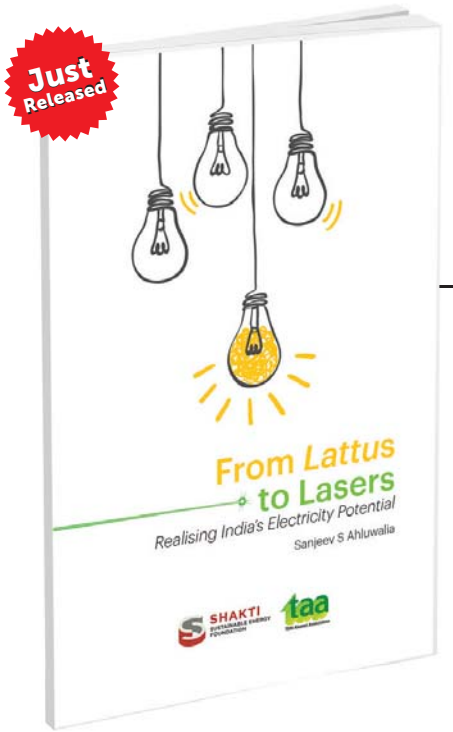

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This book is useful for adults who are concerned about topical issues but lack the understanding to make sense of what they read or watch in the mass media.

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SUN SHINING ON THE JOB MARKET

The ever expanding horizon of renewable energy brings new possibilities for our planet's future. Not only does renewable energy provide a solution for the imminent risks of climate change, but it also answers the very human issue of unemployment. In this article, **Dr Suneel Deambi** speaks about how in the Indian context, the rising solar power industry has the capacity to meet India's net zero ambitions as well as the career ambitions of its youth.

The Early Context

Solar power and wind power are now energizing the nation together in a spirit of respecting each other's terrain. Take for example the heavy wind resource richness in the southern state of Tamil Nadu. Likewise, the sun-soaked regions in the country are witnessing the solar revolution of sorts, lately. Another interesting question is if, the sun and wind are also teaming up together: the large wind farms are throwing up a possibility or two to take the solar panels beneath the fold of wind turbines, i.e., in the vacant land available. That is not all, the sun and wind resources are joining hands to churn out a hybrid power system – with one supplementing the battery recharging capability of the other much in accordance with the time of day.

Take for example the solar panels working in a hybrid mode on the rooftop space available within the ONGC township in Mumbai. The micro-wind turbines sit pretty on the roofs alongside the aesthetically pleasing solar panels, making the residents proud with an assured supply of clean, safe and reliable green energy. A metro journey in the NCR shows more such systems working on the available rooftop spaces

in tandem. The purpose is not to say that other renewable energy sources, like small hydro and biopower, are not contributing to the renewable energy might of the country. Well, the fact is that cumulative installed grid power capacity from the renewables stood at 114, 064 MW as on 30 June 2022. Out of this, solar contributed the largest share of 50.5%, followed by wind (35.7%) and distantly by biopower (9.36%) and small hydro power (4.2%). So, let us focus our attention on the accompanying description of Solar Photovoltaics (PV).

Livelihood generation assisted by sunshine and wind energy availability is today opening up as a job avenue too. Around 3, 400,000 new jobs (both in the short and long term) are up for grabs, if we succeed to set up 238 GW of solar and 101 GW of wind capacity targets – as enshrined in the mega scheme of 500 GW non-fossil fuel electricity generation capacity by 2030. Let us try to chart this job opportunity path by following the sun closely enough; though dead impossible in the physical terms for anyone.

Tracking the Solar Footprint Globally

The year 2021 witnessed a solar capacity addition of around 172 GWdc. In cumulative terms, the capacity rose to a respectable 940 GWdc. An important question to ask is which of the countries installed the maximum capacity in 2021. It was China which deployed a record of 55 GWdc capacity, thus taking its total tally to 309 GWdc. China has an enviable distinction of being the largest market player in the global solar PV arena today. The frontrunners in terms of annual global PV installations till 2026 are expected to be China, the United States, Europe and India. As for the global PV shipments for manufacturing, in 2021, it touched 194 GW marking a 47% increase from 2020. Interestingly enough, around 95% originated from the original workhorse of the PV industry, i.e., monocrystalline or single crystal silicon technology alone.

In sum total terms, between 2010 and 2021, global PV capacity additions grew from a modest 17 GWdc to a high of 172 GWdc. Incidentally, the European markets took the lead in the initial years, but finally paved way to the Asian market. It is evidenced by around 57% of the cumulative PV installations being in Asia, followed up by 21% in Europe, with America recording around 16% at the end of 2021. It makes up for an interesting mention of sorts to say that at least twenty countries could install more than 1 GW of PV. That is not all as today more than fifteen countries can boast of more than 10 GW of cumulative capacity. Table 1 gives a country-wide scenario of cumulative PV installations at the end of 2021.

It is of an equal interest to know how much PV technology contributed to global electricity generation in 2021. The answer, in terms of IEA estimates, is just around 5%. Table 2 highlights such contribution from the selective few countries.

Cell technologies by market share

Crystalline silicon, more so the mono-crystalline silicon continues to drive the PV market globally. In 2021, around 95% of the PV shipments owed their origin to

Table 1: Cumulative PV installations at the end of 2021

Country	Capacity (GWdc)	Global Ranking
China	309	I
United States	120	II
Japan	78	III
India	60	IV
Germany	59	V
Australia	25	
Italy	23	
South Korea	20	
Spain	19	
Vietnam	17	
Rest of Europe	78	
Rest of World	131	

Source: *IEA – Snapshots of Global PV Markets 2022*

Table 2: Electricity generated from PV technology in 2021

Country	% of Electricity Generation
Australia	15%
Spain	14%
Greece	13.5%
Honduras	12.5%
Netherlands	11.75%
Germany	11%
Japan	9%
Italy	8.75%
India	8%
China	4.75%
USA	4%
South Africa	3.75%

Source: *Snapshots of Global PV Markets 2022*

the mono-c Si technology as compared to 35% in 2015. Mono PERC emerged as the dominant cell type in 2021, with n-type shipments surging ahead to 40 GW from a meagre 6 GW in 2019. Table 3 depicts the market share by cell type in 2021.

India on a fast market recovery note

The cumulative PV capacity of solar installations was around 3 GWdc during 2007-2014. Remarkable additions to this capacity started taking place around 2017-2019. It was in 2021 that solar installations showed an upward swing to an all-time high of 10 GWdc. The projects which got delayed in 2020 catalyzed this fast growth in the following year. The grid-connected solar power generation turned out as a clear winner from among the rest of the renewable energy technologies – more so the wind power. It is interesting to note here that the ground mounted, i.e., large-scale projects accounted for as much as 83% of the 2021 capacity, with the rooftop systems clinching the remaining 17% installations. It is pertinent to mention here that India is almost going to achieve its prior set target of 60 GW via the ground mounted projects by the year end. However, it is a distant target realization from 40 GW for the rooftop segment. There is a view, though, that this does not matter much, as long as the solar installations continue to grow even on the ground mounted side. The underlying rationale is that it is equally important to register a desirable growth in the rooftop segment for a variety of end-use considerations. Table 4 mentions the sectoral distribution of solar rooftop systems for the period 2016-2021.

Quite clearly, C&I consumers are the biggest drivers of solar rooftop movement in India. Another interesting facet to look at is the module imports which accelerated to exploit an 8-month zero import tax period that took off in August 2021. The basic customs duty of 25% for solar cells and 40% for solar modules came into effect from April 2022.

The Ministry of New and Renewable Energy (MNRE) has produced Approved Models and Manufacturers of Solar Photovoltaic Modules in a concerted effort to stimulate the domestic module manufacturing. The underlying rationale

Table 3: Types of cell technology and their market share in 2021

Cell Technology Type	Full Form	Market Share
Mono P PERC	Passivated Emitter and Rear Cell	76%
Mono N PERC	Passivated Emitter and Rear Cell	6%
TOP Con (N)	Tunnel Oxide Passivated Contact Cell	9%
HJT/HIT (N)	Hetero Junction Technology/Hetero Junction with Intrinsic Thin layer	4%
CdTe	Cadmium Telluride	4%

Source: *Paula Mints. "Photovoltaic Manufacturer Capacity, Shipments, Prices and Revenues" 2021/2022*