AN INDO-NORWEGIAN KNOWLEDGE PARTNERSHIP ON GREEN HYDROGEN
TOWARDS BUILDING AN INTERNATIONAL HYDROGEN ALLIANCE

# INDIA IS AN ATTRACTIVE DESTINATION FOR GREEN HYDROGEN

## A WAY FORWARD

   

A KNOWLEDGE BOOK BY PHD CHAMBER OF COMMERCE AND INDUSTRY INDIA

DR J P GUPTA
DR KAREN LANDMARK

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## INDIA WORLD'S CHEAPEST HYDROGEN HUB BY 2030

As demand for energy rises worldwide, there is a growing need for tapping alternative energy sources that are not only greener, but also renewable and abundant in supply. Hydrogen is one such source that has a much higher energy output per unit mass. India's advantage due to its geographical location, climate conditions and abundance of renewable sources of energy like solar, wind and hydro make it ideal for becoming the world's cheapest hydrogen hub by 2030.

"

**Let noble thoughts and knowledge come from all directions.**

**— Rig Veda 1.89.1 —**

Earth provides enough to satisfy everyone's need, but not for everyone's greed.

**— Mahatma Gandhi**

I used to think the top environmental problems were biodiversity loss, ecosystem collapse and climate change;
I thought that with 30 years of good science we could address those problems;
But I was wrong, the top environmental problems are selfishness, greed and apathy and to deal with those we need a spiritual and
cultural transformation and we scientists don't know how to do that.

**— Prof James Gustave Speth**
Former Administrator, United Nations Development Programme, United States,
Honorary Director, Natural Resources Defense Council & WRI, Member, Advisory Board, United Republic

# DEDICATION

With genuine gratitude and warm regards, the authors dedicate this knowledge book
to

Hon'ble Prime Minister of India
**Shri Narendra Modi**

His visionary thoughts and proactive steps for *Aatma Nirbhar Bharat* (Self-reliant India) concerning the energy roadmap for the country have immensely motivated the authors to write the second volume of the Knowledge Book on the event of
International Climate Summit 2022: 'Opportunities for Green Hydrogen in India'
at Bergen, Norway on 30-31 August 2022.

This Knowledge Book offers information and knowledge to international investors, knowhow suppliers and electrolyser companies, about the opportunities India offers, as an attractive destination for production of Green Hydrogen in India.

# GREEN TRANSFORMATION: A WIN-WIN OPPORTUNITY FOR INDIA

**Erik Solheim** is a Norwegian diplomat and former politician. He served in the Norwegian government from 2005 to 2012 as Minister of International Development and Minister of the Environment, and as Under Secretary-General of the United Nations and Executive Director of the United Nations Environment Programme (UNEP) from 2016 to 2018


Image Credit: PMO

The craziness of western arrogance was at full display during the climate conference in Glasgow last year. India argued that the world should phase down rather than phase out coal, a small, hardly significant change of wording. Some western media, NGOs and politicians came down on India, blaming India for lack of climate courage and claiming that India was blocking progress.

Few focused on the fact that North American historical climate emissions are more than 25 times than Indian. Even today the US emits eight times more than India per capita every year. India has no reason to accept blame. But India has all the reasons to adopt a new win - win formula for a greener future. Climate action is not a problem to India and even less a cost. It's an enormous opportunity for Indian triple wins. Creating prosperity, making Indian lives better, protecting Mother Earth.

For many decades the debate in India was simple: Do we want to develop or do we want to care for the environment?

Economists argued that rapid development would always come with costs to mother earth while environmentalists countered that we should put the planet first. The economist always won this debate. Not surprisingly for nearly all Indians rapid development, bringing Indians out of poverty, was the number one priority.

This discussion now smells so much of the 20th century. From the industrial revolution until recently no nation could develop fast and protect the environment at the same time. Industrialization came with an assault in nature. Economic growth was based on fossil fuels, coal in particular. The pattern was the same everywhere - rapid economic growth with a lot of harm both to the workforce and to the environment.

The good news in the 21st century is that for the first time in human history a new development paradigm is possible. The win-lose debate where you had to choose between development and environment is replaced by the win-win opportunity where rapid parallel progress on both economy and ecology can establish an ecological civilization. Climate change and the environment crisis become an opportunity for jobs and prosperity.

At the core of this change is the drop in price of renewables. When the world came together for the famous disaster of climate talks in Copenhagen in 2009 all focus was on climate diplomacy. No one talked about the climate economy. I cannot remember anyone even hinting to a future with a 90% fall in the price of solar energy.

Thanks mainly to China but also to India, solar energy is now cheaper than coal everywhere. Solar energy in India is indeed the cheapest energy which has ever existed on the planet. Going solar brings more jobs and saves money.

No one has understood this better than Prime Minister Modi. He has cast around the Indian debate from win lose to win win. When my good friend Jairam Ramesh came back from climate talks during the time of Congress rule he was normally always accused of 'selling out'. If he had agreed to common positions during the talks, domestic critics claimed that he had not fought hard enough for Indian development. Now fortunately, it's all about the win - wins.

GOING SOLAR BRINGS MORE JOBS AND SAVES MONEY. NO ONE HAS UNDERSTOOD THIS BETTER THAN PRIME MINISTER OF INDIA NARENDRA MODI. HE HAS CAST AROUND THE INDIAN DEBATE FROM WIN LOSE TO WIN WIN. INDIA TODAY IS A GLOBAL LEADER IN SOLAR ENERGY.

India is a global leader in solar energy. With president Macron of France, Prime Minister Modi formed the International

Solar Alliance to support the global solar economy. India is home to the first all solar airport in the world in Kochi, Kerala and the first all solar rail station in Assam. Some of the largest concentrated solar plants on the planet are hosted in states like Rajasthan, Karnataka and Madhya Pradesh. Roof top solar provides energy for homes and village businesses in Uttar Pradesh and many other states.

When Prime Minister Modi recently launched a green hydrogen mission for India the response was univocal and promising. Two of the tycoons of Indian business, Ambani from Mumbai and Adani from Ahmedabad put enormous amounts of rupees on the table for green hydrogen. Many smaller enterprises reacted in unison.

The war in Ukraine will supercharge this move towards energy independence. India does not share the European focus on independence from Russia. But nearly all oil and gas consumed in India is imported. Volatile and high prices create a huge burden for the Indian economy. The sun, the wind and the waterfalls are all Indian, all domestic. Every megawatt of energy produced by solar rather than imported oil creates jobs in India and saves money for better use for the people of India.

Agriculture is next to renewables in importance for the green transition of India. Andhra Pradesh shows the way, with Sikkim, Madhya Pradesh and others following. The Zero Budget Natural Farming programme in Andhra is the world leading charge towards green agriculture. One million farmers, six million people, have made the move from traditional chemical heavy agriculture into a future where pesticides and fertilizer are reduced or avoided. They are replaced by a scientific mix of cow dung and cow urine, with use of residues from previous harvests as fertilizer. Insect repellent plants replace pesticides. The result is better yields and income for farmers, improved health and better care for soil.

The Andhra programme is called a pilot. But it is already encompassing more people than the inhabitants of my nation Norway. Soon all farmers in Andhra may join. Prime Minister Modi has highlighted this great initiative as a model for India.

This summer Sadhguru, the most inspiring spiritual leader from Coimbatore, embarked upon an epic motorbike ride from London to Delhi to bring attention to the need to save soil. If we destroy soil, we destroy life, he says Andhra Pradesh shows how we can act better and smarter.

Tree planting and greening of landscapes add to the benefits of better farming. Telangana is an Indian and global front runner in tree planting. The state has increased its tree cover by three percent over a few years. Hyderabad has been awarded title as a Tree City of the World. I was very impressed visiting its beautiful urban forests and parks. The greening of such a mega city is a great example of win - win policies. Hyderabad becomes more attractive for its citizens and for tourists while at the same time contributing to climate mitigation and pollution control.

Electric mobility adds to renewables, eco agriculture and tree planting as a fourth pillar in a green and climate friendly India. India will soon be the worlds second biggest solar power. The young population and the current higher economic growth give India 'long-term' advantages. ■


ENERGY
STORAGE

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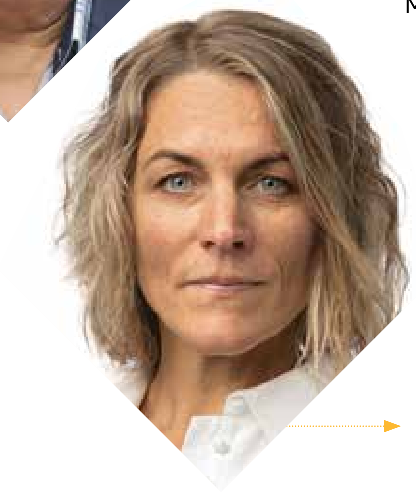
# FOREWORD

**Dr J P Gupta** | Chairman
Environment Committee, PHDCCI
MD, Greenstat Hydrogen India Pvt Ltd



**Dr Karen Landmark** | Chair
Board Greenstat Asia
Greenstat ASA, Norway

Last fall, less than three months before COP 26, the Inter-governmental Panel on Climate Change (IPCC) launched a landmark assessment that was the first major review of the science of climate change since 2013. The report argued, beyond any reasonable doubt, that human activity is changing the climate in unprecedented and sometimes irreversible ways. The study continued to warn of increasingly extreme heat waves, droughts and flooding, and a key temperature limit being broken in just over a decade. The report 'is a code red for humanity', said the UN Secretary-General António Guterres, when giving his comments to the report.

The code red for humanity is first and foremost a dire threat and a call for rapid action. Time is running out. On a more positive note, it may provide an opportunity to fundamentally change the systems that on a daily basis undermines our natural world and hence our very existence. Further, it may assist us in changing the way we think of ourselves as part of nature and all living systems. For one thing is certain, change is needed on an individual, organizational and societal level and the necessary change is deeply linked to how we perceive ourselves in the world or as part of the world. History shows us that man's relationship to nature has changed over time, yet our dependence on our eco-systems for food, water and air remains crucial.

> The Earth does not belong to man. Man belongs to the Earth. All things are connected. Like the blood that unites us all. Man did not weave the web of life, he is merely a strand in it. Whatever he does to the web, he does to himself
>
> —**Chief Seattle**

As we know, sustainability is based on the principle that everything we need for our survival and well-being depends, directly or indirectly, on the natural environment. Hence, sustainability creates and maintains the conditions under which humans and nature can co-exist in a productive harmony. Ideally, this harmony should allow for the satisfaction of social, economic and other needs, both for the present as well as future generations. Sustainability is concerned with making sure that we have, and will continue to have, water, materials, and other basic resources that are paramount for protecting both human existence and the natural environment. In other words, sustainability is a precondition for human survival on the planet earth.

The way we perceive and relate to the world influences how we relate to sustainability on an individual, organizational and societal level. We are deeply concerned that the speed and pace of our efforts do not match the seriousness of climate change and environmental degradation, as the global emissions keep rising alongside global average temperatures. The global system of nature on which we all depend probably cannot support present rates of economic and population growth much beyond the year of 2100.

Urgent change is needed and to facilitate that, we need a more holistic approach covering all parts of the global society. Mitigation of climate change is only possible in a just and transparent way, allowing emerging economies the chance to create good lives for their peoples. The use of energy and resources on the planet is unequally distributed and the global action on climate change in the coming years, should take this into account. For example, the average carbon footprint of the world is about 4 ton per person per annum compared to just about 0.5 ton per person per annum in India.

Global energy demand is growing as a consequence of population growth, industrialization and increasing access to energy. At the same time, the world is in a necessary and crucial energy transformation, where fossil fuels must be replaced by renewable energy and alternative energy carriers. Hydrogen is an alternative energy carrier to fossil fuels, which humans can produce themselves, based on renewable energy. India's advantage due to its geographical location, climate conditions and abundance of renewable sources of energy like solar, wind and hydro, make it ideal for becoming the world's cheapest hydrogen hub by 2030.

Further, we strongly believe that Ancient Wisdom can offer solutions and insights to combat climate change. Ancient wisdom can help us tap into the very essence of humanity and can assist us in seeking and embracing an environmentally conscious lifestyle that focusses on mindful and deliberate utilization, instead of mindless and destructive consumption. The principles of circularity, reduce, reuse and recycle should become an integral part of our culture and lifestyle It saddens us to have to also make the connection between climate change and peace. At this very moment, world leaders' talk about peace, yet they prepare for war. In fact, they say, we are preparing for war to preserve peace. Most irrational! To preserve peace, one can only prepare for peace. War is destruction, peace is creation. Peace can be achieved through spiritual and cultural transformation. By doing so, we can change our lifestyles from being greed-based to becoming need-based and hence, support the changes we needto see it happen rapidly.

We hope and believe that change is possible, but we need to act NOW!

# ACKNOWLEDGEMENTS

We deeply thank Shri Pradeep Multani, President PHD Chamber of Commerce and Industry, and Shri Saurabh Sanyal, Secretary-General PHD Chamber of Commerce and Industry, for their constant support and inspiration. Our thanks is due also to other members of the PHD staff who helped us complete the Knowledge Book.

I may mention my wife Dr Purnima Gupta and my three daughters and sons-in-law in London and New York who provided constant inspiration and relieved me from the tiredness of long hours in the office.

My sister Dr Karen Landmark, Norway, guided me at every step and made significant contributions in infusing spirit in this book. I owe special appreciation and gratitude to her.

Sturle Pedersen, Chairman, Greenstat Hydrogen India Pvt Ltd, whose leadership provided guidance and support to this voluminous project, is a leader in true sense, and a teacher too.

Dr C P Kaushik, Co-Chair, PHDCCI contributed significantly in editing the entire manuscript. He has not only been a source of inspiration, he has contributed significantly in technical contents of the knowledge book.

We are thankful to Dr Niti Bhasin, Professor, and Dr Kiran Bala, Assistant Professor, from the Department of Commerce, Delhi School of Economics, University of Delhi; Dr Neha Arora, Professor of Economics at International School of Business & Media, Pune; Laxmi Devi, PhD research scholar registered at Delhi School of Economics, University of Delhi and Ashima Dua, Economist, PHD Chamber of Commerce and Industry for their support.

**—Dr J P Gupta**

Chair, Environment Committee

PHD Chamber of Commerce and Industry

# SUMMARY


- Like the Knowledge book 2021, *Harnessing the Power of Hydrogen*, this book is also intended to provide a simplified overview of the potential benefits of using hydrogen as an energy carrier, in the context of India's ambition for increased growth in renewables and the government's willingness to take a lead role in combating climate change.

  The book is a starting point for further developing a national road map for hydrogen that supports a stronger and faster energy transition beyond India's current climate change initiatives, growth in renewables and policy initiatives.

  The book leans on '*Atma Nirbhar Bharat Abhiyaan*' – the government's call for self-reliance – emphasizing that becoming self-reliant doesn't advocate a self-centred system. As stated by the Prime Minister Narendra Modi, in India's self-reliance there is a concern for the whole world, its happiness, cooperation and peace. Cooperation within the country and globally for a better livelihood for the poor is the key to real self-reliance philosophy.

The book presents hydrogen as a critical catalyst to meet India's extremely ambitious target of 450 gigawatt of renewable energy by 2030 and that hydrogen plays a vital role in India becoming self-reliant in energy.

The book outlines the potential of hydrogen as an important part of the total energy system and as a potential new industry that can lead to technology development, green energy export and high-value job creation, particularly for the younger generation and positive societal development.

The first part of the book presents the strength and competitive advantages, India offers to international investors, technology suppliers and international energy companies interested in setting up large-scale hydrogen production facilities.

The second part of the book focuses on, '*What India needs to do now*'. Finalization of safety standards and regulations are key, to kickstart hydrogen production, introduction of hydrogen in end applications and exports. Also, setting up of 'Centres of Excellence' for process safety using advanced tools has been suggested. Furthermore, there is a need for more than a lakh trained skilled manpower in the use of hydrogen energy in coming years. These 'Centres of Excellence' will provide training and skills using virtual reality and augmented virtual reality.

The book offers important steps for the way forward needed for the hydrogen economy. In the initial period it has been suggested to look aside 'Make in India' for a limited period of 10 to 15 years. The overall goal being to become self-reliant by replacing the import of fossil fuels with renewable energy and hydrogen as an energy carrier, at the earliest possible. This is possible by encouraging international collaboration, knowledge sharing and import of plants and machinery etc. Incentives such as 'zero duties' on imports and tax reductions have been suggested. This would not be a financial burden on the government, as it would have been offset by reduced import of fossil fuels and carbon credits.

Also, it has been emphasized that there is a need to create nodal agency, under DRDO for development of all types of electrolysers, i.e. PEM, Alkaline, AEM and solid oxide, to reduce costs and make electrolysers available within the country to meet the rapid increased demand for green hydrogen.

Despite India having alliances with several countries such as the USA, Germany, Norway, Australia and Japan, it is suggested to have an 'International Hydrogen Alliance' for better coordination and availability of technology and to make the knowhow freely available. The book also highlights the significance of ESG in business and also the domestic and international trend of ESG.■

# INTRODUCTION

Green Hydrogen – The National Agenda | Opportunities for Green Hydrogen | India's Efforts for Hydrogen Economy | Way Forward


> *The Hon'ble Prime Minister in his Independence Day speech on 15 August 2021 has announced five key initiatives, the first being Mission Hydrogen.*

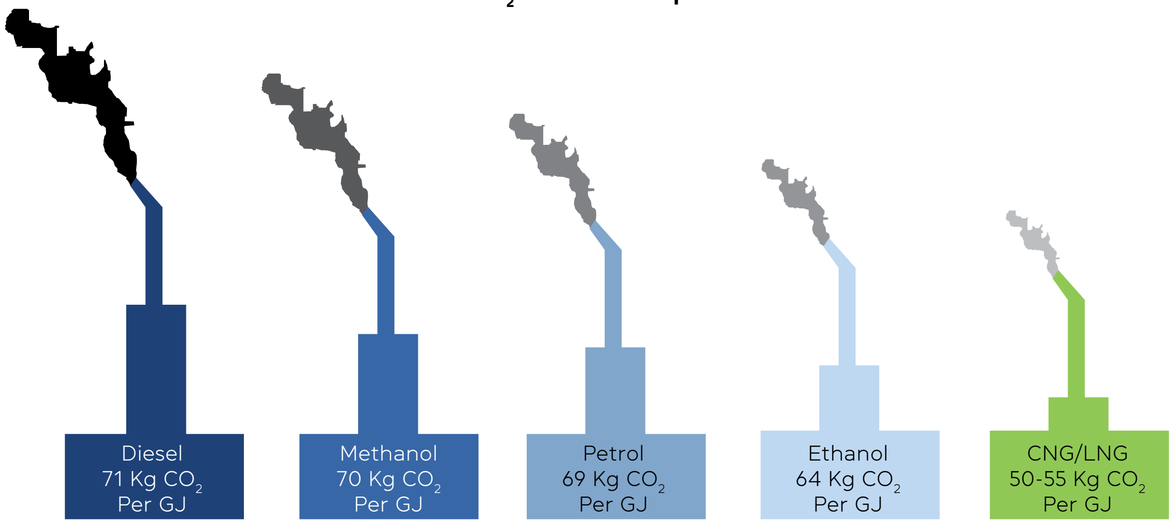
India has a large growing population and economy, but comparatively has limited availability of fossil fuels to fulfill its energy demands. The key point to consider here is the ever-increasing fuel demand and its dependence on imported crude oil for domestic needs. India's annual energy import cost was in excess of USD 112 ($ BN) in 2018-19. More than 82% of this cost is consumed in importing crude oil and natural gas.

As per the International Energy Agency, India will be importing 90% of its energy consumption by 2040. To reduce the environmental pollution and petroleum imports in India, there is need to look for an alternative source of clean energy to meet the growing requirement.

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

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

**$CO_2$ Emission Comparison**




Source: US Energy Information Administration

We may look at solar photovoltaic (PV) and wind, which have revolutionized India's green energy sector in the past decade or so. Diversification of electricity sources by integrating renewable energy in its grid is helping India achieve the Paris Agreement targets. The country has pledged to achieve 50mmaa installed capacity from renewable energy sources by 2030 and reduce emissions intensity by 33-35% below 2005 levels in its nationally determined commitments to the 2015 Paris Agreement.

## GREEN HYDROGEN – THE NATIONAL AGENDA

The Hon'ble Prime Minister in his Independence Day (15 August 2021) speech announced five key initiatives, the first being Mission Hydrogen. He outlined a vision of becoming a global leader and enabling a substantial domestic hydrogen economy. Hydrogen has the promise of transforming India from an energy-deficient to an energy-rich country. It can even make India a net exporter of energy. In February 2022, India made a big splash in the hydrogen ecosystem by announcing its Green Hydrogen Policy. The policy takes forward the vision articulated by the Prime Minister, to make India a global hub for the production and export of Green Hydrogen. The policy lays out incentives for investors to use this new-age fuel and gradually move away from the traditional sources of energy.

Hydrogen is considered as one of the most sustainable fuels of the future. When hydrogen is burned, we get water vapor, with no residue or climate-harming impact. The challenge has been to make green hydrogen, which was the thrust of the Prime Minister's proclamation. For this, a lot of energy is needed for n electrolysis of water. Unless this electricity is produced with a zero-carbon footprint (solar or wind), it defeats the key aspect of green hydrogen.

All other modes that do not use electrolysis to split a molecule of water are methods where hydrogen is produced as a by-product, or through a carbon burning process. The success of a massive breakthrough for scalable hydrogen production must be seen in confluence with factors like declining costs, financial incentives and carbon taxes, as it happened for the breakthrough of other renewables. Thankfully, India is blessed with a clear-minded Prime Minister, sunshine round the year and a large coastline. About 5,000 trillion kWh per year of energy is transferred from the sun to India's land area with most parts receiving 4-7 kWh per sq. m per day. In India, with an average of **300 sunny days a year,** solar photovoltaics' power can effectively be harnessed providing huge scalability in India. This very clearly indicates that there is a high potential of harnessing the green hydrogen energy in India. Solar-to-hydrogen also solves an intermittence challenge, as hydrogen has the potential to reduce/substitute the need for battery storage.

## OPPORTUNITIES FOR GREEN HYDROGEN

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

The concept of  a Green hydrogen economy brings many opportunities for India to become energy independent. Over the last decade, India is constantly focusing on enhancing its renewable energy capacity by taking advantage of its geography.

Since hydrogen is expected to be an integral part of the energy system of the future, at an overall level, it seems logical to proceed with scaling of renewable energy in connection with scaling of hydrogen production.

Mass production offers India an opportunity to export green hydrogen to other nations in the long term, after meeting its own needs to replace fossil fuels. Green Hydrogen when used with fuel cells can help India significantly reduce its petroleum imports and environmental pollution.

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

At present, hydrogen is being primarily produced with the help of fossil fuels for use in the chemical, steel, and refinery industry. Today, it is possible to produce hydrogen with the help of renewable energy-based electricity. The 'net-zeroness' of hydrogen depends on the method of production. Steam Methane Reforming (SMR) incurs a measurable amount of emissions when used to produce hydrogen (Hydrogen produced by such a process is called Grey Hydrogen). Green hydrogen (made from water and green electricity using an electrolyser) is considered the next big movement toward sustainable development. It has found relevance in today's energy policy narrative, given its ability to decarbonise 'hard-to-abate' industries. Hard-to-abate sectors (like the steel industry) require a more significant investment of green technology than existing carbon-based technologies.

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

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

## INDIA'S EFFORTS FOR HYDROGEN ECONOMY

India's ambitious plans of installing 500 GW of renewable energy capacity will fuel its drive to become the global hub of green hydrogen manufacturing.

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

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

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

## WAY FORWARD

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

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

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

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

# INDIA IS ATTRACTIVE FOR INVESTMENTS IN GREEN HYDROGEN

Abundance of Renewable Energy | India's Competitive Advantage in Green Hydrogen Production | Phasing out Coal | Biofuels/Bio-CNG | Alternative Fuels | Infrastructure Facilities | R&D Facilities in India | Ease of doing business in India


In 2021, India announced its National Hydrogen Mission, which aims to aid the Government in meeting climate targets and make India a green Hydrogen hub. The Ministry of Power notified the Green Hydrogen/Green Ammonia Policy on 17 February 2022.

**Target by 2030:** The government has set the production target of green hydrogen at 5 million tons per annum (MTPA) by 2030. Currently, India uses around 6 MTPA as a heating fuel in refineries and petrochemicals and as a feedstock in fertilizer production which is entirely produced from fossil fuels.

The proposed National Hydrogen Energy Mission's aim is to develop India as a global hub to manufacture hydrogen and fuel cell technology across the value chain. The mission will put forward specific strategy for short term (4 years) and broad stroke principles for long term (10 years and beyond).

**Reduced dependence on imported Crude:** The implementation of this policy will provide clean fuel, and reduce dependence on fossil fuel and crude oil imports. The objective also is for India to emerge as an export hub for Green Hydrogen and Green Ammonia.

**Facilitating demand creation**: The mission will provide necessary flexibility to capture benefits from advances that are taking place in the technological landscape. The Union Government will facilitate demand creation in identified segments such as petrochemicals, steel, and fertilizers. Major activities envisaged under the mission include creating volume and infrastructure, demonstrate in niche applications like transport and industry, goal-oriented R&D, facilitating policy support and putting in place a robust framework for regulation of hydrogen technologies.

India is the third largest oil consumer and fourth biggest emitter of carbon dioxide after China, the US and the EU.

India imported around 200 million tonnes of crude oil in the last fiscal year ending March 2022.

Crude oil import bill was $ 119 billion in FY 22 compared to $ 62.2 billion in the previous year.

The government had given impetus to scaling up the gas pipeline infrastructure across the length and the breadth of the country and has introduced reforms for power grid, including the smart grids to catalyse the integration of renewable energy into the present power mix. Creating demand for hydrogen will ensure its rapid scale-up and long-term contribution to decarbonisation efforts.

**Advantage India**: Green hydrogen and green ammonia are the key steps in National Hydrogen Mission. Transiting to green hydrogen and green ammonia is one of the major requirements for the reduction of emissions. India has a huge edge in green hydrogen production owing to its favourable geographic conditions and the presence of abundant natural elements. With appropriate capacity in addition to renewable power generation, storage, and transmission, production of green hydrogen can be made cost-effective. In addition, India's long coastline and port infrastructure will be an added advantage for export of green ammonia from the proposed hubs/clusters. Currently, hydrogen produced from natural gas is used for production of nitrogenous fertilizers and petrochemicals. India's annual ammonia consumption for fertilizer production is about 15 million tons and 15 per cent of this demand is met by imports. Mandating 1% green ammonia share will save about 0.4 million standard cubic feet per day of natural gas imports.

### COMMITMENTS MADE BY INDIA AT COP 26

Under its commitment towards global community, India announced the following at the Glasgow Summit during COP 26:

- **Achieve net-zero emissions** by 2070
- **Bring its non-fossil energy capacity to 500 GW** by 2030
- **Bring its economy's carbon intensity down to 45 per cent** by 2030
- **Fulfill 50 per cent of its energy requirement through renewable energy** by 2030
- **Reduce 1 billion tonnes of carbon emissions from the total projected emissions** by 2030

The use of hydrogen in the steel industry can substitute the import of cooking coal. India imports more than 51.83 MT of cooking coal. Green ammonia will help the country reduce its cooking coal imports dependency. BEV vehicles are dependent on imported Lithium and Cobalt for Lithium-Ion batteries. The hydrogen fuel cell supply chain will make India self-reliant in the clean transport segment.

The policy decisions that were announced in the notification on 17 February 2022 are mentioned below:

- **Ease in procurement of renewable energy**: Green hydrogen/ammonia manufacturers may purchase renewable power from the power exchange or set up renewable energy capacity themselves or through any other, developer, anywhere.

- **Open access** will be granted within 15 days of receipt of application.

- **Banking of energy**: The green hydrogen/ammonia manufacturer can bank unconsumed renewable power, up to 30 days, with a distribution company and take it back when required.

- **Procurement of RE by Discoms**: Distribution licensees can also procure and supply renewable energy to the manufacturers of green hydrogen/green ammonia in their states at concessional prices which will only include the cost of procurement, wheeling charges and a small margin as determined by the State Commission.

- **Waiver of inter-state transmission charges** for a period of 25 years will be allowed to the manufacturers of green hydrogen and green ammonia for the projects commissioned before 30 June 2025.

- **Connectivity on priority**: The

manufacturers of green hydrogen/ ammonia and the renewable energy plant shall be given ISTS connectivity to the grid on a priority basis to avoid any procedural delays.

- **Applicability of RPO to green hydrogen**: The benefit of Renewable Purchase Obligation (RPO) will be granted as an incentive to the hydrogen/ ammonia manufacturer and the distribution licensee for consumption of renewable power.

- **Ease of doing business:** To ensure ease of doing business a single portal for carrying out all the activities including statutory clearances in a time-bound manner will be set up by MNRE.

- **Facilities at ports for export**: Manufacturers of green hydrogen/ green ammonia shall be allowed to set up bunkers near ports for storage of green ammonia for export or use by shipping sector. Land for storage shall be provided by the respective port authorities at applicable charges.

Some policy decisions being discussed at the Central Government of India level:

- **Hydrogen purchase obligation**: To encourage the hydrogen economy, the Government is considering introducing a Hydrogen Purchase Obligation for industries, and has decided to initiate action to establish seven to eight green hydrogen pilot plants through the Oil PSUs immediately.

- **Mandate to Oil PSUs**: The government is likely to come out with mandates that the oil refining, fertilizer, and steel sectors procure green hydrogen and green ammonia for a certain proportion of their requirements which could initially be for the refinery sector in the range of 15-20 per cent of the sector's total requirement.

- **PLI Scheme**: Introduction of performance-linked manufacturing scheme(PLI) for indigenous manufacturing of electrolysers and its components like electrodes and membranes, manufacture of hydrogen and ammonia storage systems etc.

- **Import duty** on electrolysers for initial few years to be low or nil to encourage initial imports and to build capacity.

- **Export of green hydrogen and green ammonia**: Policy encouraging exports of green hydrogen and green ammonia to potential importing countries like Republic of Korea and Japan to start with.

Improving ease of doing business in green hydrogen and green ammonia sectors by various state governments:

- To come up with a road-map

and policies that attract FDIs in green hydrogen development which include manufacturing of electrolysers, storage systems, fuel cells and also green hydrogen generation projects catering to the demand of the states and also export at a later date.

- Identify and showcase investment destinations (manufacturing hubs, generation project sites, ease of tying up renewable energy and green hydrogen demand projections.
- Introducing concept of a global industry hub based on inclusive and balanced regional growth and job creation.
- Creating investment facilitation portal and concept of relationship manager for each investment.
- Applying the existing single window industrial clearance system to green hydrogen projects.
- De-link incentives from SGST.
- Around 10-12% of fixed capital investment may be given to large industries for setting up electrolyser, storage systems and fuel cell manufacturing industries in the state in the form of capital subsidies.
- Strengthening integrated value chains encouraging innovation and research.
- Focus on skill development in hydrogen technologies and manufacturing through industry – academia collaboration.

However, after initial concessions in custom duty, Government should hike basic custom duty on electrolysers import to support domestic industry. According to privy to the matter, MNRE has given a proposal to increase in basic customs duty on import of electrolysers to support domestic industry.

Another positive development is that India will hold the G-20 (IRENA) presidency from 1 December 2022 for one year and will convene the G-20 leaders' summit in 2023 for the first time, which will provide the opportunity to share its renewable energy and strengthen the renewable energy capabilities.

Further, the Ministry of New and Renewable Energy (MNRE) in January 2022, signed a strategic partnership agreement with 167-member countries IRENA to further strengthen its collaboration in the field of renewable energy. According to IRENA, hydrogen will account for around 12% total energy supply in a 1.5 degree celsius compatible world by 2050.

MNRE has been supporting a broad-based Research Development and Demonstration (R&D) programme on hydrogen energy and fuel projects in industrial, academic and research institutions for use of renewable sources, storage systems for green hydrogen manufacturing. With respect to transportation, major work has been supported by Banaras Hindu University, IIT Delhi, and Mahindra & Mahindra.

This has resulted in the development and demonstration of internal combustion engines, two wheelers, three wheelers, and minibuses that run on hydrogen fuel. Two hydrogen refueling stations have been established (one each at Indian Oil R&D Centre, Faridabad, and National Institute of Solar Energy, Gurugram).

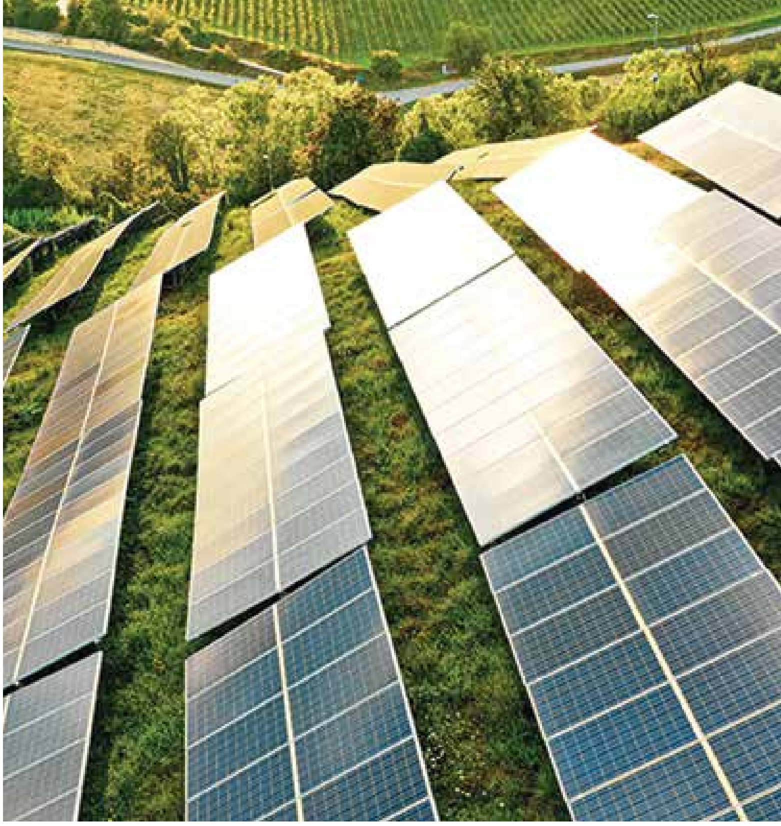
With Prime Minister Narendra Modi's ambitious Panchamrit targets set during COP26, India is all set to achieve net zero by 2070 and install 500 GW of non-fossil fuel capacity by 2030. To promote green hydrogen economy, India has estimated an outlay of Rs 25,425 crore INR. The Green Hydrogen Mission aims to generate 5.0 million tons of green hydrogen annually.

***The Government may hike basic custom duty on electrolysers import to support domestic Industry. The Ministry of New & Renewable Energy (MNRE) has prepared proposals for the companies producing green hydrogen, green ammonia and also manufacturing allied equipment. MNRE has also given a proposal to increase basic customs duty on the import of electrolysers to support domestic industry, said sources privy to the matter.***

## ABUNDANCE OF RENEWABLE ENERGY

There has been a visible impact of solar energy in the Indian energy scenario during the last few years. Solar energy-based decentralised and distributed applications have benefited millions of people in the Indian villages by meeting their cooking, lighting and other energy needs in an environment-friendly manner.

Over the years, the solar energy sector in India has emerged as a significant player in the grid connected power generation capacity. It supports the government agenda of sustainable growth while emerging as an integral part of the solution to meet the nation's energy needs and an essential player for energy security. The National Institute of Solar Energy has assessed the country's solar potential at about 748 GW assuming 3 per cent of the waste land area to be covered by Solar PV modules. Solar energy has taken a central place in India's National Action Plan on Climate Change with the National Solar Mission as one of the key missions. The Mission's objective is to establish India as a global leader in solar energy by creating the policy conditions for solar technology diffusion across the country as quickly as possible. To achieve the target, the Government of India has launched several schemes to encourage the generation of solar power. These include Solar Park Scheme, VGF Schemes, CPSU Scheme, Defence Scheme, Canal bank and Canal



Top Scheme, Bundling Scheme, Grid Connected Solar Rooftop Scheme, etc. Various policy measures undertaken include declaration of trajectory for Renewable Purchase Obligation (RPO) including Solar, Waiver of Inter-State Transmission System (ISTS) charges and losses for inter-state sale of solar and wind power for projects to be commissioned up to March 2022, must run status, guidelines for procurement of solar power through tariff-based competitive bidding process, standards for deployment of solar photovoltaic systems and devices, provision for roof top solar and guidelines for development of smart cities, amendments in building by-laws for mandatory provision of rooftop solar for new construction or higher floor area ratio, infrastructure status for solar projects, raising tax free solar bonds, providing long tenor loans from multi-lateral agencies, etc.

India added a record 10 Gigawatt (GW) of solar energy to its cumulative installed capacity in 2021. This has been the highest 12-month capacity addition, recording nearly a 200 per cent year-on-year growth. India has now surpassed 50 GW of cumulative installed solar capacity (as on 28 February 2022). This included 40.4GW of utility scale, 8.57GW of rooftop solar, and 1.47GW of off grid capacity. Total project capacity in the pipeline (projects allocated to developers and at various stages of development) stood at 63.3GW. Several new players have announced ambitious plans, while many key thermal power producers are now focusing primarily on expansion in the renewable space, including solar.

Solar energy is also powering other essential infrastructure, including transport. One of India's flagship solar projects, the giant Rewa solar park, powers the New Delhi metro rail system: a network that serves over 2.6 million commuters daily. Vital government-led initiatives like 24x7 Power for All, which is committed to providing each household round the clock access to electricity, are helping communities to empower -- both literally and figuratively, improving the quality of life.

India's path towards fully realizing its renewable energy potential could be a game changer: for its own citizens certainly, as well as for global efforts to tackle climate change and as a guide for other countries as they invest in solar energy, said a World Bank report.

## INDIA'S COMPETITIVE ADVANTAGE IN GREEN HYDROGEN PRODUCTION

Though green hydrogen was long touted as the fuel of the future given its potential for use as a fuel and a chemical feedstock, it lacked cost competitiveness and economic viability. The cost of producing hydrogen is highly dependent on the costs of its critical inputs such as electrolysers and renewable energy, particularly solar and wind energy.

A recent decline in the prices of renewable energy with solar and wind energy cheaper than fossil fuels, has helped bring down the cost of the electrolysis process of hydrogen. As per IEA analysis, the cost of producing hydrogen from renewable sources could fall 30% by 2030 as a result of falling prices of renewable energy and scaling up production of electrolysers, fuel cells, and refueling equipment used in manufacture of hydrogen.

Looking at Table 1, which provides the minimum and maximum production cost of green hydrogen in top 10 countries for 2020 and projected production cost for the years 2030 and 2050, we can observe that India is likely to emerge as one of the top contenders in the next three decades. As of 2020, India's current renewable infrastructure is allowed for the production of green hydrogen at a cost ranging from 4.25 and 4.5 Euros per kilogram. In 2050, it is projected that India will be able to produce renewable-derived hydrogen for just one Euro per kilogram.

**Table 1: Green hydrogen production cost (in Euros per kg) outlook 2020-2050**

| Sr. No. | Country | 2020 Min | 2020 Max | Country | 2030 Min | 2030 Max | Country | 2050 Min | 2050 Max |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Chile | 3.5 | 3.75 | Chile | 2 | 2.25 | India | 1 | 1.25 |
| 2 | Russia | 3.75 | 4 | China | 2 | 2.25 | China | 1 | 1.25 |
| 3 | Canada | 3.75 | 4 | Russia | 2.25 | 2.5 | Saudi Arabia | 1 | 1.25 |
| 4 | United Kingdom | 3.75 | 4 | Saudi Arabia | 2.25 | 2.5 | Chile | 1 | 1.25 |
| 5 | China | 4 | 4.25 | Argentina | 2.25 | 2.5 | Morocco | 1 | 1.25 |
| 6 | India | 4.25 | 4.5 | Brazil | 2.25 | 2.5 | South Africa | 1 | 1.25 |
| 7 | Saudi Arabia | 4.25 | 4.5 | India | 2.5 | 2.75 | United States | 1 | 1.25 |
| 8 | Morocco | 4.25 | 4.5 | United Kingdom | 2.5 | 2.75 | Brazil | 1 | 1.25 |
| 9 | South Africa | 4.25 | 4.5 | Canada | 2.5 | 2.75 | Australia | 1 | 1.25 |
| 10 | United States | 4.25 | 4.5 | Morocco | 2.5 | 2.75 | Spain | 1 | 1.25 |

Source: Author's Analysis, Raw Data from statista.com

The market for green hydrogen in India is still in its nascent stage but the potential of green hydrogen for decarbonising emission-intensive industries is immense. With declining renewable energy costs in India, hydrogen produced from renewable sources will provide a cost-competitive alternative to traditional hydrogen manufacturing systems. With the availability of cheaper renewable energy, India can be a forerunner in producing hydrogen competitively without the use of fossil fuels and will provide India with a cost advantage over other countries.

### Leveraging renewable energy capacity

In India, the consumption of hydrogen is around 6.9 million tons a year and is expected to increase to 12 million tons by 2030 and 28 million tons a year by 2050. The cost of producing zero-emission hydrogen depends on the cost of renewable energy like solar and wind.

India, being a tropical country with sunlight around the year is home to numerous solar parks with an operational capacity of plus 2GW (Gigawatt) that can be leveraged for producing green hydrogen. It is estimated that India can generate over 1000 GW of solar energy due to the availability of natural resources and favorable climate and geography.

Producing hydrogen from solar is likely to be cheaper than producing it from fossil fuels. In addition to this, lower solar tariffs, easy access to land, transport and co-location of solar parks will help bring down the cost of hydrogen development. Integration of the production of hydrogen with renewable energy will facilitate scaling up of the green hydrogen production in India.

## PHASING OUT COAL

Energy fuel that has a 38 per cent share in global generation is coal. Britain, Germany, and other European countries have laid down a clear road-map for phasing out coal-based power plants. India has 70 per cent of its power generated from coal. In a developing economy like India, where there will be a growing demand for power; it is important to note that the energy eco-system feeds on cheap power and low dependence can hardly

change in near future. Recently, in a bid to meet the ambitious 500 GW renewable energy target and tackle the annual issue of coal demand, the Union Power Ministry has identified 81 thermal units that will replace coal with renewable capacity by 2026.

This includes generation units of the state-owned NTPC and privately owned units of TATA Power, Adani Power, CESE and Hindustan Power among others.

The coal-based power generation units, which have high tariffs, have been identified by the ministry. These will operate at a technical minimum (Operative Ratio) of 40 per cent and the balance generation capacity will be met by renewable energy sources.

It has been found that about 58,000 million tons of thermal power generation in Central, State, and private sectors can be substituted with Renewable Energy (RE) Generation. RE capacity of about 30,000 MW would be required for the purpose. It is also suggested that any power plant be also allowed to blend renewable energy with conventional power. It is estimated that this would help to conserve 34 million tons of coal and reduce carbon emission by 62.2 million metric tons.

The ministry has also notified for flexibility in power generation through bundling thermal and hydro with solar and wind power. It allows conventional power generation to set up renewable capacity at their units and sell at average rates. The country is committed to adding 500 GW of renewable energy capacity by 2030 and also aims to be a net-zero carbon economy by 2070. India is also committed to reducing its carbon emissions by 1 billion tons by 2030. Also, the government has proposed a scheme worth of Rs 1000 crore to invite private companies to set up manufacturing zones for power and renewable energy (RE Equipment). The move is a part of the plan to cut down reliance on import and build domestic capacity.

## BIOFUELS/BIO-CNG

A number of measures have been taken to implement solutions and improve the starting point for the utilization of biofuels. The following point-by-point listing provides an overview of a number of important activities and opportunities:

- Ten per cent ethanol-petrol mix achieved. This achievement has reduced carbon emissions by 27 lakh tons, saving the country Rs 41,000 crore in foreign exchange on oil imports.
- Working towards 100% ethanol.
- Conversion of paddy straw to Bio-CNG is in progress. 50,000 tons/year of paddy straw is generated which will be utilised to generate electricity.
- One acre of paddy straw generates 2-2.5 metric tonnes of straw.
- Recent developments for the use of LNG as transport fuel have taken momentum.
- Bio-CNG is being produced. Segregated waste provided by municipal waste collection has generated momentum.

## ALTERNATIVE FUELS

Other options that can reduce emissions are as follows:

- Dimethyl CNG is obtained from the gasification of low-grade coal via natural gas reforming process. This is an excellent substitute for LPG Gas (can be blended into LPG up to 20% without any modification)
- Substitute for domestic cooking and heating
- Methanol can be used for production of marine fuel. India produces 800 tons/day of methanol. It is proposed to run buses on methanol.

## INFRASTRUCTURE FACILITIES

At present, India has excellent infrastructure facilities to support setting up of a company in hydrogen sector.

### Engineering and fabrication companies in operation:

- Bharat Heavy Electricals Ltd. (https://www.bhel.com/)

- Cummins India Ltd. (https://www.cummins.com/en/in/company/cummins-india)
- ElgiEquipment's Ltd. (https://www.elgi.com/in/)
- Engineers India Ltd. (https://engineersindia.com/)
- Everest Industries Ltd. (https://www.everest-ind.com/)
- Greaves Cotton Ltd. (http://www.greavescotton.com/)
- HEG Ltd. (https://hegltd.com/)
- Isgec Heavy Engineering Ltd. (https://www.isgec.com/)
- Kirloskar Brothers Ltd. (https://www.kirloskarpumps.com/)
- Larsen & Toubro Limited (https://www.larsentoubro.com/)
- Hindustan Petroleum Corporation Limited (https://www.hindustanpetroleum.com/)
- Mahindra and Mahindra Limited (https://www.mahindra.com/)
- Motherson Group (https://www.motherson.com/)
- Forbes Marshall Pvt. Ltd. (https://www.forbesmarshall.com/India)

## INSTRUMENTATION AND CONTROL SYSTEMS

**National Instruments:** National Instruments is US-based company that has operations in India as well. They are located in New Delhi and Bangalore. The company was established with the objective of propagating a revolution in virtual instrumentation technology in the nation and to achieve their objective, they are always on the lookout for young and energetic instrumentation and control engineers.

**ABB:** ABB is a world leader in the automation and power technologies that enables industry and utility customers to improve performance, while lowering the impact on the environment. They have operations in over 100 countries all over the world through their group companies and more than 1,00,000 people are working for this organisation. They are hiring not only experienced engineers, but fresh graduates as well.

**Larsen & Toubro:** Known as L&T, Larsen and Toubro is one of the country's largest construction and engineering firms with additional interest in areas like IT, electronics and electricals. Their constant quest for top-class quality has made them to recruit the best engineering graduates from different branches of engineering.

**Bosch:** Bosch is a German-based company operating in India for last half a century. They are known for their automotive technology, industrial technology, customer goods and building technology and engineering & IT solutions. For carrying out operations effectively in these fields, they look for qualified instrumentation and control engineers.

**Invensys:** Invensys are into the field of instrumentation and control engineering through their group company called Invensys Control, which is a leading international provider of control devices for products in commercial applications and residential homes. They are in operation from early 1990s.

**GE:** GE has marked their presence in India from the year 1902 when the first hydro power plant was installed by them. They have over the years diversified into financial services, healthcare, energy, transportation, etc. They have technology centres in cities like Bangalore and Hyderabad and they have more than 13,000 people working for them in India. They recruit instrumentation engineers for effectively carrying out their operations in different fields.

**Suzlon:** Suzlon is a big name in alternative energy in India. They have the capacity to produce 4400 MW of wind energy through their plants located in different parts of the country.

In addition to these top players, there are also other companies like Apna Technologies, Whirlybird and Essar that recruit instrumentation and control engineers.

## R&D FACILITIES IN INDIA

**Council of Scientific & Industrial Research (CSIR):** CSIR is one of the world's largest publicly funded Research and Development organisations. It is a premier national R&D organisation that has a number of institutes under it. Below is the list of research institutions under CSIR labs in India:

- CSIR-Advanced Materials and Processes Research Institute (CSIR-AMPRI), Bhopal
- CSIR-Central Building Research Institute(CSIR-CBRI), Roorkee
- CSIR-Centre for Cellular Molecular Biology(CSIR-CCMB), Hyderabad
- CSIR-Central Drug Research Institute(CSIR-CDRI), Lucknow
- CSIR-Central Electrochemical Research Institute(CSIR-CECRI), Karaikudi
- CSIR-Central Electronics Engineering Research Institute(CSIR-CEERI), Pilani
- CSIR-Central Food Technological Research Institute(CSIR-CFTRI), Mysore
- CSIR-Central Glass Ceramic Research Institute(CSIR-CGCRI), Kolkata
- CSIR-Central Institute of Medicinal Aromatic Plants(CSIR-CIMAP), Lucknow
- CSIR-Central Institute of Mining and Fuel Research(CSIR-CIMFR) Dhanbad
- CSIR-Central Leather Research Institute(CSIR-CLRI), Chennai
- CSIR-Central Mechanical Engineering Research Institute(CSIR-CMERI), Durgapur
- CSIR-Central Road Research Institute(CSIR-CRRI), New Delhi
- CSIR-Central Scientific Instruments Organization (CSIR-CSIO), Chandigarh

- CSIR-Central Salt Marine Chemicals Research Institute(CSIR-CSMCRI), Bhavnagar
- CSIR Fourth Paradigm Institute(CSIR-4PI), Bengaluru
- CSIR-Institute of Genomics and Integrative Biology(CSIR-IGIB), Delhi
- CSIR-Institute of Himalayan Bioresource Technology (CSIR-IHBT), Palampur
- CSIR-Indian Institute of Chemical Biology (CSIR-IICB), Kolkata
- CSIR-Indian Institute of Chemical Technology (CSIR-IICT), Hyderabad
- CSIR-Indian Institute of Integrative Medicine (CSIR-IIIM), UT of J&K
- CSIR-Indian Institute of Petroleum (CSIR-IIP), Dehradun
- CSIR-Indian Institute of Toxicology Research (CSIR-IITR), Lucknow
- CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), Bhubaneswar
- CSIR-Institute of Microbial Technology (CSIR-IMTECH), Chandigarh
- CSIR-National Aerospace Laboratories (CSIR-NAL), Bengaluru
- CSIR-National Botanical Research Institute (CSIR-NBRI), Lucknow
- CSIR-National Chemical Laboratory (CSIR-NCL), Pune
  CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur
- CSIR-North – East Institute of Science and Technology(CSIR-NEIST), Jorhat
- CSIR-National Geophysical Research Institute(CSIR-NGRI), Hyderabad
- CSIR-National Institute For Interdisciplinary Science and Technology
- (CSIR-NIIST),Thiruvananthapuram
- CSIR-National Institute of Oceanography(CSIR-NIO), Goa
- CSIR-National Institute of Science Communication And Information
- Resources(CSIR-NISCAIR), New Delhi
- CSIR-National Institute of Science, Technology And Development Studies
- (CSIR-NISTADS), New Delhi
- CSIR-National Metallurgical Laboratory(CSIR-NML), Jamshedpur
- CSIR-National Physical Laboratory(CSIR-NPL), New Delhi
- CSIR-Structural Engineering Research Centre(CSIR-SERC), Chennai
- CSIR Madras Complex(CSIR-CMC),Chennai

### Other R&D Centers:

- SRIRAM Institute for Industrial Research
- SRIRAM Analytical Laboratory
- DRDO- (Defense Research and Development Organization)
- Institute of Science, Bangalore
- Bhabha Atomic Research Centre, Mumbai
- TATA Institute of Fundamental Research, Mumbai
- 23 Indian Institutes of Technology including Delhi, Mumbai, Kharagpur, Roorkee.

## EASE OF DOING BUSINESS IN INDIA

In 2014, under the visionary leadership of Hon'ble Prime Minister, Shri Narendra Modi, businesses underwent a complete change with the government responding innovatively. This started the journey of government process reengineering, bringing various ministries and departments of the Centre and State together to achieve a common goal of making India the most preferred business destination.

It bore fruit as India today ranks 63 in the World Bank's Doing Business Report 2020, a meteoric rise of 79 ranks from 142 in 2014.

Following steps were taken to achieve the task:

- Introduction of SPICe+ and AGILE PRO form by the Ministry of Corporate Affairs (MCA) saves time and effort required for a nascent Company Incorporation. This form combines various services like PAN/TAN/Director Identification Number/GSTN etc.

- Online Building Permission System (OBPS) is an online Single Window for obtaining all building permissions. In Delhi and Mumbai, all relevant agencies have been brought on board this single window system thereby eliminating requirement on the part of the applicant to engage with each agency individually.

- Digitization of land records has been one of the top priorities to bring efficiency and transparency in property related transactions. It allows citizens to view property transaction records in a digital mode.
  Faster resolution of commercial disputes is pivotal to boost investor confidence in the dispute resolution mechanism of the country. Dedicated commercial courts have been established in Delhi and Mumbai dealing exclusively with commercial cases. Adoption of technology for case management by lawyers and judicial officers is leading to speedier dispute resolution.

- Introduction of Insolvency and Bankruptcy Code of India (IBC) in 2016 was a game changer in resolving insolvency. The objective of the Code is maximization of value of assets by aiming at reorganisation rather than liquidation of the Corporate Debtor. The Code has seen success as the creditor is in charge rather than debtor in charge. The increase in recovery rate to 71 % is evidence of its success. This law is evolving and once a long drawn and painful process, of closure of business is now a faster and more efficient process.

- Time and cost to export and import has been considerably reduced by allowing online completion of all activities.

- India has identified 6,000 burdensome compliances, both at the central and states levels, that would be eased as part of the government's plan to make it easier to do business towards 'Ease of doing business in India'. 'A systematic exercise across the Centre and states is being undertaken to eliminate or reduce compliances which have an adverse impact on time and cost of businesses,'

- Presently FDI up to 100% is permitted in the Renewable energy sector under the Automatic route and no prior government approval is required in India.

- 100% Repartition of profit is allowable from India to the Investors. ■

# India jumps to 63rd position in World Bank's Ease of Doing Business 2020 report

By Yogima Seth Sharma, ET Bureau • Last Updated: Oct 24, 2019, 12:53 PM IST



**Synopsis**
The country was 77th among 190 countries in the previous ranking, an improvement by 23 places compared to its position a year before.

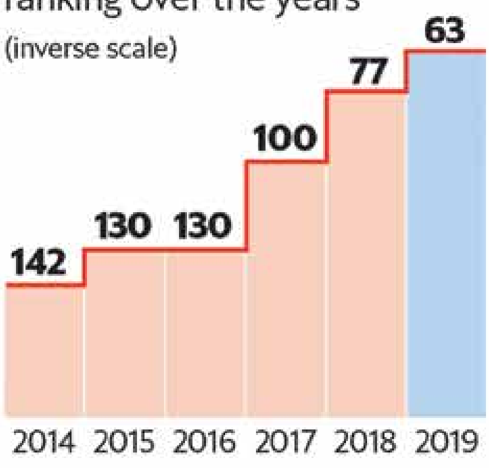
In the 2019 report, India had improved its rank on six out of the 10 parameters relating to starting and doing business in a country.

India has moved 14 places to be 63rd among 190 nations in the World Bank's ease of doing business ranking released on Thursday on the back of multiple economic reforms by the Narendra Modi government. However, it failed to achieve government's target of being at 50th place.

countries in the previous ranking last year, an improvement by 23 places. The report assess improvement in ease of doing business environment in Delhi and Mumbai.

## A steady climb

India's Doing Business ranking over the years (inverse scale)




### India ranking in categories

| | 2018 | 2019 |
|---|---|---|
| **THE GOOD** | | |
| Dealing with construction permits | 52 | 27 |
| Trading across borders | 80 | 68 |
| Resolving insolvency | 108 | 52 |
| **THE BAD** | | |
| Protecting minority investors | 7 | 13 |
| Getting credit | 22 | 25 |
| Enforcing contracts | 163 | 163 |

Source: World Bank

2BHK & 3BHK Flats in Sohna
Signature Global

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# WHAT INDIA NEEDS TO DO NOW

Accelerating the Hydrogen Economy through Safety Standards & Regulations | Setting up Excellence Centers in Process Safety and Risk Management in Hydrogen Economy | Technologies for Hydrogen Production | Electrolysis technologies | Hydrogen Storage | International Hydrogen Alliance | India H2 Alliance | The 25/25 Green Hydrogen Hub Development Plan

## ACCELERATING THE HYDROGEN ECONOMY THROUGH SAFETY STANDARDS & REGULATIONS

The adoption of relevant international hydrogen standards and the development of new Indian standards, guidelines and policies for public health and safety risk associated with production, storage delivery and use of hydrogen is the need of the hour and extremely important.

The adoption of global practice will help remove barrier for India to enter the International market.

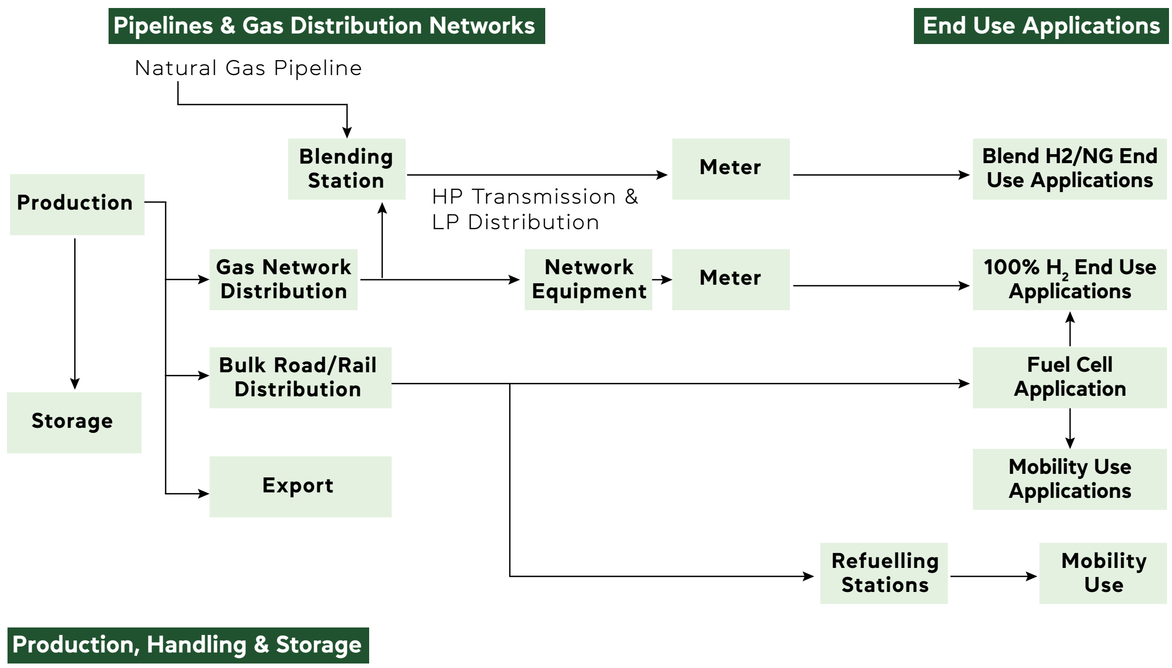
Licensing with IEC and ISO will enable India to keep abreast of hydrogen and its associated technologies, and monitor the best operating practice.

India needs to develop its standards, keeping in view international standards, so that India represents India's national interests in hydrogen technologies at ISO and IEC.

The followings areas of standards need mapping with the international standards;

- Hydrogen fuel specification
- Hydrogen production and purification by multiple processes
- Hydrogen storage, handling and transport systems both gaseous and liquid
- Hydrogen fuelling stations and associated infrastructure
- Hydrogen 'micro-grids' using pure hydrogen in a small-scale network/grid
- Hydrogen use for storage in the form of compressed gaseous, liquid and solid state such as in metal hydride, electricity generation, grid stabilisation and other electrical applications
- Hydrogen use in existing pipelines and appliances both as blends with natural gas and 100% hydrogen
- Hydrogen use in fuel cells for mobile and stationary applications
- Hydrogen export via transport vectors where not adequately covered through other standards
- Hydrogen safety systems and devices

**Flow Sheet of Hydrogen Production Distribution and Use:**



## Health and Safety Related Issues

<table>
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## Matrix of Hydrogen Production and Specification

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</table>

## RELATIONSHIP BETWEEN HYDROGEN TECHNOLOGIES

- Regulators and Certifying Bodies International Standards
- Research and Technologies
- Federal and State Governments
- International
- Community
- Industry
- Industry Bodies
- Training Organisations

## WORK INVOLVEMENT

- Review of current standards.
- Review of published international standards or guides related to appliances, components and installations for potential use.
- Monitor Indian and global research relevant to end use applications specifically for:
  - Testing of appliances with natural gas/hydrogen blends and 100% hydrogen
  - Testing of appliances used for steel, glass and cement manufacturing in the mid term

## FUEL CELL APPLICATIONS

The scope of the Fuel Cell Applications:

- Stationary fuel cell power systems for distributed power generation; and combined heat and power systems
- Fuel cells for transportation, such as propulsion systems (e.g. all-electric systems for ground vehicles, ships and aircrafts)
- Auxiliary power units
- Portable fuel cell power systems
- Micro fuel cell power systems
- Reverse operating fuel cell power systems.
- Component, sub-system and fuel cell suppliers
- Fuel cell and system installers
- Fuel cell and system manufacturers
- Testing and certification bodies
- Regulators, authorities and approval organisations
- Original equipment manufacturers.
- Review standards associated with fuel cell technologies and their associated applications; and recommend the adoption of

- IEC TC 105 standards as Indian Standards, with modifications where applicable.

- Provide technical input into IEC TC 105 international standards development, adopt global practice in fuel cell applications; keep abreast of developments in fuel cell technologies; and accelerate technology uptake within India with minimal barriers-to-entry.

## MOBILITY APPLICATIONS

The scope of the Mobility Applications including refuelling stations:

- Hydrogen fuel specification including sampling and testing protocols

- Hydrogen fuelling stations and associated infrastructure

- Refueling protocols for light, heavy and marine applications

- Hydrogen safety systems and devices

- Review and adopt (as appropriate) of ISO 19880, Gaseous hydrogen — Fuelling Stations Series.

- Monitor and assess the need for India to establish National Mirror Committees to ISO/TC 22, Road Vehicles and ISO/TC 110, Industrial Trucks and/or relevant sub-committees to facilitate hydrogen use in these sectors. Develop a proposal for membership in conjunction with the Fuel Cell Applications Working Group if appropriate.

- Review published international standards or guidance related to hydrogen refuelling facilities, both gaseous and liquid, including the impact of hazardous areas for potential use in Australia and development of content where gaps exist.

## International Safety Standards and Regulations

| | |
|---|---|
| **Federal Regulations** | |
| **OSHA Regulations 29 CFR 1910 SubpartH** | Safe storage, use, and handling of hydrogen in the workplace |
| **DOT Regulations 49 CFR 171-179** | Safe transport of hydrogen in commerce |
| **U.S. National Codes** | |
| **International Building Code (IBC)** | General construction requirements for building based on occupancy class |
| **International Fire Code (IFC)/NFPA 1 Uniform Fire Code** | Requirements for hydrogen fuelling stations, flammable gas, and cryogenic fluid storage |
| **International Mechanical Code (IMC)** | Requirements for ventilation for hydrogen usage in indoor locations |
| **International Fuel Gas Code (IFGC)** | Requirements for flammable gas piping |
| **Norway Codes and Standards** | |
| **SN / K 182** | Hydrogen Technology - This committee is responsible for following up the standardization work in CEN-CLC / TC 6 'Hydrogen in energy systems' and ISO / TC 197 'Hydrogen Technology' |
| **Indian Codes and Standards** | |
| **IS 1090: 2002** | Compressed Hydrogen - Specification (Third Revision) |
| **IS 16061: 2021/ISO 14687:2019** | Hydrogen Fuel Quality Product Specification |
| **(MoRTH, 2020) [Press Information Bureau (pib.gov.in)]** [2] | Standards for Safety Evaluation for vehicles propelled by hydrogen fuel cells, to allow testing of vehicles using higher pressure tanks, in line with international standards. |
| **Hydrogen Technologies Specific Fire Codes and Standards** | |
| **NFPA 2 Hydrogen Technologies Code** | This code provides fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH2) form or cryogenic liquid (LH2) form. Comprehensive code for hydrogen technologies constructed of extract material from documents such as NFPA 55 and 853 and original material |
| **NFPA 55 Compressed Gas and Cryogenic Fluids Code** | Comprehensive gas safety code that addresses flammable gases as a class of hazardous materials and also contains hydrogen specific requirements |
| **NFPA 853 Standard for the Installation of Stationary Fuel Cell Power Systems** | Covers installation of all commercial fuel cells including hydrogen PEM fuel cells |
| **Hydrogen Technologies Component, Performance, and Installation Standards** | |
| **ASME B31.3 and B31.12 Piping and Pipelines** | Piping design and installation codes that also cover material selection |
| **ASME Boiler and Pressure Vessel (BPV) Code** | Addresses design of steel alloy and composite pressure vessels |
| **CGA S series** | Addresses requirements for pressure relief devices for containers |
| **CGA H Series** | Components and systems |
| **UL 2075** | Sensors |
| **CSA H series of hydrogen component standards** | |
| **CSA FC1** | Stationary fuel cells |
| **SAE J2601/SAE J2600** | Dispensing and dispenser nozzles |

| Overview of Hydrogen generation Standards | |
|---|---|
| RCS Document | Matter of Subject |
| **NFPA 2 Hydrogen Technologies Code** | Chapter 13 hydrogen production |
| **NFPA 2 13.2.2 Interconnection** | Requirements for connecting system to the grid |
| **NFPA 2 13.2.4 Siting** | Structural requirements, exclusion from electrical classification zone, and safe venting per Chapter 6 |
| **NFPA 2 13.3.1.2 Ventilation** | Provisions for indoor venting |
| **NFPA 2 13.3.1.5 Indoor installation** | Setback distances for installations below and above the maximum allowable quantity |
| **NFPA 70 National Electrical Code** | Electrical requirements for classified areas |
| **CGA H-5.5** | Vent stack design including vent termination geometry |
| **ASME B31 (.3 and .12)** | Piping design for hydrogen piping systems including dimensions and materials |
| **CGA S-1. 1-1.3** | Pressure relief device design |

| List of Hydrogen Transport Standards | |
|---|---|
| Transport Method | RCS Document |
| **Hydrogen pipelines – hydrogen is covered under the scope of this part of the U.S. Department of Transportation (DOT) regulations as a flammable gas** | DOT 49 CFR Part 192 Subparts A–P cover:<br>Materials<br>Pipe design<br>Welding, joining, and corrosion control<br>Test requirements<br>Operations, maintenance, and qualification of personnel<br>Integrity management |
| **Tanker truck** | DOT 49 CFR Part 172 (provisions T75 and TP5) |
| **Rail transport** | DOT 49 CFR Part 174 |

| List of Some other International Codes & Standards | |
|---|---|
| RCS Document | Matter of Subject |
| **ISO/IEC 80079 (All parts)** | Explosive atmospheres |
| **IEC 60079 (All parts)** | Explosive atmospheres |
| **IEC 60204-1: (2005)** | Safety of machinery — Electrical equipment of machines — Part 1 General requirements |
| **IEC 60529,** | Degrees of protection- provided by enclosures (IP Code) |
| **IEC 62282-3-100** | Fuel cell technologies- Stationary fuel cell power systems. Safety |
| **IEC: TC 105** | Fuel Cell Technologies |
| **EN 13445-5,** | Unfired pressure vessels-Inspection and testing |
| **SAE J2600: 2015-08,** | Compressed Hydrogen Surface Vehicle - Fuelling Connection Devices |
| **CEN: TC 268** | Cryogenic Vessels—WG5 Specific Hydrogen Technologies Applications |

## SETTING UP EXCELLENCE CENTERS IN PROCESS SAFETY AND RISK MANAGEMENT IN HYDROGEN ECONOMY

The size of the global chemical industry exceeded $5 trillion in 2017 and is expected to double by 2030. Dependence on chemicals for technological advancement is also increasing, and many substances used to implement new technologies are dangerous. Over the past decades, consecutive major accidents have caused death, injuries, significant environmental pollution and huge economic losses.

According to the EBS database, from November 2014 to the end of June 2020, 1592 chemical occurrences were reported from 121 countries involving 252 different chemical agents. The United States is among the top five countries with the most instances detected, accounting for more than half of all events., with 322 (20.2%), followed by India with 225 (14.1%), UK with 130 (8.2%), China with 117 (7.3%) and Russia with 55 (3.5%) detected incidents, respectively.

Chemical Industrial emergencies and disasters involving highly toxic, flammable and explosive chemicals are not uncommon worldwide. India is a victim of one of the largest chemical industrial disasters 'the Bhopal gas tragedy'. On 3 December, 1984, over 40 tons of deadly Methyl Iso-cyanate (MIC) gas leaked from a Union Carbide Corporation (UCC) pesticide factory in Bhopal city, leading to the death of more than 2500 people and long-term injuries for over 300,000. Recently, the toxic gas Styrene release at the LG Polymer on 7 May 2020 (12 deaths, over 1000 injuries) reminded of the Bhopal UCC disaster that had occurred 37 years back. Industrial accidents, despite their regular occurrence in India, are not given due attention within the civil society. According to *The Hindu* news article published on 10 July 2020 during 2014-17 a total of 8004 industrial accidents in India claimed 6,300 lives. However, the spate of accidents has not abated so.

The authors in this article have collected the dates of the industrial accidents, published in Indian newspapers in the years 2020, 2021 and 2022, specifically aiming at chemical, petrochemical, pharmaceutical, steel, and power plants. The data was then collated and analysed. A shocking figure of 70+ accidents (170 deaths and 1332 injuries) for 2020 and 141+ (211 deaths and 401 injuries) for 2021 and 50+ in (January-June) 2022 (30+ deaths and 200+ injuries) accidents were noted. As these numbers are based on reported incidents, the real number may be far higher.

In India, industrial accidents data is generally available from media and press articles. Unfortunately, there is no centralised system like CSB, MARS, FACTS, etc. which documents investigate and educate people about chemical accidents in

India. The high application of hazardous chemicals in industrial processes and the day-by-day increment in frightening numbers of industrial accidents create fear in society, making these industries unpopular and unsafe. We researchers, consultants, governments, councils, and chemical industries need to create a Center of Excellence (COE) in process safety and risk management at the international level to collect industrial accident consequence analysis data and to address, train, and share development in hazardous chemicals by conducting research, education, training, mitigation programmes.

- India, recorded 1.6 million fires, 27,027 deaths, according to a 195-nation analysis by Global Diseases Burden, *The BMJ Injury Prevention* journal.
- Indian deaths number 2.5 times the figures in China.
- Process safety needs importance globally. Educational research institutions, industries, policy makers and regulatory agencies must accord the topmost priority to safety measures.
- Corporate Governance in Process Safety is inadequate.
- India has a long way to go in process safety to adopt advanced techniques and develop R&D activities.
- Training through VR is needed.
- Industrial towns, sensitive ecological zones around industries /installations need urgent attention.
- Though, industries were planned, habitant around never planned – need attention.
- Eco System in Process Safety that is missing needs constant nurturing.
- Most importantly, safety issues must be addressed for successful hydrogen technology acceptance and its deployment. Hydrogen can be used safely.
- However, because hydrogen's use as a fuel is still a relatively new endeavor, the proper methods of handling, storage, transport, and use are often not well understood across the various communities in the world.
- Centre of Excellence (COE) in Process Safety is the need of the hour.

## PROCESS SAFETY

A significant accident involving a hydrogen project could negatively impact the public's perception of hydrogen system as viable, safe, and clean alternative to conventional energy systems. However, insufficient knowledge about critical safety aspects related to the widespread roll-out of hydrogen technology presents a bottleneck for industry, authorities, end-users and the general public. Thus, if hydrogen and hydrogen-based solutions are to become viable alternatives for users, the use of hydrogen and hydrogen-based systems must be safe for the potential users to adopt new technology and new solutions.

India already has a CSIR network of 38 National Research Laboratories of which 13 plus CSIR laboratories and premium institutes like the various IITs, NITs, and universities cover a wide spectrum of science and technology in the meadow of hydrogen ecosystem. However, it does not have any centre or organisation that focuses on hydrogen safety. The commercial safe use of hydrogen needs co-ordination among the ministries and its regulatory bodies. To address the hydrogen technology and its safety challenges there is a need for the setting up of a Centre of Excellence (CoE) in Hydrogen by energy companies in India. CoE is a concept whereby industries, academics, research institutes, and knowledge partners collaborate in all aspects of R&D.

### GLOBAL DEVELOPMENTS

- Continuous research to have inherent safe and reliable design, to ensure accidents do not occur.
- In case accident occurs, minimise the damage by effective training (Virtual Reality) to firefighting team, employees, and disaster management team.
- Globally advanced 3D models used to assess risk and virtual reality (VR) to create real scenarios for training.
- Industry, government and universities/ institutes working together by developing 'center of excellence' (USA, UK, GERMANY, CHINA, NORWAY etc.)
- Corporate governance in process safety from board room to front line – making safety second nature.
- Safety Process is given the topmost priority in all activities to create strong eco system for sustainable development.
- Globally, educational institutions have joined hands with industries to develop applied research and educational programmes to improve safety/ environment in design of plants and develop educational programmes.
- The NORSOK (Norsk Sokkels Konkurranseposisjon, which means the Norwegian shelf's competitive position) standards are developed by the Norwegian petroleum industry in coordination with universities to ensure adequate safety, value addition and cost effectiveness for petroleum and other industries developments and operations. NORSOK standards serve as reference in regulations, and are considered global references in process industries.
- The University of Bergen research programme in process safety technology gives a basic understanding of current challenges in the field. The work involves analyzing measurements and evaluating the results in the light of the hypotheses that are tested. The study will give experience of oral and written presentation of results and theories, and training to read and evaluate relevant scientific literature.
- A team of global scientists worked with University of Bergen on several research projects and developed revolutionary Computational Fluid Dynamics (CFD) technologies to provide the best risk analysis using validated three-dimensional advanced computer models based on actual fire and explosion studies carried out at test site. Flame Acceleration Simulator (FLACS) computer codes based on computational fluid dynamics is

considered as global standard in carrying out dispersion, fire and explosion studies.

## CREATING ECO-SYSTEM OF PROCESS SAFETY IN INDIA

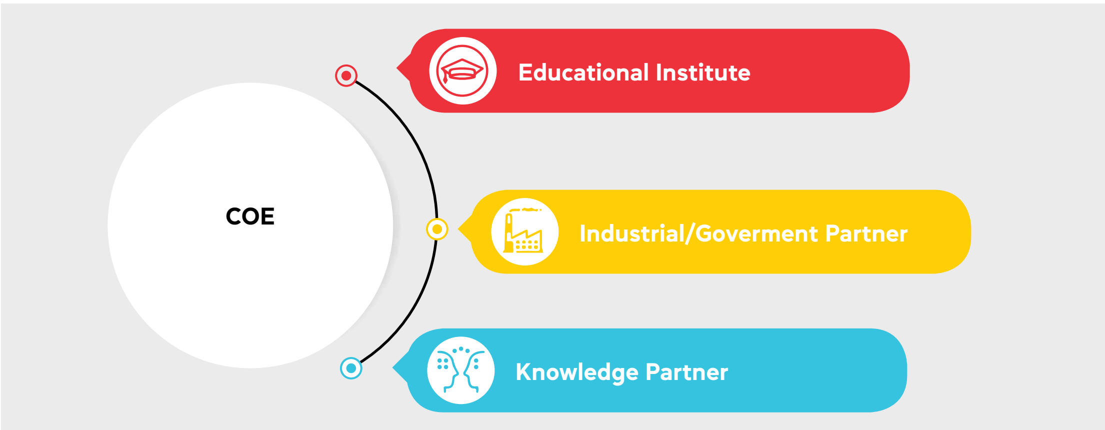
- 'COE' is a centre for higher knowledge and learning.
- Educational institutes, industries and government join to set up 'COE'.

## SCOPE ACTIVITIES OF 'COE'

- Promote education, research, and support industries and regulatory authorities.
- Offer services to industries in process safety studies.
- Work during process design organisation for safe and reliable designs.

## ADDRESSING CHALLENGES IN H2 VALUE CHAIN AND ITS SAFETY

- To address the challenges in hydrogen value chain and its safety, there is need for the setting up of a Centre of Excellence (COE) in Hydrogen by GOI in partnership with academia and industry in India.




| Centre of Excellence | | | |
|---|---|---|---|
| COE is Centre for higher knowledge and learning | | | |
| **Scope of Activities of 'COE'** | **Structure of COE** | | |
| Promote education, research and support industries & regulatory authorities.<br>Offer Services to Industries in Process Safety Studies.<br>Work towards process design optimization for safe and reliable designs | **International Support**<br>Green Hydrogen-Technology Partner<br>Hydrogen and Process Safety Partner | **Industries/R&D Centres/ Knowledge Consultants**<br>Consultants | **Academic Partner** |

## COE GOALS AND OBJECTIVES

### Hydrogen Process Safety

- The COE will take initiatives to develop higher education and research in basic and fundamental research, need of the industries, support of regulatory authorities to maintain international best practices and at the same time build awareness and expertise about regulatory and compliance needs for the process safety and protection of human life, infrastructure, and environment through international conferences.

- The COE will collaborate with world-class universities in Process Safety and Risk Management as well as join hands with the research laboratories of Ministry of New and Renewable Resources, Ministry of Petroleum, Government of India, CSIR laboratories such as IIP Dehradun, NCL and NEERI Nagpur.

- The COE will enable scientific and industrial partners to work together in developing new innovative solutions.

- The COE will help regulatory authorities to upgrade Indian standards with international standards for fires, explosions, and toxic releases.

- The COE will develop expertise in forensic audits of accidents.

- The COE will be the best in the world in line with similar global COEs and will contribute in innovation solutions to prevent accidents in Indian/ global industries.

## THE COE SHALL HAVE THE FOLLOWING OPERATIONAL VERTICALS

- Advanced laboratory for research (High Performance Computing Clusters, Explosivity Testing Laboratory, Virtual Reality Laboratory)

- Support to regulatory authorities to develop new regulations.

- Research collaborations/tie-ups.

- Cover entire hydrogen value chain from R&D to technology development, patent rights, start-ups, pilot plants and to industry led scale-ups.

## TECHNOLOGIES FOR HYDROGEN PRODUCTION

**There are several processes for hydrogen production, namely:**

**Thermal processes:** Use the energy in various feed stocks i.e. natural gas, coal and biomas to release hydrogen that is the part of their molecular structure. thermo-chemical processes use heat in combination with a closed chemical cycle to produce hydrogen from water. Steam reforming of natural gas is the main thermal process for hydrogen production. The process involves reaction of natural gas and steam over nickel based catalyst. The process breaks methane component of the natural gas into carbon monoxide (Cr) and $H_2$ gas.

**Electrolytic processes:** These processes use electricity to split water into chemical constituents hydrogen and oxygen (O2) using electrolyser.

**Photolytic Processes:** These processes use light energy to split water into hydrogen and oxygen.

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

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

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

## ELECTROLYSIS TECHNOLOGIES

**Water Electrolysis**

- It is the simplest form by using two electrodes in water and passing electrical current. Water is split into hydrogen and oxygen. The water electrolysis method can be divided into three different types of the electrolyte—alkaline, proton exchange membrane (PEM), and solid oxide electrolysers (SOE). The Table below has listed the typical specifications of the water electrolysis technologies methods. The commercial low temperature electrolysers were developed and have efficiencies of (56% - 73%) at conditions of (70.1 - 53.4 kWh · kg–1 H2 at 1 atm and 25°C) . Alkaline electrolysis systems are the most commonly compared to other water electrolysis methods. Solid oxide electrolysis (SOE) is the most electrically efficient but still are under development. Corrosion, seals, thermal cycling, and chrome migration are the major challenges faced by the SOE technology. The Proton exchange membrane (PEM) electrolysis systems are more efficient than alkaline electrolyser. Also, corrosion and seals issues don't exist as (SOE), but the cost of (PEM) is too high compared with alkaline electrolysers systems. Alkaline electrolyser systems have the lowest capital cost and have the lowest efficiency so the electrical energy cost is too high. Recently, electrolysers used for producing pure hydrogen and high pressure units have been developed.

The advantage of using the high pressure operation unit is to eliminate using expensive hydrogen compressors. The hydrogen production using the water electrolysis systems have shown too high a cost to generate hydrogen on large scale using the water electrolysis method. Additionally, the water electrolysis systems utilise non-renewable power generation source to produce electricity for the water electrolysis systems.

**Alkaline Electrolyser**

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

| THE TYPICAL SPECIFICATIONS OF ALKALINE, PEM AND SOE | | | |
|---|---|---|---|
| Specification | Alkaline | PEM | SOE |
| Technology maturity | State of the art | Demonstration | R & D |
| Cell temperature, ˚C | 60 - 80 | 50 - 80 | 900 - 1000 |
| Cell pressure, bar | <30 | <30 | <30 |
| Current density, A/cm² | 0.2 - 0.4 | 0.6 - 2.0 | 0.3 - 1.0 |
| Cell voltage, V | 1.8 - 2.4 | 1.8 - 2.2 | 0.95 - 1.3 |
| Power density, W/cm² | Up to 1.0 | Up to 4.4 | - |
| Voltage efficiency, % | 62 - 82 | 67 - 82 | 81 - 86 |
| Specific system energy consumption, kWh/Nm² | 4.5 - 7.0 | 4.5 - 7.5 | 2.5 - 3.5 |
| Partial load range,% | 20 - 40 | 0 - 10 | - |
| Cell area, m² | <4 | <300 | - |
| Hydrogen production, Nm²/hr | <760 | <30 | - |
| Stack lifetime, hr | <90,000 | <20,000 | <40,000 |
| System lifetime, yr | 20 - 30 | 10 – 20 | - |
| Hydrogen purity, % | >99.8 | 99.999 | - |
| Cold start-up time, min | 15 | <15 | >60 |

**Proton Exchange Membrane Electrolyser**

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

**Solid Oxide Electrolyser**

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

**Biomass**

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

**Biomass Gasification Process**

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

**Biological Hydrogen Production Process**

- This is another biomass method to produce hydrogen gas fuel using biological technologies. It can be utilised using the anaerobic bacteria which is grown in the dark fermentation bioreactors. Algae can be used in the light or photo fermentative process. The main processes include photolytic process to produce hydrogen from water using green algae, the hydrogen production using dark-fermentative process of anaerobic digestion, the two-stage dark/fermentative process, photo-fermentative processes and WGS method for hydrogen production. By using anaerobic microorganisms dark fermentation reaction is carried out to convert the carbohydrate to hydrogen and other final products. Biological Hydrogen Production Process limits the low hydrogen production capacity compared with unit capital investment. This is the major challenge of the dark fermentation method.

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

## HYDROGEN STORAGE

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

Liquefaction of hydrogen requires a significant energy input as the boiling point of hydrogen is very low (253$^0$C) but liquid hydrogen provides comparatively a high storage density. Liquefaction consumes about 30% of hydrogen energy. The high volumetric density is the main advantage of liquid hydrogen storage.

Another means of hydrogen storage is adsorption which exhibits van der Waals bonding between hydrogen molecules and materials that store hydrogen in the

solid phase. Metal hydrides and chemical hydrides exhibit these reactions and operate at low pressure.

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

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

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

## STORAGE TANKS

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

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

## HYDROGEN STORAGE PROJECTS UNDERTAKEN IN INDIA

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

There are some problems for hydrogen storage such as:

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

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

## RESEARCH AND DEVELOPMENT IN HYDROGEN STORAGE IN INDIA

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

## LIQUEFACTION

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

In this storage method, first gas phase is compressed at high pressure then liquified at cryogenic temperature in liquid hydrogen tank ($LH_2$). The condition of low temperature is maintained by using liquid helium cylinder. Hydrogen does not liquefy until -253 °C (20 degrees above absolute zero). Therefore, such high energy must be employed to achieve this temperature. However, issues remain with $LH_2$ tanks due to the hydrogen boil-off, the energy required for hydrogen liquefaction, volume, weight, and high tank cost. About 40% of the energy content of hydrogen can be lost due to the storage methods. Safety is also another issue with the handling of liquid hydrogen as does the car's tank integrity, when storing, pressurizing and cooling the element to such extreme temperatures.

## SOLID STATE HYDROGEN STORAGE

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

In these systems, hydrogen molecules are stored in the mesoporous materials by physisorption (characteristic of weak van der Waals forces). In the case of physisorption, the hydrogen capacity of a material is proportional to its specific surface area. The storage by adsorption is attractive because it has the potential to lower the overall system pressure for an equivalent amount of hydrogen, yielding safer operating conditions.

The advantages of these methods are that the volumetric and cryogenic constraints are abandoned. In recent decades, many types of hydrogen storage materials have been developed and investigated, which include hydrogen storage alloys, metal nitrides and imides, ammonia borane, etc.

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


## INTERNATIONAL HYDROGEN ALLIANCE

The establishment of an 'International Hydrogen Alliance', to create greater synergies between science, technology and entrepreneurship in order to create win-win for all, inspired by the International Solar Alliance (ISA), would be a good way to attract partnerships with countries with common goals and complementary competency. Norway has already shown interest in the formulation and collaboration of such a venture.

To succeed with necessary and rapid technology transfer and development, increased global cooperation is needed. No single country can complete the entire value chain for hydrogen and thus, there is a need for cooperation among countries to secure markets and make green energy available at the earliest opportunity. At the 2021 United Nations Climate Change Conference (COP 26) in Glasgow the Indian Government should have put forward the development of an International Hydrogen Alliance. This alliance would serve the global community, making green energy available as soon as possible by bringing the world's organisations together on one platform.

No single country or single company can achieve excellence in the entire value chain of green hydrogen. In view of this, there is a need for alliance between several developed nations, who have offered their support to India in the transition journey of becoming a carbonless country.

## COLLABORATION WITH GERMANY

Germany in May 2022 committed additional 10 billion euros assistance to India to help achieve climate action targets set for 2030, which includes sourcing 50% energy requirement from renewables and installing 500 GW of non-fossil fuel electricity capacity.

'Germany intends to strengthen its financial and technical cooperation and other assistance to India with a long-term goal of at least 10 billion euros of new and additional commitments till 2030 under this Partnership (for green and sustainable development),' said a joint statement issued after the sixth India-Germany Inter-Governmental Consultations (IGC) here.

The joint statement was issued after talks between Prime Minister Narendra Modi and German Chancellor Olaf Scholz.

Both Mr Modi and Mr Scholz said the Indo-German Cooperation on Sustainable Development and Climate Action was guided by their commitments under the Paris Agreement and the SDGs, including making efforts to limit the increase in the global average temperature to well below 2 degrees Celsius above pre-industrial levels and to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels.

## COLLABORATION WITH USA

The United States and India have a long and successful strategic partnership in the energy sector. The energy cooperation between the two countries, which is technical, economic, and bilateral, is strengthening year after year.

In November 2009, the United States and India launched the Partnership to Advance Clean Energy (PACE), which is working to accelerate inclusive, low carbon growth by supporting research and deployment of clean energy technologies. During their first bilateral summit in September 2014, Hon'ble Prime Minister, Mr Narendra Modi, and the US Hon'ble Former President, Mr Barack Obama, announced a commitment to strengthen and expand PACE through a series of priority initiatives. When the two leaders met again in January 2015, they announced several new activities under PACE.

Over the past year, India has revised its renewable energy target to 175 GW by

2022. The national solar target was scaled up by five times, reaching 100 GW by 2022, of which 40 GW is expected to come from solar rooftop. The activities of the PACE initiative are aligned to support India's ambitious clean energy targets.

In 2021, at the Leaders Summit on Climate, the United States and India launched the US-India Climate and Clean Energy Agenda 2030 Partnership. Led By Hon'ble President, Mr Joe Biden, and Hon'ble Prime Minister, Mr Narendra Modi, the partnership represents one of the core venues for U.S.-India collaboration and focus on driving urgent progress in this critical decade for climate action. Both the United States and India have set ambitious 2030 targets for climate action and clean energy. In its new nationally determined contribution, the United States has set an economy-wide target of reducing its net greenhouse gas emissions by 50–52 percent below 2005 levels in 2030. As apart of its climate mitigation efforts, India has set a target of installing 450 GW of renewable energy by 2030. Through the Partnership, the United States and India are firmly committed to working together in achieving their ambitious climate and clean energy targets and to strengthening bilateral collaboration across climate and clean energy.

The partnership aims to mobilise finance and speed up clean energy deployment; demonstrate and scale innovative clean technologies needed to decarbonise the sectors including industry, transportation, power, and buildings; and to build capacity to measure, manage, and adapt to the risks of climate-related impacts. The partnership proceeds along two main tracks: the Strategic Clean Energy Partnership and the Climate Action and Finance Mobilisation Dialogue, which builds on and subsumes a range of existing processes. Through this collaboration, the United States and India aim to demonstrate how the world can align swift climate action with inclusive and resilient economic development, taking into account national circumstances and sustainable development priorities.

## COLLABORATION WITH NORWAY

'Norway and India have a long tradition of cooperation in a variety of fields, including a number of joint projects on climate change and the environment.

'Norway offers expertise in areas such as electrification, smart grids and renewable energy financing. Norwegian participation in the clean energy sphere in India is expanding, particularly in the private sector.

Norway has decided to become a member of the International Solar Alliance, an initiative of India aimed at promoting renewable energy and sustainable development. Membership of the ISA will increase the visibility of India as a market for Norwegian companies.

## COLLABORATION WITH THE UNITED KINGDOM

To ensure the Glasgow Climate Pact is brought to life, the UK is committed to working with India to achieve its goals and is already facilitating British electric vehicle companies to set up manufacturing hubs in India.

Ahead of COP26, the UK pledged $1 billion investment from British Investment International into Indian green projects over the next five years and announced a guarantee for $1 billion World Bank lending to India. International Trade Secretary Anne-Marie Trevelyan launched the Clean Growth programme to encourage more UK exporters to tap into a sector expected to be worth £1.8 trillion by 2030. The intent is to encourage clean growth businesses to start exporting their innovation globally. We also launched 'Climate Finance Leadership Initiative India', a private sector group led by Bloomberg and Tata, to move quickly to identify catalytic investments into Indian green projects.

India and the UK already have a strong history of partnership on climate, ranging from knowledge exchange and innovation in areas like electric mobility and power sector reform to climate resilience. In May 2021, our Prime Ministers agreed to enhance the adoption of electric mobility. They also adopted an ambitious India-UK Roadmap to 2030 to steer cooperation for the next ten years. They emphasized that enhanced India-UK bilateral cooperation cannot only reap mutual benefits but also be a global force for good to revive lives and livelihoods, promote peace and prosperity around the world and protect and preserve the planet for the future generations. Given that climate is also one of the pillars of the India-UK 2030 Roadmap Agreement, a continuous collaboration between the UK and India will be vital. Looking ahead, offshore wind is another foreseeable area to boost collaboration.

The UK is also investing in India's clean energy transition and mobilizing public and private sector investment into green finance. The UK has invested over £67 million to date in projects on solar energy, water, climate and more. Plus, the Green Growth Equity Fund (GGEF), a joint investment of £120 million from both India and the UK, is now the largest single-country emerging market climate fund in the world. Together, this has enabled an additional installed capacity of 413 MW of renewable energy, mitigated 1.14 million tonnes of greenhouse gas emissions, and created over 53,000 jobs.

## COLLABORATION WITH JAPAN

In March, 2022 in a bid to achieve sustainable economic growth, and ensure energy security in areas of electric vehicles, India and Japan have launched a Clean Energy Partnership (CEP). The Ministry of External Affairs said the partnership will lead to clean growth by boosting job creation, innovation, and investments.

'Cooperation under this partnership will build on the work already being covered out by the two sides under the foundation of the 'India-Japan Energy Dialogue' established in 2007 and will substantially expand the areas of collaboration for mutual benefit,' the statement further said.

The initiative was launched on the 14th India-Japan Annual Summit held in New Delhi. The two countries committed to continuing further discussions for establishing the Joint Crediting Mechanism (JCM) between India and Japan for the implementation of Article 6 of the Paris Agreement.

Besides, they also reaffirmed their determination to promote environmental cooperation in other areas.

'The Prime Ministers, building on the outcome of COP26, recognized the importance and imminence of tackling climate change and shared the importance of various pathways for pragmatic energy transitions reflecting different national circumstances and constant innovation to achieving global net-zero emission,' the joint statement said.

## COLLABORATION WITH AUSTRALIA

India and Australia in February, 2022 inked a letter of intent for working together towards reducing the cost of new and renewable energy technologies and scaling up their deployment to reduce emission globally.

This LoI will pave the way for working towards reducing the cost of new and renewable energy technologies and scaling up their deployment in order to accelerate global emissions reduction, it stated.

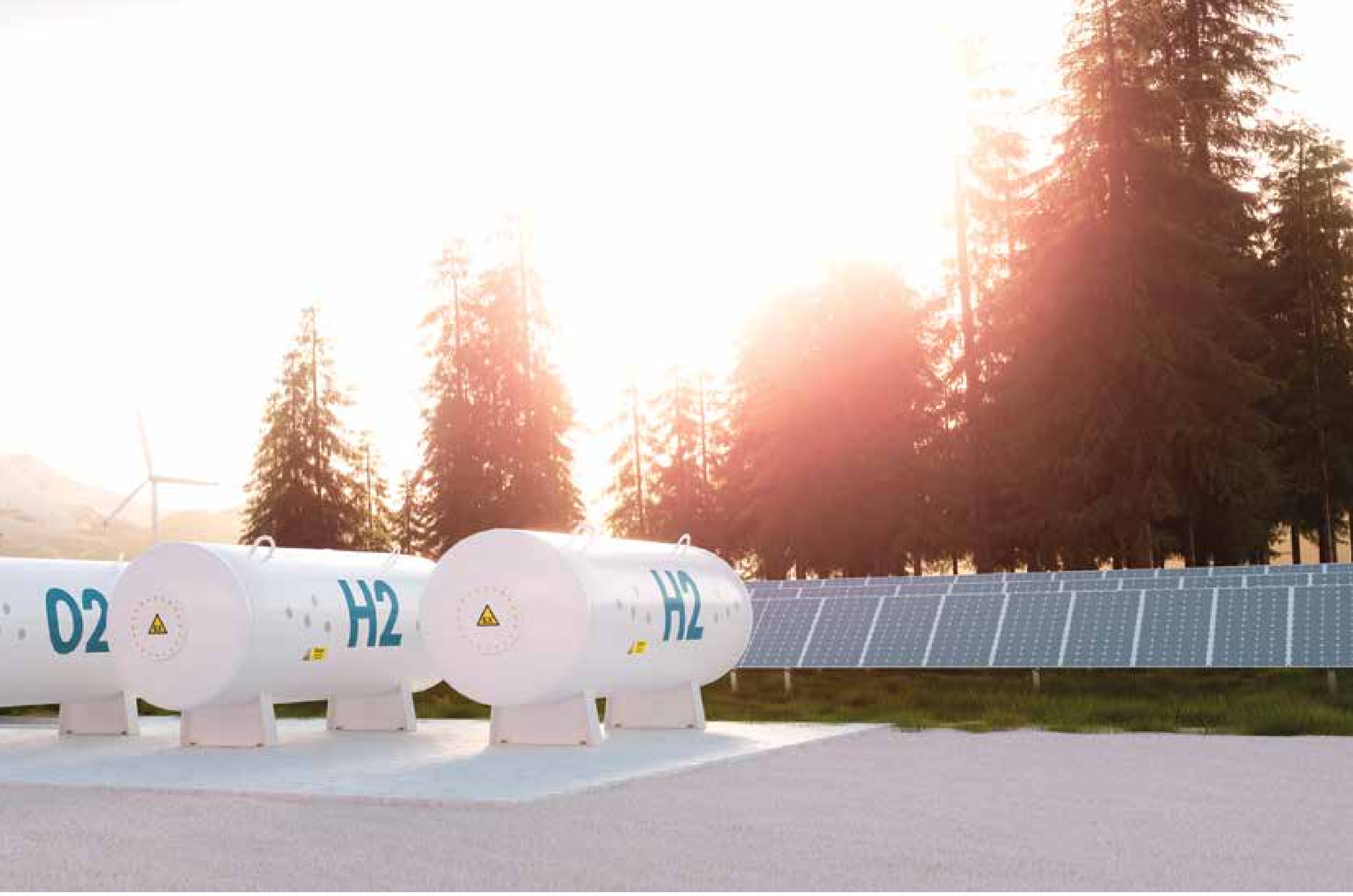
The focus of this LoI will be scaling up manufacturing and deployment of ultra low-cost solar and clean hydrogen, it stated.


## INDIA H2 ALLIANCE

Global energy and industrial majors have come together to form a new energy transition coalition, the India H2 Alliance ('IH2A'), focused on commercializing hydrogen technologies and systems to build net-zero carbon pathways in India. The India H2 Alliance will work together to build the hydrogen economy and supply chain in India and help develop blue and green hydrogen production and storage as well as build hydrogen-use industrial clusters and transport use-cases with hydrogen-powered fuel cells. The India H2 Alliance will focus on industrial clusters, specifically steel, refineries, fertilizer, cement, ports and logistics; as well as heavy-duty transport use- cases and the establishment of standards for storage and transport of hydrogen in pressurized and liquified form.

The India H2 Alliance will work with the government on five areas:

- Develop a National Hydrogen Policy and Roadmap 2021-2030.
- Create of a National H2 Taskforce and Mission in a public-private partnership format.
- Identify National Large H2 Demonstration-Stage Projects.




- Help to create a national India H2 Fund.

- Create hydrogen-linked capacity covering hydrogen production, storage and distribution, industrial use-cases, transport use-cases and standards.

Alliance between PHD Chamber of Commerce and Industry and Greenstat Norway addressed following key issues:

- Centre of Excellence between Greenstat India Pvt. Ltd. and Indian Oil Corporation in R&D.

- Centre of Excellence in Process Safety and Risk Management at IIT Delhi.

- Centre of Excellence at SRIRAM Institute of Industrial Research, New Delhi for research in green hydrogen cooking stove, R&D in hydrogen storage area, and Process Safety and Standards at SRIRAM Institute.

- Centre of Excellence at SRICT University (UPL), Ankleshwar in Process Safety and Risk Management.

- Setting up of a factory for electrolysers, alkaline, Pem, and solid oxide. It is the first factory in India for electrolysers.

# The 25/25 Green Hydrogen Hub Development Plan was submitted by IH2A to NITI Aayog and the Ministry of New and Renewable Energy, Government of India


**By Pravin Prashant**

Industry body India Hydrogen Alliance (IH2A) has proposed public finance support of US $360 million over the next three years for creation of 25 National Green Hydrogen Projects and creating a National Hydrogen Development Corporation.

IH2A is planning a 25/25 National Green Hydrogen hub development plan for creation of 25 National Green Hydrogen projects and five national H2 hubs by 2025.

The 25/25 Green Hydrogen Hub Development Plan was submitted by IH2A to NITI Aayog and the Ministry of New and Renewable Energy, Government of India.

IH2A is focusing on creating scalable green hydrogen projects and hubs that can grow to gigawatt-scale projects in three years.

As per plan, India should build at least 25 scalable green hydrogen projects, aggregating to 150 MW installed electrolyser capacity by 2025, designated first-generation 'national green hydrogen projects' – 12 industrial decarbonisation projects in chemicals, refinery, steel industries; three heavy-duty transport projects, three H2-blending in CGD projects and seven distributed waste-to-H2 municipal projects.

Five National Green Hydrogen hubs in Gujarat, Karnataka, Maharashtra, Kerala and Andhra Pradesh; clustering the 25 Green Hydrogen projects where multi-sectoral demand for green hydrogen can be produced and used, without building expensive new infrastructure in the next three years.

Public finance support of US $360 million over next three years from Government of India for capital expenditure on electrolysers, balance-of-plant (BoP) equipment; and a green hydrogen price support of US $2 per kg of H2 in first-generation green hydrogen projects. Public funding is important for inducing early-stage green hydrogen demand and supporting first-generation projects that create public project development experience which can be applied to the next generation of scaled-up projects, after 2025.

Speaking on the 25/25 National Green Hydrogen Hub Development Plan, Jill Evanko, Chief Executive and President, Chart Industries and founding member, IH2A said, "This is a blueprint of how the green hydrogen economy can be developed over the next three years in India. The estimated US $ 360 million public finance support in project development will help India quickly commercialize green hydrogen projects at scale in the region. Government support for hydrogen project development contributes to further investment from both global green climate investors and the private sector."

Speaking on key challenges in the short term, Sanjay Mashruwala, President, Reliance, and IH2A member said, "The next few years will be critical for rapidly developing expertise and developing end to end green hydrogen ecosystem. While individual industrial groups can execute some aspects of green hydrogen projects at scale, developing a national hydrogen end-to-end ecosystem – from renewable power, electrolysis, storage, logistics, and consumption will require collaboration across the industry as well as in the form of stronger public-private partnerships. The 25/25 Green H2 Hub Development Plan lays out a roadmap for this to be achieved."

Elaborating on identified national hubs in the 25/25 plan, Prabodha Acharya, Chief Sustainability Officer, JSW Group and IH2A member said, "The 25/25 Plan shows a pathway for India to leverage green hydrogen for industrial decarbonisation in hard-to-abate sectors. Industrial majors must collaborate and co-build the green hydrogen economy through national hubs, as has been demonstrated in the plan. This goes beyond individual actions for green hydrogen commercialisation and longer-term net-zero action plans announced by companies. We will lead by example in the steel and cement sector, by helping build these national hubs."

Speaking on preparation of the 25/25 Green Hydrogen Hub Development Plan, Amrit Singh Deo, Senior Managing Director, FTI Consulting, and IH2A Secretariat lead said, "The 25/25 plan addresses immediate project development priorities by providing a pathway to first 150 MW that will help India learn, improve, collaborate, and build scalable GW-scale green hydrogen projects in the 2025-30 period. It benefits government and industry decision makers so that they can commercialize green hydrogen in a focussed, cost-effective manner. The proposed public spending is a fraction of what other economies are spending."

# INDO NORWAY ALLIANCE FOR GREEN HYDROGEN

Norway's Hydrogen Strength |
Norway's Technologies on Green Hydrogen | norwegian support to make india self-reliant in green hydrogen


## NORWAY'S HYDROGEN STRENGTH

For over a century, Norway, often called an 'energy nation', has worked hard to create value from its natural resources; first hydropower, later oil and gas. This green transition is giving rise to new opportunities and challenges within the energy sector. To meet its emission targets, Norway will need to leverage its long experience with hydrogen, but at the same time, also promote new developments through collaboration across borders and value chains. In this chapter, we present Norway's hydrogen history in broad strokes and highlight the current developments that position the country as a knowledge and technology provider for the future global hydrogen economy.

### NORWAY'S HYDROGEN HISTORY: ALMOST 100 YEARS OF EXPERIENCE

The first instance of hydrogen production in Norway dates back to 1926 when a small ammonia plant at Notodden was established by Hydro, back then, a fertiliser producer. Much of the technology in the ammonia plant was American, but Norwegian engineers in Hydro played an active role in developing and improving the process of production. Among other things, it was decided that hydrogen produced by water electrolysis should be used for the process.  Developed in Norway, the process was very power-intensive but gave pure hydrogen in return.

When the small factory in Notodden was built, it was intended as a supplement to Birkeland and Eyde's arc process to produce nitrogen fertiliser. This innovative technology laid the foundation for the establishment of Norsk Hydro in the year 1905 and contributed to the development of the industrial communities in both Notodden and Rjukan.

In the year 1927, to combat rising costs, the Birkeland-Eyde process had to be substituted by the far more efficient Haber-Bosch process. With the locally developed electrolysis process based on cheap Norwegian hydropower, Norsk Hydro continued to produce ammonia to serve the fertiliser plant at Herøya. The water electrolysis plant at Vemork, completed in 1928, became the largest in the world reaching a capacity of 30,000 $Nm^3$ $H_2$/hour in 1953. Another plant was also established at Glomfjord in 1947.

During World War II, a covert operation by the Norwegian military sabotaged the Vemork plant. The factory had the technology to produce heavy water which could be used to manufacture nuclear weapons. The operation was executed in the year 1943 to mitigate the risk of German military gaining access to the technology. In the year 1977, the hydrogen plant at Vemork was demolished and the production of hydrogen was transitioned to fossil-based steam reforming, a cheaper alternative though not low-emission. The last Norwegian electrolysis plant was shut down in the year 1993.

However, the electrolysis technology developed for the plant at Vemork did not get lost to time. Instead, Hydro continued to develop the electrolysers, and in 2011 established NEL as a separate entity. Today, NEL is one of the leading electrolyser manufacturers in the world and expanding its production capacity in Norway to meet the rising demand for reliable electrolyser systems worldwide.

## NEW DEVELOPMENTS: LARGE SCALE LOW-CARBON HYDROGEN PROJECTS AND R&D EFFORTS

Norwegian research institutions were active in collaborative programmes on hydrogen and fuel cell research under the International Energy Agency (IEA) and European framework programmes since their inception. From the 1980s, SINTEF took a leading position, and in 1996 the Norwegian Hydrogen Association was established. One of its first flagship projects was a feasibility study by Shell and Aker Kværner in 2002-03, for a demonstration plant at Kollsnes, outside Bergen. The concept was to apply Solid Oxide Fuel Cell (SOFC) technology, using natural gas as the primary energy source. The project was considered a success, but the follow-up would cost around 150 million NOK (OECD, 2006) and the plans for a 6 MW Kollsnes II plant were not realized. In 2021, ZEG Power and Coast Center Base (CCB) announced a partnership to produce blue hydrogen with integrated carbon capture. It would be connected to the large-scale open-source $CO_2$ transport and storage infrastructure Northern Lights.

The Utsira project, which combined windmills with fuel cells for power generation, was set up in 2004. The demonstration received a lot of attention. As the world's first 'hydrogen society', the island community would be self-sufficient and independent from the national grid. The plant was established by Norsk Hydro in collaboration with Enercon. The system efficiency for hydrogen production was 53%. However, wind utilization was low, and the fuel cell would have to be improved to make the project commercially viable.

The most distinguishable project in this early phase was HyNor, where Statoil and Norsk Hydro joined efforts to carry out a market-realistic demonstration of hydrogen refuelling stations and vehicles. This was met with national support. The first station opened in 2006 near Stavanger, the second in Porsgrunn (Grenland) in 2007, and two more stations were opened in Oslo and Lier, near Drammen, in 2009. Since 2010-11, the scale of Battery Electric Vehicles (BEVs) in Norway took off. As a result, the international producers prioritised other markets for Fuel Cell Electric Vehicles (FCEVs). The market penetration of FCEVs remains negligible compared to BEVs today, but the National Hydrogen Strategy published by the Norwegian Government in 2020 marks a new beginning for hydrogen as an energy carrier in Norway.

## LARGE SCALE HYDROGEN PRODUCTION PLANS IN NORWAY

Several initiatives are being taken to establish large scale hydrogen production for its use as an energy carrier. The projects vary in maturity, energy source, capacity, and potential users. Some examples of current projects are being discussed further. Other important projects have been announced, and more are expected as plans for zero-emission solutions accelerate.

### WIND AND HYDROGEN INTEGRATION

Located at the Varanger peninsula in northern Norway, the 45 MW Raggovidda wind farm was commissioned in 2014. Due to capacity constraints in the grid, the owner company, Varanger Kraft, has identified hydrogen production as an opportunity for value creation. A large innovation project funded by the EU called HAEOLUS (Hydrogen-Aeolic Energy with Optimised electrolysers Upstream of Substation) aims to demonstrate control strategies for wind-hydrogen systems that enable wider penetration of renewable energy in the European grid. The grand opening of the project was organised on 15 June 2022.

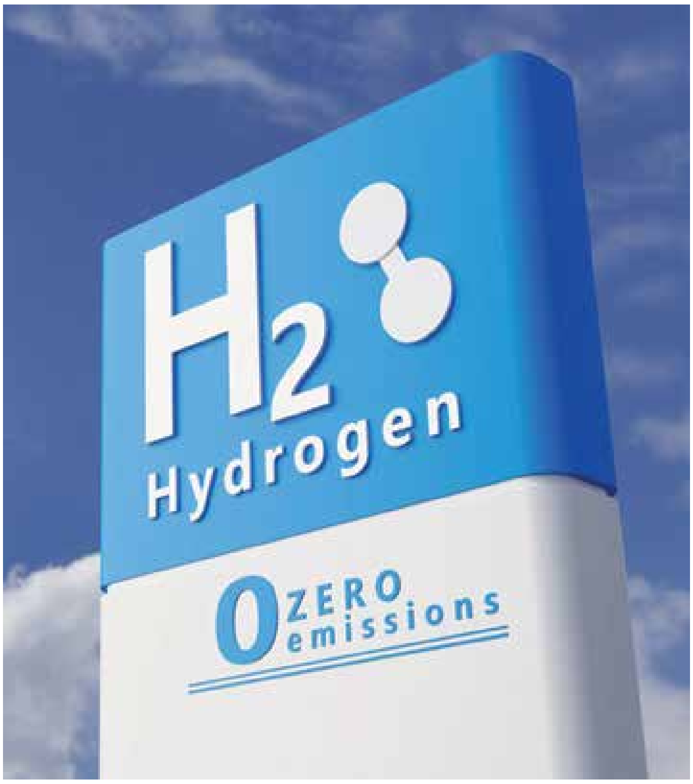
> ## HYDROGEN AS AN INDUSTRIAL FEEDSTOCK
>
> Since 1986, TiZir Titanium & Iron Ilmenite plant has produced titanium products and high-purity pig iron with reduction by coal. Greenstat, together with energy company Sun Hordaland Kraftlag, completed a study on using green hydrogen instead of coal as feedstock to reduce $CO_2$ emissions by almost 90 %. The TiZir project has been awarded an Important Project of Common European Interest (IPCEI) status by the EU. A full-scale pilot demonstration of the project is planned within the next 5 years.

### GLOMFJORD HYDROGEN

The small town of Glomfjord used to host one of the largest water electrolysis plants in the world between 1949 and 1993. In recent years, a push to re-establish large scale hydrogen production has been led by Greenstat. The planned capacity of renewable hydrogen is 6 tons per day or 2190 tons per year. Lack of identified customers has been the main obstacle, but potential customers include ferries, fleet vehicles, railways, heavy-duty transport, and nearby industry.

### RESEARCH AND DEVELOPMENT ACTIVITIES

In Energi21, Norway's national strategy for research, development and commercialisation of climate-friendly energy technology, hydrogen is a




recommended area for investment. Through the Research Council of Norway, Innovation Norway and Enova, the authorities are contributing to the research, development, and demonstration of zero-emission technologies for transport, including hydrogen.

MoZEES (Mobility Zero Emission Energy Systems), a Centre for Environment-friendly Research (FME), funded by the Research Council of Norway is helping to improve knowledge about battery and hydrogen technologies in the transport sector through research measures such as helping to design and develop safe, reliable, and cost-effective zero-emission solutions and propulsion systems for the transportation of heavy goods.

Norway's state aid schemes have funded several pilot schemes and demonstration projects for hydrogen and support the government's objective to increase the number of pilot and demonstration projects. Through the Zero Emissions Fund that was established in the year 2019, Enova will also provide funding for vehicles and vessels.

In 2022, two new Centres for Environment-friendly Energy Research (FME) were awarded by the Norwegian Research Council to carry out targeted long-term hydrogen research. The HyValue and HYDROGENi centres are funded for eight years and will address hydrogen value chains for maritime use, scalable hydrogen production for export, transport and storage solutions, applications, and safety. Several Norwegian research institutes and universities have facilities adapted to answer important research questions for the hydrogen value chain and to accelerate industrial development. The Norwegian Fuel Cell and Hydrogen centre is located in Trondheim and Kjeller and operated by Sintef and IFE. These laboratories are equipped to test fuel cells and electrolysers under different operating conditions and as a part of fully integrated systems.

The Trondheim laboratory houses low and high-temperature test facilities for fuel cells and electrolysers in single-cell or short stack configurations. As a complement, the Systems Laboratory at Kjeller enables fully integrated power system tests with battery modules, fuel cell systems and water electrolysers connected to the grid. In addition, the facility includes a process room for testing and development of continuous hydrogen production by sorption-enhanced reforming of methane with an integrated process for $CO_2$ capture. The Sustainable Energy Catapult Centre located in Stord, not far from Bergen, enables testing of a wide range of renewable energy technologies, as well as fuel cells.

Most of the technology development and future demand for hydrogen solutions will come from outside Norway. It is therefore important for the Norwegian authorities and Norwegian research and technology communities to participate internationally, both to benefit from what is happening outside Norway, and to participate internationally by providing knowledge and technology.

## HYDROGEN SAFETY REGULATIONS IN NORWAY

Norway has a strong safety culture, in large part due to developments in the oil & gas sector. Mitigating risk in hydrogen projects is critical to enabling a viable and sustainable green transition. Experience gained through hydrogen projects will be important for the Norwegian authorities to develop regulations. In general, the reigning principle for hydrogen safety follows the 'As Low As Reasonably Practicable' (ALARP) principle. Regulations are 'functional-based' hence, there are very few prescriptive regulations stating how a hydrogen plant should be built and operated. Instead, the full responsibility to build, operate and decommission any facility handling dangerous goods is placed on the owner and operator of the facility. It is up to them to document that the safety level is within satisfactory safety levels.

The Norwegian Directorate for Civil Protection (DSB) is responsible for ensuring that the handling of ignitable, pressurised, and explosive substances is done according to society's need to ensure the safety of life, health, and infrastructure. Standard Norway's mirror committee SN/K 182 Hydrogen technology monitors the standardisation work of CEN-CLC/TC 6 'Hydrogen in energy systems' and ISO/TC 197 'Hydrogen Technology'. The committee works with experts in working groups set up by the ISO and CEN and receives drafts of new standards to comment and vote on.

DSB is also the specialist authority for the road transport of hazardous goods and is responsible for electrical safety, i.e., requirements for the safe design and use of distribution networks and electrical systems. These also include hydrogen production systems, storage batteries, charging stations for electric vehicles and shore connections for ships. DSB also administers the regulations that set out requirements governing the design of electrical systems onboard ships.

## NORWAY'S TECHNOLOGIES ON GREEN HYDROGEN

There is a global agreement that renewable and low-carbon hydrogen will be a key energy carrier in tomorrow's energy world system, as well as a feedstock in industrial processes. The main challenge seems to be that the energy transition takes 'too long'. While the challenge to overhaul a global energy system is formidable, it is also pressing, and the consequences of inaction are critical. Therefore, we must focus on the solutions that give the greatest effect in the short term while at the same time facilitating the long-term goals of covering relevant market segments. In addition, we cannot afford to make mistakes along the way. We depend on having the trust of the population, who will use the new energy in all possible contexts. Safety must, therefore, be a priority.

In the long run, renewable energy will be the most important form of energy production. As long as a new supply of renewable energy covers the existing electricity demand in a relevant area, it is direct consumption that is the most efficient utilization of supplied energy.

The most common sources of renewable energy are hydropower, solar power and wind power. Hydropower differs from solar and wind energy, in that the power comes from stored energy in dams, which makes it possible to regulate the supply of energy as needed 24/7. The dams as such represent powerful resources as energy carriers. Balancing the grid helps to meet the primary needs of the population and is, therefore, an imminent first focus in the global energy transition. On the other hand, not all areas have access to hydropower and the grid must be balanced with the help of other forms of energy carriers. Hydrogen has great potential in this context.

Today, hydrogen is produced on a large scale but is based on a production process with significant greenhouse gas emissions i.e. through the reformation of natural gas, without carbon capture. This form of hydrogen is called 'grey hydrogen'. In India, about 7 Mt of grey hydrogen is consumed annually in industry. This consumption is expected to increase significantly in the coming years. There is a great potential in replacing grey hydrogen with green hydrogen, produced renewably. What makes this a particularly exciting market segment is its established experience with hydrogen—handling it in a safe way. Because of this, the market represents an opportunity to quickly scale up critical technology required to produce green hydrogen with very low risk to the wider population. Reducing the technology cost through economies of scale and reduced material cost is a priority to accelerate the conversion to renewable hydrogen by making it competitive with the fossil alternative.

To succeed with the fastest possible energy transformation, we must use all the means. There is no 'silver bullet' but by combining technological solutions that are available at a scale with ambitious targets and the right incentives, we can bring about a successful green transition.

## HYDROGEN PRODUCTION PROCESSES

Hydrogen is easily the most abundant element in the universe. It can be found in the sun and most of the stars, and it makes up most of the planet Jupiter. On Earth, water is the largest source of hydrogen. Today, however, most production is based on fossil fuels through processes like Steam Methane Reforming (SMR) and coal gasification.

The hydrogen commonly produced is labelled **grey**. There are significant greenhouse emissions from these processes. But development of Carbon Capture and Storage or utilisation (CCSU) technology aims at reducing these. This hydrogen is then labelled as **blue**. Substituting fossil fuels with biomass and biogas doesn't eliminate $CO_2$ emissions but makes it renewable.

Utilizing water as the hydrogen source can eliminate most GHG emissions, as long as the power sources are renewable. Renewable or **green hydrogen** is mostly produced through water electrolysis. It is a well-known process through which water molecules are split into hydrogen and oxygen gas using electricity. There are several alternative electrolyser technologies available, with various strengths, weaknesses, and maturity. The most prevalent are alkaline electrolysers and PEM electrolysers. Gaining traction are also SOEC and AEM electrolysers, though these have a lower maturity.

The most well-established electrolyser technology is called Alkaline Electrolysis or AEL, where the ionic conducting medium is an alkaline liquid electrolyte. The electrolyte is generally an aqueous solution of ~30% potassium hydroxide (KOH) which offers higher ionic conductivity. Now, many electrolyser companies offer pressurised cell systems, up to 30 bar, which can reduce the need for external gas compression. Critically, the cells contain a separator to isolate the hydrogen gas from oxygen to avoid forming a potentially explosive mixture. AEL benefits from the use of low-cost non-precious metal catalysts, such as nickel for the electrodes which helps keep the capital costs relatively low.

In more recent years, commercial development has focused on an acid electrolyte, typically using a solid polymer electrolyte called a Proton Exchange Membrane (PEM). This enables a compact, and higher efficiency system which can deliver pressurised hydrogen (typically 30 bar). Due to the relatively high material cost of the membrane and precious-metal-based (Pt, Ir, Ru) catalysts, PEM still suffers from high capital costs.

As a middle ground between PEM and AEL, anion exchange membrane electrolysis offers a solid membrane and liquid electrolyte combination, and lower cost catalysts. The electrolyser performance is similar to PEM, however, the maturity is still low, and the reliability has not been demonstrated at the same level as other mature technologies.

High temperature electrolysis of steam has been driven by considerable attraction to increasing the temperature of operation of electrolysers from the perspective of thermodynamics. The technology is based on the solid oxide (ceramic) ionic conductor technology, developed on Yttria-stabilised zirconia. The high temperature operation reduces the overall electrical energy required to split water and improves the process's efficiency.

The energy transition may go from grey through blue to green hydrogen to achieve the decarbonisation of the system and contribute to regional, national, and global climate targets (**Figure A**). The different technologies for Power-to-hydrogen production will play an important role to meet the climate targets. Government and industry needs to keep looking at any potential technology enabling environmentally friendly and cost-efficient hydrogen production.

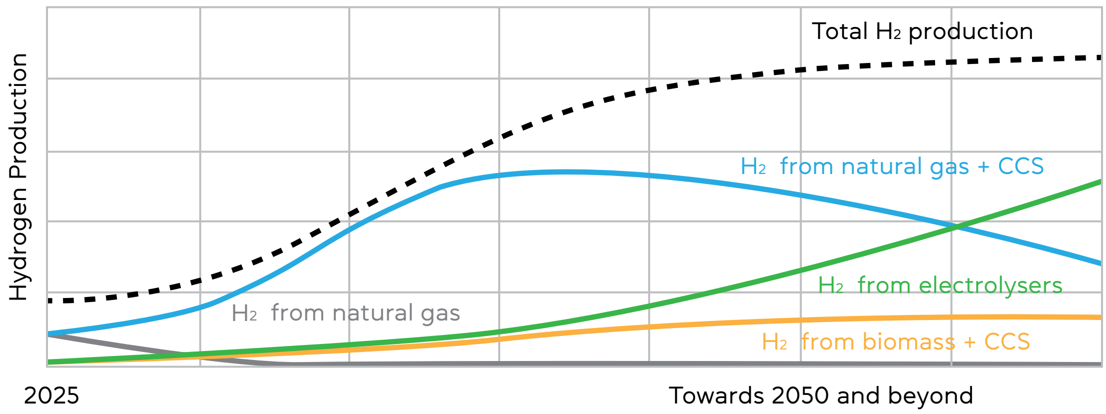



**Figure A**. Indicative production of hydrogen from natural gas, biomass, and electrolysis using renewable power.[2]

2 Reigstad, G. A., Coussy, P., Straus, J., Bordin, C., Jaehnert, S., Størset, S. Ø., & Ruff, B. (2019). Hydrogen for Europe-Final report of the pre-study. *SINTEF Rapport*.

The technologies have been tested to a large extent, but there is still a great potential for continuous improvement, and also of reducing production costs through automated production processes. The latter is a latent potential, which, however, presupposes that strong purchasing power is set in motion. It is, therefore, important that heavy financial instruments facilitate the pace of development. There is always a financial risk in being 'out early', at the same time, it is probably just as big a risk to 'sit on the fence'. Those who take part in the energy transformation will in all probability also be among those who have significant export resources as the rest of the world 'follows'.

For alkaline electrolysers, research on electrode materials and novel cell designs aims at increasing efficiency. In addition, higher pressure systems are being developed to reduce balance of plant cost, improve dynamic operation and reduce plant size. For PEM systems, reducing and recycling of platinum group metals in the catalysts has been a key focus to reduce cost.

The EU has pushed this through its Horizon Europe calls, setting specific targets on critical raw material's content in electrolysers. Other research is focused on the materials used in other components such as the membrane and bipolar plates. SOEC and AEM, being less mature technologies, still require research and development efforts to reach broad adoption. However, their advantages may give them market shares in the years to come as their reliability is demonstrated at pilot and industrial scales.

Reforming of natural gas can be combined with $CO_2$ Capture and Storage (CCS). This technology greatly reduces emissions, and is considered 'pure hydrogen', leading to 'blue hydrogen'. There are also significant challenges associated with the technology costs for CCS, and in the same way as 'green hydrogen' presupposes that one invests heavily in order to succeed in reducing costs at a competitive level down to the price of grey hydrogen. CCS technology also has great potential for use in other production processes where $CO_2$ emissions occur.

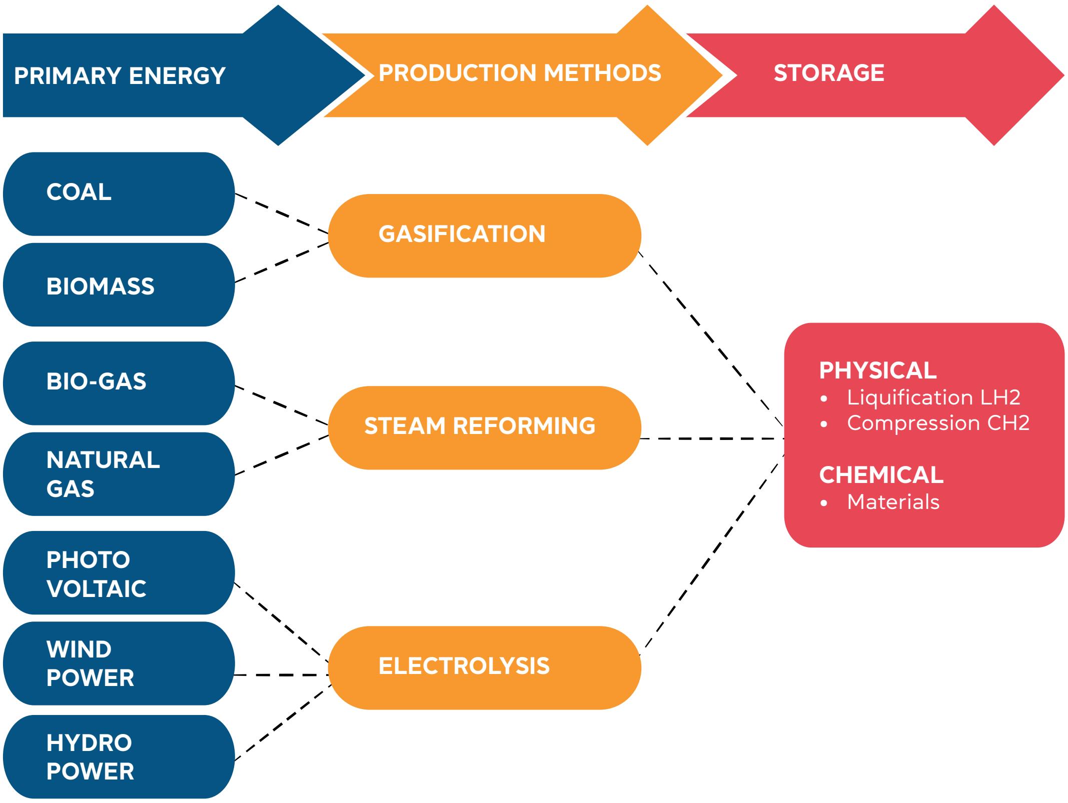



**Figure B**. Hydrogen production and storage methods.[2]

## HYDROGEN STORAGE

Hydrogen gas or liquid can be stored physically. Physical state methods constitute compressed (high-pressure), liquid (cryogenic), and cryo-compressed tanks. Alternatively, materials can be used for storing hydrogen as well. This process consists of either chemical storage (absorption within the material) or physisorption (absorption on the material surface). Chemical storage includes materials such as ammonia ($NH_3$), metal hydrides, formic acid, carbohydrates, synthetic hydrocarbons, and Liquid Organic Hydrogen Carriers (LOHC), while porous materials like carbon, zeolites, complex hydrides, metal/covalent organic frameworks do by absorption processes.

Although hydrogen gas compression is the most widespread method used to store hydrogen, this process is volumetrically and gravimetrically (weight percentage,

2 Adapted from: Salvi, B. L., & Subramanian, K. A. (2015). Sustainable development of road transportation sector using hydrogen energy system. *Renewable and Sustainable Energy Reviews*, *51*, 1132-1155.

wt%, of stored hydrogen in relation to the total weight of the system) inefficient[3]. Whereas the volumetry hydrogen energy density increases with pressure, the gravimetric density decreases due to thicker walls needed for the pressure cylinder. Under high-pressure gas cylinders with a maximum of up to 800 bar, hydrogen can achieve a volumetry density of 36 kg/m³ which is about half of the density reached under its liquid form.[4] Storing hydrogen in its liquid state (liquefaction) requires cryogenic temperatures (below -253° C). This storing method allows higher volumetric hydrogen storage density compared to gas compression, although, the tank must be thermally well isolated and stays under vacuum conditions (**Figure C**). It implies a high cost of materials among other difficulties related to long-term storage periods (boil-off issue) and the energy needed for the liquefaction of hydrogen gas. Storing hydrogen in materials (e.g. ammonia) provides a good volumetric density, although its gravimetric hydrogen storage density is quite poor.

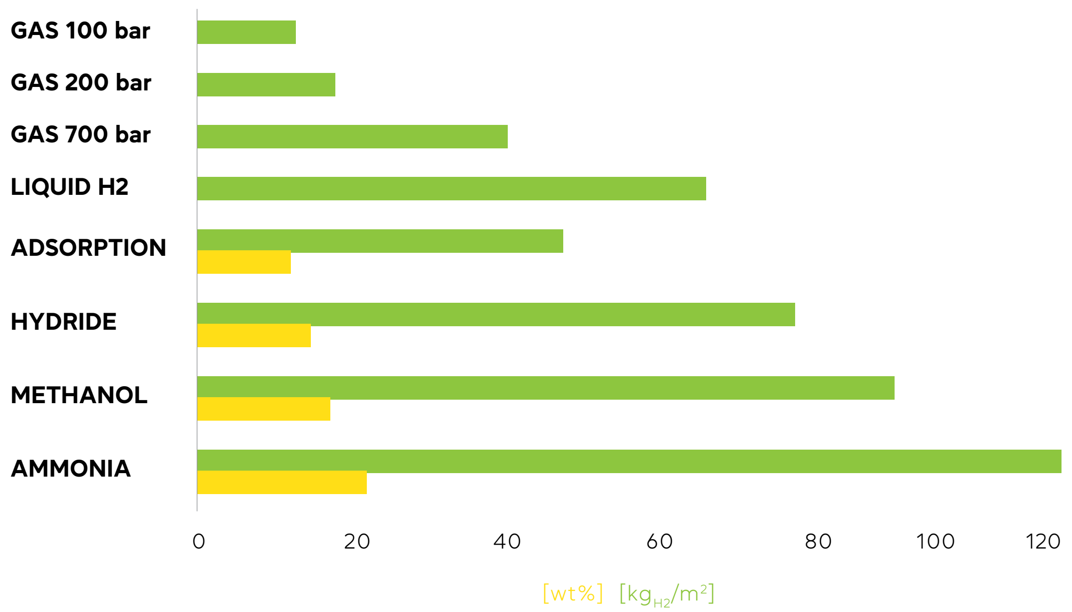



**Figure C.** Gravimetric (wt%) and volumetric (kg/m³) hydrogen storage densities of some hydrogen storage technologies.[5]

Hydrogen storage is also a demanding challenge. Maybe not so strange for those who know the location of hydrogen in the periodic table. Hydrogen is the smallest

3 Li, Y., & Yang, R. T. (2006). Significantly enhanced hydrogen storage in metal– organic frameworks via spillover. *Journal of the American Chemical Society*, *128*(3), 726-727.

4 Zheng, J., Liu, X., Xu, P., Liu, P., Zhao, Y., & Yang, J. (2012). Development of high pressure gaseous hydrogen storage technologies. *International Journal of Hydrogen Energy*, *37*(1), 1048-1057.

5 Adapted from: Andersson, J., &Grönkvist, S. (2019). Large-scale storage of hydrogen. *International Journal of Hydrogen Energy*, *44*(23), 11901-11919.

atom we know of in the universe, atom number 1. Hydrogen acts as an energy carrier by being kept isolated from other atoms, in gaseous or liquid form.

The packaging that is used to encapsulate the hydrogen must necessarily be composed of other atoms, which are larger, and this makes it challenging to ensure that the hydrogen does not escape. Storing hydrogen will depend on its state; Solid, liquid, or gas hydrogen will be achieved by a combination of temperature and pressure. At temperatures below -259 °C, hydrogen will be in its solid-state (70.6 $kg/m^3$ of volumetric density: mass of hydrogen stored by volume unit of the system) while it will be in a liquid-state at -253 °C (70.8 $kg/m^3$) and gas at 0 °C (0.09 $kg/m^3$), 1 bar of pressure. Hydrogen's energy content by volume is low. One kilogram of hydrogen takes about 11 $m^3$ at ambient temperature and atmospheric pressure. Consequently, for storing hydrogen gas[6] it needs a reduction of a large volume requiring high pressures, low temperatures, or chemical processes. However, compression, cooling and chemical processes in themselves are energy-intensive.

Ammonia is a highly discussed, suitable medium for storing hydrogen, as the molecular bond is far more stable than hydrogen alone, while at the same time containing a significant concentration of energy. Ammonia is used in fertilizer production, to give the plants fast energy, but can also be used as an energy source directly. In connection with, among other things, maritime transport, ammonia is often discussed as an alternative fuel to hydrogen, and then it is important to understand that these are two sides of the same coin (substance). One can also produce other chemical bonds with hydrogen, which can contribute to easier handling, which can provide advantageous properties with regard to storage and distribution, in particular. However, there are many different types of challenges associated with the various solutions, and not one conclusion that trumps all the other alternatives. As with other demanding technologies, volume production will contribute to reduced costs, which will be the fastest way to make hydrogen available as an efficient energy carrier. At the same time, new and improved technologies and materials must be researched in parallel.

## NORWAY AND INDIA – GREAT POTENTIAL FOR TECHNOLOGY COOPERATION

Both Norway and India are investing heavily to take leading positions in hydrogen as a crucial energy carrier in the energy system.

Compared to India, Norway is a very

6 Züttel, A. (2004). Hydrogen storagemethods. *Naturwissenschaften*, *91*(4), 157-172

small country. India, for its part, represents a huge market and a clear ambition to become energy independent as soon as possible through the transition to renewable energy and the production, consumption and export of hydrogen.

In this context, Norway has some advantages that make Norway a very attractive collaborate partner with India. Norway is, more than anything else, an energy nation, with very long experience of fossil energy and renewable energy. The experience with handling fossil energy for more than 50 years also involves very high risk in terms of safety. Norway has become a pioneer in safety management through this experience. It is reasonable to assume that much of the knowledge gained in risk management, related to the handling of fossil fuels, is transferable to hydrogen. As a consequence of being an oil and gas nation in a world moving towards clean energy, Norway has been doing a lot of R&D and piloting within the field of CCS. There are high expectations about CCS also being an important part of the solution to reduce climate emissions.

There is a particularly great interest in implementing hydrogen in the shipping industry in Norway. This is an initiative to which the Norwegian authorities strongly contribute. Norway is also considered to be among the world's leading nations in shipbuilding, an area which in itself can also be a particularly exciting area of cooperation between Norway and India.

Norway invests heavily in research in hydrogen and has several institutions with a highly respected international reputation. SINTEF, IFE and NORCE stand out in this context, and have a number of laboratories and prominent researchers who participate in many national and international projects to facilitate the upscaling of hydrogen production and its use in various application areas. On the websites of these institutions, one can easily find many relevant areas and projects that are transferable to the Indian market. There is great potential for closer cooperation between our countries to contribute to significantly faster development. There are also several universities in Norway that work purposefully with knowledge dissemination related to hydrogen, where especially UiA, HVL, UiO and USN, can be highlighted as prominent —all very interested in contributing to knowledge sharing and bilateral cooperation ■

**NORWAY IS ONE OF THE COUNTRIES IN THE WORLD WITH THE LONGEST EXPERIENCE IN THE USE AND DEVELOPMENT OF EQUIPMENT FOR THE PRODUCTION AND HANDLING OF GREEN HYDROGEN.**

## NORWEGIAN SUPPORT TO MAKE INDIA SELF-RELIANT IN GREEN HYDROGEN

### GREENSTAT GROUP NORWAY

Greenstat is a green energy company founded in 2015 in Bergen, Norway; The company is a frontrunner in the transition towards a sustainable future.

The mission of the company is to reach the emission-free society by using available knowledge and technology and continue its research and explore innovative solutions to achieve zero emission society. Greenstat will develop and invest in projects and companies within renewable energy production, storage, distribution, and consumption.

The company is organized as a corporation with a shared goal, strategy, and values, including commercial subsidiaries in various areas of focus. Greenstat aims to be a vertically integrated energy company with a specific focus on green hydrogen as a central part of the future energy mix.

By being technology neutral, Greenstat can go for the best market opportunities in the green shift - where adaptability, speed and cost focus will be decisive criteria for success. As of today, the company has chosen hydrogen, renewable energy, energy stations and energy analysis as its fields of interest. Greenstat hydrogen projects are attracting international interest for co-ownership and development.

https://greenstat.no/en

## GREENSTAT HYDROGEN INDIA PRIVATE LIMITED (GHIPL)

Greenstat Hydrogen India Private Limited is a subsidiary of the Greenstat Group. GHIPL is a green energy company facilitating energy transition throughout the whole value chain of green hydrogen – from analysis to execution with tools which assist our business partners and customers (public or private) in finding the best emission-free solutions, based on tailor-made assessments.

Greenstat Hydrogen India Pvt Ltd is primarily into design, development, construction, and operation of facilities for green hydrogen and green ammonia. Greenstat Hydrogen India will own and operate green hydrogen facilities, alone or in partnership with others.

Greenstat Hydrogen India Pvt Ltd has formalized cooperation with the leading market suppliers of GH technology and has close cooperation with key personnel in the respective companies.

Project opportunities have been identified through in-depth sector analysis and feasibility studies in collaboration with established network connections in Norway and India. Project opportunities are being realized through the co-ownership model and establishment of SPVs.

In a short span of its establishment in India, Greenstat has been able to work with state governments, academic institutions, and large private companies. Greenstat has commenced working on feasibility studies for creation of large green hydrogen clusters in specific states and creating 'Centre of Excellence' in prestigious academic institutions and Oil PSUs. Greenstat is also developing pilot projects to produce green hydrogen under co-ownership model with a large renewable energy generation company. Also,


through a technology tie-up with a global company it will be manufacturing electrolysers in India.

ln a short period of time, GHIPL has supported in centre of Excellences as knowledge partners with IocL'in R&D, llT Delhi in process safety and Risk Management in Hydrogen Economy, Shriram lnstitute of Industrial research in R&D in hydrogen production and process safety and capacity building.

https://greenstat-india.com/

## GEXCON NORWAY

Gexcon is a world-leading company in the field of safety and risk management and advanced dispersion, explosion and fire modelling. There experience arises from detailed knowledge of explosion phenomena built up through years of extensive research projects, carrying out safety assessments, performing accident investigations and conducting physical testing at the company's facilities. Their team of experienced engineers and specialists assists in identifying hazards, understanding risks and contribute to improving company's overall safety performance.

https://www.gexcon.com/

# CATALOGUE OF HYDROGEN PRODUCTION FACILITIES GLOBALLY

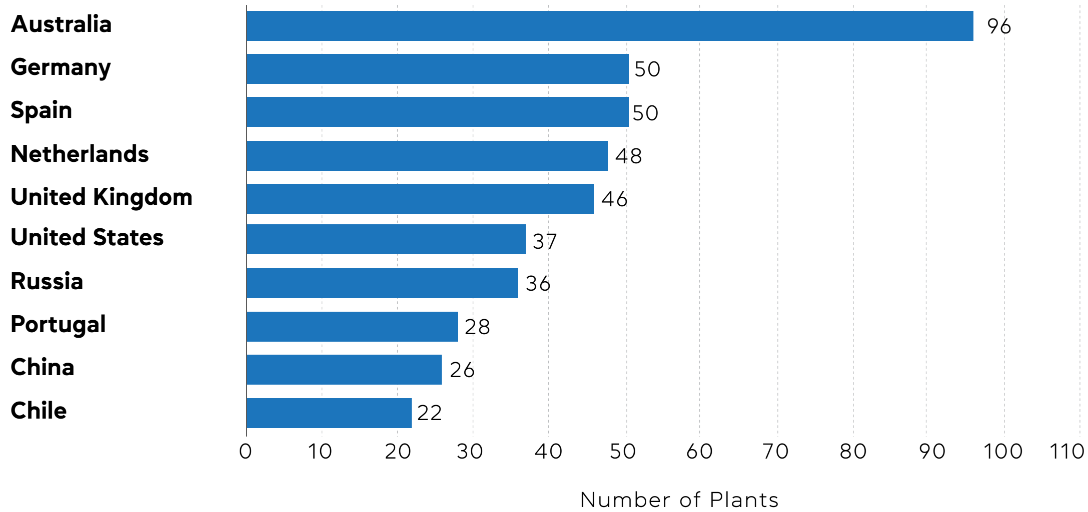
Hydrogen Production Facilities—Location Wise


## HYDROGEN PRODUCTION FACILITIES—LOCATION WISE

Many developed countries such as Australia, the European Union, and Russia have already set up their manufacturing facilities for producing hydrogen to achieve their national hydrogen goals. Data reveals that among individual countries, Australia has the highest number of green hydrogen plants in the world followed by countries in the European Union. As of 2022, there were 96 such plants in Australia.

On the other hand, India has a total of 26 hydrogen projects with a total capacity of 2,55,000 tonnes per year according to S&P Global Commodity Insights. However, most of these plants are still at an infant stage and only 8,000 tonnes per year capacity is expected to be met by 2024.

Number of green hydrogen production facilities worldwide: 2022




## GREEN HYDROGEN PRODUCTION FACILITIES ALL OVER THE WORLD

Countries all over the world are lagging behind in their 'zero emission target'.[2] We are not only looking forward to create strong world leaders to become large green hydrogen producers but establishing a global hydrogen market is also the great matter of concern[3]. According to the Columbia Climate School, approximately 70 million metric tons of hydrogen was reported to be produced all over the world every year.[4]

Green hydrogen is created using renewable energy instead of fossil fuels and its only by-product is water. It can be used in any form, gas or liquid. Green hydrogen has the potential to provide clean energy for transportation, manufacturing, oil refineries, chemical and fertiliser production, food processing, metallurgy and more.

However, currently there are many uncertainties on the pathway of development for the hydrogen market and in outlining policy considerations to navigate through such uncertainties and country specific challenges. To summarise the uncertainties and the solutions that the leading countries are focusing on, a detailed catalogue, containing key information like the annual consumption and production units, major challenges and policy framework among other things, is being provided in this chapter.

2 IRENA's (International renewable Energy Agency) report on 'geopolitics of the energy Transformation: the hydrogen Factor'

3 India qualifies for this possibility, i.e. a large market for green hydrogen

4 https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen/

The key objective is to work out a comparative international framework to evaluate the cost trajectory and the regional challenges faces by other leading countries worldwide as it helps in having a more realistic projection. It would also provide a better understanding of the ground rules to become an energy exporter.

## GREEN HYDROGEN PRODUCTION GLOBALLY: COUNTRY WISE PROFILE

### CHINA

China is the largest producer of green hydrogen as well as hydrogen fuel. The country is all set to achieve its 'zero emission targets' by unveiling its production targets and pledging to increase the low emission fuel's usage across various sectors. In March 2022, the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) of China released a hydrogen development plan that laid out a series of policy guidelines to build a strong hydrogen supply chain by 2035. They are aiming to produce 100,000 – 200,000 MT of green hydrogen from renewables per year by 2025. The country has launched a four-year programme to support the local government in researching hydrogen technology and developing an industry chain.

Sixteen provinces and cities of China have already launched 'Hydrogen Development Five-Year Plan' including Beijing—where accelerated planning and construction of hydrogen refueling stations has started and Jiangsu—where plans to develop hydrogen fuel cell vehicles and hydrogen fuelling infrastructure are underway.

According to the Chinese government, there are more than 300 companies involved in supply chain management of green hydrogen. China's key advantage lies in its strong governmental support and huge market. However, the firms are facing problems with availability of critical material, technical capabilities and innovative fuel cells.

Moreover, the country is also focusing on areas where there is a demand for hydrogen, particularly the transportation sector, industrial sector and aviation.

### UNITED STATES OF AMERICA

The US government is striving to develop its energy security in the long run in accord with world's leading concern of carbon emissions. US has spent a wide range of funds to support research and development of upgraded technologies to achieve the target of clean energy production domestically.

The primary challenge that the US government is facing with production of green hydrogen is reducing the cost of production technologies to make the resulting hydrogen more cost competitive with conventional fuel. US Department of energy is focused towards developing the technology to achieve ‘cost efficiency of hydrogen production’. The target is to produce hydrogen at $ 2 per kg by 2025 and $ 1 per kg by 2030 via ‘net zero carbon pathway’.

As far as demand is concerned, the primary users of hydrogen in US are petroleum refineries, metal treating, fertiliser production and food processing industries. The government is working towards increasing the number of users for clean energy. This is only possible if green hydrogen is available at a competitive price.

In US, the major producing states are California, Texas, and Louisiana. Most of hydrogen used in US is produced close to the place of demand. However, US still requires a lot of infrastructural development for distribution. Fuel cell electric vehicles still need to be developed. Currently, hydrogen is distributed through: pipeline, high pressure tube trailers and liquefied hydrogen tankers.

## EUROPEAN UNION

The European Union has outlined a clear pathway to move towards clean energy with a collaborative effort of various stakeholders. The EU commission has been set up to take all necessary steps and decide the future course of action to achieve targets in a definite timeline.

It has defined ‘green hydrogen’ as ‘hydrogen produced through the electrolysis of water,
provided the electric energy used as input is generated from renewable sources’.

EU has set an ambitious target for the inland production of GH. The European Clean Hydrogen Alliance was launched in 2020 with the objective to bring together industry, national and local authorities, civil society and other stakeholders. It aims to promote research and innovation projects via ‘Horizon Europe,’ a public private partnership.

The entire EU Hydrogen strategy is based upon investment agenda, boosting demand, scale up production, creating a supportive framework and promotion of research and innovation. It prioritises energy security and cost optimization by combining long distance imports, internal imports and internal production.

The EU plans to produce 10 million tonnes of GH in EU by 2030 and to import 10 million tonnes from other countries. A huge investment has been pipelined to achieve the objectives in due course of time.

Chile, Japan, Germany, Saudi Arabia and Australia are the major investors and active participants in the GH production and promotion programme.

## JAPAN

Japan is a highly industrialized country with a severe lack of hydrocarbon resources. It's a leading country in fuel cell technology, especially FCVs and is willing to export internationally. However, the country hasn't achieved the status of self-sufficiency as far as energy security is concerned.

To fill the gap Japan issued 'Basic Hydrogen Strategy' in 2017 becoming the first country to adopt national hydrogen framework. The focus is on securing access to hydrogen feedstocks. They have already started to test various options for sourcing hydrogen.

A robust funding for research, development, demonstration and deployment has been provided by the Japanese government to support GH production commitments. Development of hydrogen supply chains is a major agenda of the GH strategy launched by the Japanese government. The country seeks to increase public spending, improve technological innovation work and collaboratewith industrial stakeholders to expand a society wide adaptation of hydrogen and fuel cell technology.

The country is equally focused on expanding the hydrogen market from two million tons to three million tons by 2030. As far as demand is concerned, the country has a broad end use approach including transportation, residential usage, heavy industry and potentially refining industries too.

## SAUDI ARABIA

Saudi Arabia seeks to become a global supplier of hydrogen—primarily the hydrocarbons. It is planning to install a multibillion-dollar hydrogen plant as the world's biggest oil exporter and biggest producer of clean energy on the north-western shores of the country.

Saudi Arabia's interest in hydrogen is primarily driven by its desire to ensure economic security. It has an abundance of resources that can help it to achieve the status of a world leader in hydrogen supply. However, the strategies and plans are more geared towards production and supply of hydrogen, not specifically, the green form.

Nonetheless, in its recent official announcements, the Arabian government is seen pledging to promote clean energy, reduce the content of carbon emission in the production process of hydrogen energy. Though any defined pathway or focused strategy for clean hydrogen production is yet to be announced.

### RUSSIA

Russia has scientific, resource and logistic capabilities to capture a significant share of market and to develop technology for production, storage and transportation of hydrogen. The Russian government has pledged to invest around $ 127 million in the next three years.

Russia, however, is geared more towards becoming the world leader in production and export of hydrogen though not very specifically of clean hydrogen. The country is more concerned about increasing the production capacities of yellow and blue hydrogen.

The Russian strategy—to become the world leader outlines the creation of low carbon, export-oriented hydrogen production facilities—is quite unclear about how much efforts will it be putting into green hydrogen.

## HYDROGEN PRODUCTION FACILITIES ALL OVER THE WORLD

The catalogue includes leading players and their course of action to become an emission free state/country in times to come. Keeping in mind the current level of production and challenges they face, a regulatory framework has been planned out with sufficient allotment of resources.

To sum up, the world is striving to become an emission free space in decades

| S. no. | Country | Description | Region | Current annual Production (in MTs) | Issued National Hydrogen strategy | Policy framework | Challenges |
|---|---|---|---|---|---|---|---|
| 1 | China | World's 1st largest producer and consumer of hydrogen. | Beijing, Tianjin, Hebei, Guangdong and Henan Provinces, Shanghai and Jiangsu. | 33 million[1] | 2016 | More than 300 companies involved in supply chain, mostly in the coastal area. | Infrastructural development for storage and production of green hydrogen. |
| 2 | United States | World's 2nd largest producer and consumer of hydrogen. | Texas, California, Louisiana | - | 2021 | Hydrogen Earthshot programme, with its '111 goals' to cut the cost of clean hydrogen. Announced $ 9.5 billion budget to boost clean hydrogen development. Large financial support for research and development activities. | Development of infrastructure for hydrogen distribution, delivery and storage.<br><br>Development of low cost technology for production of cost competitive fuel alternatives. |
| 3 | European Union | Invested on a detailed strategy to make EU climate neutral through the application of GH. | (Chile, Japan Germany, Saudi Arabia and Australia: major investors) | negligible | 2020 | $430 billion investment by 2030. Scaling up the development of hydrogen infrastructure and hydrogen investment are the key elements of GH for EU. | Differences in economic structure and natural conditions call for different levels of support and investment. |
| 4 | Japan | A highly industrialized country with a severe lack of hydrocarbon resource. | - | 0.3 million tonnes | 2017 | 'Basic Hydrogen Strategy' was launched, making it the first country to adopt national hydrogen framework. | Japan largely depends upon imports for its energy requirements. The journey to become GH production leader is likely to be very long, costly and challenging for Japan. |
| 5 | Saudi Arabia (looking for one) | Have abundance of resources to achieve status of world leader in hydrogen supply. | Neom: the futuristic city | At the planning stage | | | |
| 6 | Russia | Has abundance of resources to achieve status of world leader in hydrogen production and sports. | - | At the planning stage. The union is more dedicated towards production of yellow and blue energy, however, efforts are being made to reduce the emission content by improving the technology. | | | |

to come. Many leading countries including India[5] have already charted out the futuristic moves to achieve this target and many are yet to lay down the same. Most of the leading countries in producing energy like China, US, Asia, EU and Saudi Arabia has already planned out a huge investment with identified targets viz. to produce more, to cut the cost of production or to spend on technological advancements and innovative ways of producing green hydrogen, which is more cost effective and safe.

> The hydrogen economy will make possible a vast redistribution of power, with far-reaching consequences for society. Today's centralised, to-down flow of energy, controlled by global oil companies and utilities, could become obsolete.
>
> **— Jeremy Rifkin —**

5 The National Hydrogen Portal is www.greenhydrogen-india.com envisioned to be a one stop information source for research, production, storage, transportation and application of hydrogen, it will be a repository of all academic & research work and other significant developments in the field of hydrogen; with a focus on Green Hydrogen.

| | | | | | | End-use sector | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Project name | Country | Announced Start Date | Currently operational (Y/N) | Technology | Product | H2 Power | H2 Grid Injection | H2 Mobility | H2 Industry | NH3 Production | |
| Asian Renewable Energy Hub | Australia | 2027-28 | N | Unknown PtX | H2 | 1 | | | 1 | 1 | |
| NorthH2 | Netherland | 2027 | N | Unknown PtX | H2 | | | | 1 | | |
| NorthH2 | Netherland | 2030 | N | Unknown PtX | H2 | | | | 1 | | |
| Aqua Ventus | Germay | 2025, 2030 | N | Unknown PtX | H2 | | | | | | |
| Murchison Renewable Hydrogen Project | Australia | 2028 | N | Unknown PtX | H2 | | | 1 | 1 | | |
| Beijing Jingneng Inner Mongolia | China | 2021 | N | Unknown PtX | H2 | | | | | | |
| Helios Green Fuels Project | Saudi Arabia | 2025 | N | Unknown PtX | H2 | | | 1 | | 1 | |
| Pacific Solar Hydrogen | Australia | NA | N | Unknown PtX | H2 | | | | | | |
| H2-Hub Gladstone | Australia | 2025 | N | Unknown PtX | H2 | | | | | | |
| HyEx | Chile | 2024 | N | Unknown PtX | H2 | | | 1 | | 1 | |
| Geraldton | Australia | NA | N | Unknown PtX | H2 | | | | | 1 | |
| Greater Copenhagen | Denmark | 2030 | N | Unknown PtX | H2 | | | 1 | | | |
| H2 Sines | Portugal | 2030 | N | Unknown PtX | H2 | | | | | | |
| Yuri | Australia | 2023 | N | SMR+ Unknown PtX | NH3 | | | | | | |
| CEIP Project | Australia | 2022 | N | Unknown PtX | Blending H2 | | 1 | | | | |
| AGN's Project | Australia | 2023 | N | Unknown PtX | Blending H2 | | 1 | | | | |
| Baofeng Project | China | 2022 | Y | ALK | H2 | | | 1 | | | |
| Sinopec Project | China | 2023 | N | ALK+PEM | H2 | | | | | | |
| Texas City Project | USA | 2022 | N | Unknown PtX | H2 | | | 1 | | | |
| NextEra's Project | USA | 2020 | N | PEM | H2 | | | 1 | | | |
| Fukushima hydrogen energy research field (FH2R) | Japan | 2020 | Y | Unknown PtX | H2 | | | | | | |
| North Jeolla Province | South Korea | 2028 | N | Unknown PtX | H2 | | | | 1 | | |
| Incheon | South Korea | 2023 | N | Unknown PtX | H2 | 1 | | | | | |
| Glomfjord Hydrogen | Norway | 2025 | N | Unknown PtX | H2 | | | 1 | | | |
| Ceara facility | Brazil | 2022 | N | Unknown PtX | H2 | | | 1 | | | |
| Neom | Saudi Arabia | 2026 | N | ALK | H2 | | | 1 | | | |
| Rotterdam | Netherland | 2023 | N | SOEC | H2 | | | 1 | | | |
| Wunsiedel hydrogen | Germany | 2022 | N | Unknown PtX | H2 | | | 1 | | | |
| Sparsely | USA | 2022 | N | Unknown PtX | H2 | | | 1 | | | |

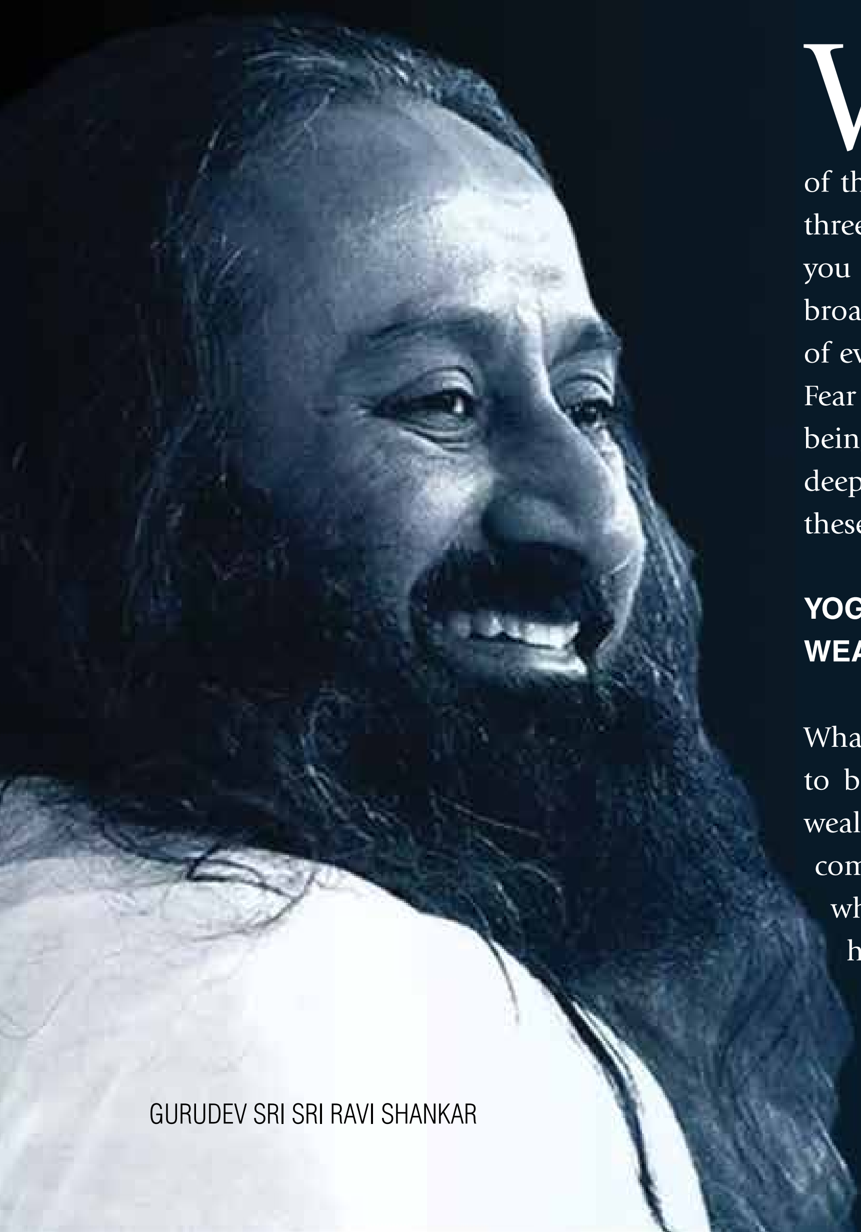
| | | | | | | | Quoted installed capacity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H2 CHP | H2 Domestic Heat | H2 Chemicals | CH4 Grid Injection | CH4 Mobility | Synfuels Mobility | MW | GW | Tonnes / yr in million | nm3h2/ hour | Tonne CO2 captured | IEA zero-carbon estimated normalized capacity [Tonnes H2/ Yr] |
| | | | 1 | | | | | 14 | 1.75 | | | 1750000 |
| | | | | | | | | 1 | 0.2 | | | 200000 |
| | | | | | | | | 4 | 0.8 | | | 800000 |
| | | | | | | | 30 | 5 | 1 | | | 1000000 |
| | | | | | | | | 5 | | | | |
| | | | | | | | | 5 | 0.4-0.5 | | | 400000-500000 |
| | | | | | | | | 4 | 0.24 | | | 240000 |
| | | | | | | | | 3.6 | 0.2 | | | 200000 |
| | | | | | | | | 3 | | | | |
| | | | | | | | | 1.6 | 0.124 | | | 124000 |
| | | | | | | | | 1.5 | | | | |
| | | | | | | | | 1.3 | | | | |
| | | | | | | | | 1 | | | | |
| | | | 1 | | | | 10 | | 320 | | | |
| | | | | | | | 10 | | 4.3 tonnes/ day | | | |
| | | | | | | | 10 | | 4.0 tonnes/ day | | | |
| | 1 | | 1 | | | | 15 | | 27000 Tonnes/yr | | | |
| | | | | | | | 26 | | 20000 Tonnes/Yr | | | |
| | 1 | | 1 | | | | 60 | | 2.5 | | | |
| | | | | | | | 20 | | 10.8 Tonnes/ day | | | |
| | | | | | | | 10 | | | | | |
| | | | | | | | 10 | | | | | |
| | | | | | | | 39.6 | | | | | |
| | | | | | | | | | | 300-385 | | |
| | | | | | | | | | | 250 | | |
| | | | | | | | | | 1.2 | | | |
| | | | | | | | | | 52000 tonnes/yr | | | |
| | | | | | | | | | 2.5 | | | |
| | | | | | | | | | 13500 tonnes/yr | | | |

# CLIMATE CHANGE

The Essence of Yoga | Sustainable Development through Ancient Wisdom |
Circular Economy | Carbon Market |
Environment, Social and Governance (ESG)

# THE ESSENCE OF YOGA

Yoga is the key that opens the floodgates of happiness for an individual as well as the community. It decimates the personal and collective misery that comes through individualistic and egoistic patterns. Today, when so many people around us are stressed and anxious, we need to be the light and spread joy. Yoga helps one manage challenging situations and brings skill to action, without getting stressed.



When you reach the root cause of conflict, you will find that it is due to fear, stress and mistrust of the other. Yoga helps you deal with all three. Fear of the other vanishes, because you have broadened consciousness, broadened awareness. You feel you are part of everyone and everyone is a part of you. Fear of losing one's existence or identity, being extinct, is something that is very deep-rooted. Yoga is the best tool to remove these fears from the minds of people.

**YOGA IS ALSO THE GREATEST WEALTH OF HUMANKIND**

What is wealth? The purpose of wealth is to bring happiness and comfort. Yoga is wealth in the sense that it brings absolute comfort, particularly at times like these when we are faced with financial and health-related worries all around us. A

GURUDEV SRI SRI RAVI SHANKAR

violence-free society, a disease-free body, a confusion-free mind, an inhibition-free intellect, trauma-free memory, and a sorrow-free soul is the birthright of everyone. Parliaments all over the world are striving to achieve this goal of human existence - happiness! Yoga is a way for that much-needed happiness to dawn in life. Yoga, meditation, and breathing techniques improve our immunity and uplift our spirit. When our state of mind is uplifted, we become hopeful, and positive in our outlook and our smiles become unshakable, irrespective of what the current circumstances are.

Yoga brings rhythm to life. This wholesome life skill can elevate the quality of one's life. It is the discipline of studying and harmonizing our inner faculties. Yoga improves inner strength and outer influence. It brings about complete balance in an individual; and puts us on a path of moderation. It also promises many solutions that today's behavioral sciences are searching for. For those seeking the ultimate truth, yoga is the vehicle to realise the blossoming of human potential to its fullness, a path of attaining the highest goal of uniting with infinity.

## NOT JUST A SET OF PHYSICAL EXERCISES

It is not just a set of physical exercises but an important vehicle to become one with our highest self.

Yoga has eight limbs and one among them is physical postures. While asanas or physical postures do provide the entry point for many, the science of yoga is vast and profound. The central teaching of yoga is to maintain an equanimous state of mind. Being able to do any action with mindfulness, and being aware of what you are saying or doing makes you a yogi. Often, we feel helpless about our negative emotions. Neither at home nor school does anyone teach us how to handle our negative emotions. Yoga has a secret to turning around this state of mind. It makes you independent. Instead of being a victim of your own feelings, it empowers you to feel the way you want to feel at any time.

## YOGA ALSO HELPS SOMEONE TO BE MORE RESPONSIBLE IN LIFE

This is Karma Yoga. We all play multiple roles in our life. We have an option to play the role either as a yogi or as a non-yogi; one who is responsible or one who is not. You can be a responsible teacher, a doctor with responsibility, or a businessman who cares. Yoga nurtures multiple characteristics in us like caring, sharing, and responsibility. All of us, the entire population have this within, but it needs some nurturing. Yoga can definitely make you more responsible as it creates more energy and enthusiasm in you. Whenever you are tired and stressed you do not like to take responsibility. If you have taken care of these issues and you have enough enthusiasm and energy, you will definitely take more responsibility, and with a sense of lightness.

7.5 billion people in this world and more are now inclined to practice yoga. We must take it to every home and every person ▪

## SUSTAINABLE DEVELOPMENT THROUGH ANCIENT WISDOM

DR J P GUPTA

Climate change and global warming is real, now proven that it is caused by human activities and that it is accelerated by the burning of fossil fuels.

As of early September 2015, the average global temperature has risen 1.4 degrees Celsius since 1880, and nine of the ten hottest years on record have occurred since 2000. Carbon dioxide stands at 400.84 parts per million, the highest levels the Earth has experienced in 650,000 years. Since March 2022 there has been an unusual rise in temperature, surpassing 47 degrees Celcius, the first time ever, in certain northern parts of India.

Evidence from ocean sediments, ice cores, tree rings, sedimentary rocks and coral reefs show that the current warming is occurring 10 times faster than it did in the past, when Earth emerged from the Ice Age, at a rate unprecedented in the last 1,300 years.

Humans' dependence on fossil fuels, economy of consumption, achieving ever-higher profits and continuous growth, are all part of the dream of the modern world. For decades, we've assumed that, in the face of development, destruction of nature is inevitable. We allowed tree-felling in favor of luxury apartment complexes or ignored the razing down of critical forests to make way for highways. But the scary reducing amounts of forest cover, the high rates of pollution, and unbearable weather shifts have put paid to that. We have and even still now acting in certain ways that drive global warming and put life on Earth—not only human life but that of all plants and animals as well—at risk.

However, the world is finally waking up to the stark reality that we can no longer degrade nature for development or stand neutral ground. To restore some semblance of balance, whatever we create next must add to nature.

Now, the search for a new paradigm – Sustainable Growth or just Sustainability that can ensure economic development without jeopardizing environmental quality is being intensified. The world seeks to establish a philosophical foundation, where people think about nature before thinking about themselves, which can make us realize the deeper underlying reality of basic oneness. Natural Science doesn't simply describe nature, it is part of the interplay between nature and mankind. This ecological harmony is possible when the entire universe is seen as a single large family, including all the living beings of the world. Vedic civilization realized this world view when they say, 'vasudhaivakutumbakam.' This world view further developed in the Upanishadic Age with a firm philosophical foundation through its cosmological unity and sustainability.

Such a holistic world view offers a new paradigm for development, a new socioeconomic system free from exploitation, defining in a novel way the relationship between man and nature, thus realizing the ecological balance we need today.

Sustainability, however, is often viewed through a futuristic prism, yet what we often miss out is that ancient wisdom can hold important lessons. The struggle to be more sustainable is a relatively new phenomenon, but inspiration can be drawn from ancient farming and water management techniques. Innovation and technology can help us adapt these techniques to meet our present-day needs.

When we think of 'innovation' and 'technology,' we probably link it directly to modernity, futurism and industrial development. The word that probably won't make the list is 'ancient.' And yet, ancient natural technologies might well give us the answer to adapting to climate change that we desperately seek in modern innovations.

Ancient wisdom can guide and teach us more sustainable infrastructure without exploiting or outright destroying nature. In responding to climate change, with complex infrastructures and monotonous high-tech design, we're forgetting that we are sitting on a goldmine of millennium-old knowledge — about living in symbiosis with nature and striking a balance between growth and harmony.

The Ancient Wisdom has always been in the world. It is knowledge of the nature of things and of human nature. It is the wisdom of understanding and compassion, of which all of us feel in need in the depths of our being. One way to shift our focus and incorporate a more Earth-friendly (and life-friendly) way of living into our everyday lives, is to weave together modern knowledge and ancient wisdom.

While we may not be able to resurrect everything we left in the past, but it's worth understanding that some ancient innovations and processes might still serve us well. The point of looking both forward and backwards is to arm ourselves with a wide range of tools to adapt to climate change. It isn't loud claim but a number of countries around the world are looking to ancient wisdom for guidance and have reached levels of innovation that perfectly balance what was previously considered un-balanceable.

Some of the examples that elucidate how ancient knowledge or ancient wisdom is being utilised:

– A study found that Tibetans living in Himalayan region are very susceptible to climate change, yet the people utilize a wide range of ecological zones for their subsistence.

Many other studies are underway to determine howmankind can utilize this type of wisdom on a global scale.

Extreme weather has played havoc with farmers across globe. While some have started adopting new technologies, others are looking back to explore old processes that worked then. Keith Elverson, an expert at UNEP, says there is probably no 'silver bullet' to solve everything but to look both forward and backwards to develop a wide set of tools as we adapt.

Below are some of the examples of such adaptations and utilizing ancient wisdom in various part of world. It's fascinating to read about lost ancient wisdom:

'Floating Rice' of Vietnam Mekong Delta, where farmers were shown by a researcher Nguyen V K how to work un-conventionally against intense floods and swamps to grow high yield variety and rediscovering ancient grains. Floating rice has become well adapted to floods as the foliage grows much above the level of floods.

Harvesting rainwater: In west coastal India's Bhuj, the ancients seem to have mastered the art of harvesting rainwater, diverting it from two ephemeral channels and then storing it in large reservoirs built on the site.

In Bhuj itself, a group called Arid Communities and Technologies (www.act-india.org), has been working for long to understand the traditional water harvesting and management system and they tried reviving it with the help of local communities. A small old well recently cleaned up by people voluntarily is now supplying water to about 50 families.

In Kolkata, India, BHERI wastewater aquaculture system management is the innovation in organic technology that has made its way to a number of countries for organic aquaculture and to use wastewater in a sustainable way. It features around 300 fishponds that carry out chemical-free water purification by relying on a combination of bacteria, algae, sewage and sun instead of coal-based power. It's also a source of food, an agricultural field, and a way of cleaning wastewater before it enters the Bay of Bengal.

There are other ancient techniques as well like using ducks instead of pesticides to manage insects etc. In Heilongjiang, China, Fang Yongjiang, a farmer, thought up a chemical-free approach that required no technology — only the clever thinking of ancestry of 600 years — and introduced ducks into rice paddies to feed on the weeds and insects so pesticides wouldn't be needed. Their droppings doubled up as natural fertilizer, which was a win-win. Fang initially began with a handful of ducks over 25 acres. In just a few years, other rice growers also implemented the ancient wisdom to bring the number up to 500 acres of pesticide- and fertilizer-free rice paddies monitored by ducks.

In Bolivia, Oscar Saavedra's non-profit, Sustainable Amazonia, has taught 500 families a method of agriculture dating back 400 BC — 7-feet high elevated fields that stood higher than floodwater levels and were surrounded by canals. During flood season, the canals would hold the water to prevent the fields from flooding. During drought, the same nutrient-rich canal water would be used to irrigate the fields.

By going back to the culture of the open well, by using only the dynamic water table, by recharging aquifers, and by reserving the deeper aquifers for droughts and other emergencies we can hope to tide over droughts in the era of climate change. This is the water wisdom, which we must learn from our ancients.

Many of ancient innovations are absolutely in tune with nature, using available resources smartly to create a mutually beneficial relationship. They might be simple or complex, but usually, they're already there in our history books if we took a closer look. As they say, history repeats itself — and a lot of our modern problems were also faced by ancestors when their times were considered 'modern'.

The Borana, a cattle-herding tribe in Kenya, is surviving droughts in arid Isiolo county by reintroducing an abandoned, centuries-old traditional grazing management method. Called 'Dedha' (which means 'council' in the local dialect), the system relies on placing decision-making authority in the hands of the elders, who ensure that all herders have adequate pasture and water for their animals. Since Dedha was reinstated in 2011, the Borana have lost fewer animals to drought, according to Victor Orindi of the Adaptation Consortium, a group that works to mitigate the effects of climate change in Kenya. Conflicts over natural resources have also been reduced, he adds. The county is in the process of passing legislation that will officially recognize the authority of Dedha councils.

Projects like AlUla's Cultural Oasis in Saudi Arabia are trying to integrate lessons from the past to create a more sustainable future for areas in need of development. These ancient techniques are being updated with new technology and innovative thinking to address sustainability issues such as desertification.

The Azawak region of West Africa has badly suffered from desertification and water scarcity due to the impact of climate change. The water crisis has had a severe impact on both the local environment and the traditional nomad communities who farmed it. NGO Amman Imman is using water harvesting methods to restore ecosystems to improve the livelihoods of those forced to migrate.

On a concluding note. large part of world's remaining ecosystems is in the heart of the lands of indigenous people. For millennia, they've lived in harmony with nature without giving up on progress – and that goes to show that there is hope for environmentally-friendly solutions to modern problems through ancient wisdom.

Ecology depends on the interdependence of multiple processes and schools of thought, so it's impossible to say that there's one right way to tackle all of the world's environmental problems. The smart way to go about adapting to climate change is to listen to those who've shown resilience in the face of it for years and reach a happy balance.

No matter where we live, we're all still dependent on the same web of life. There is immense value in looking at solutions that succeeded in the past to see whether we can correct our course in time. Ancient Wisdom integrating with Sustainability means not only integrating the economy with nature and society but also integrating the past with the present, the present with the future, and technology with culture. This will bring spiritual and cultural transformation from greed-based to need-based development.

> There can be no sustainable development without sustainable energy development
>
> —Margot Wallstrom

## SUSTAINABLE DEVELOPMENT THROUGH LIFESTYLE CHANGE

DR J P GUPTA

In the era of Industrial Revolution, there has always been a struggle for survival between humans, nature, and other species. The existence of life on this planet is intricately linked to the environment we live in. It fulfils all the necessities required for survival of human beings and animals of this planet. Before the era of industrial revolution humanity lived in harmony with nature. The problem occurred as industrialisation began. It marked a major shift in the relationship between humans and nature. The real impact of the Industrial revolution started appearing in the early 1960s. The real problem arises when human greed increased and they started demanding more than required. It was the time when machines started replacing humans and mass production of goods increased. Simultaneously, automation and mechanization in various aspects like agriculture increased, which in turn reduced employment opportunities in rural areas, which resulted in more and more people moving from rural to urban areas. Apart from that, because of better facilities and modern healthcare, the global population increased exponentially.

The sole purpose of the Industrial revolution was to improve living standards of human life and fulfil their needs, but now we see the focus has shifted from fulfilling necessities to extract more and more comfort. Which in turn is making the human body increasingly prone to diseases and damaging the environment badly. For example, by 2018 approximately 1.6 billion air conditioning were installed worldwide, with the international Energy Agency expecting this number to grow to 5.6 billion units by 2050. Installing more and more air conditioners will increase the global temperature, which in turn will make the survival of humans difficult. Mental illness has been increasing in the society. People are getting prone to more and more diseases. More than one-third of Americans are obese. There has been a lack of harmony in society.

Greenhouse gas emissions are increasing rapidly. There has been frequent droughts and floods in various parts of the world. Weather patterns are becoming more and more unpredictable, resulting in manifold natural disasters all over the world. The sea level is rising at a slow and continuous rate, Oceans are absorbing more and more CO2, resulting in ocean acidification. Increased plastic has been accumulating in the sea bed, affecting marine life severely. Massive deforestation in order to meet increased demand for agriculture and human habitation has reduced forest cover drastically.

Detaching oneself from nature has created many problems. In ancient times people lived in harmony with nature and with their surroundings, which helped them to live a happy and prosperous life. Even their rituals and practices were those that motivated them to live in harmony with nature. Each and every ancient practice and ritual has a hidden benefit for humans and helping them exist in nature with harmony. Since the time the roots of ancient wisdom started weakening in society, the relation between human and nature started deteriorating. Unnecessarily increasing demands for extracting comfort and money has brought this world to a stage of extinction. Although there has been massive economic growth, it has come at a great environmental cost. There has been a huge decline in agriculture and available fresh water.

In today's fast-moving world, humans are exploiting natural resources by deforestation, mining, fossil fuel usage, industrialization, carbonisation, and emission of harmful chemicals in air, water, and land. Ignoring their consequences has led people to resume traditional and sustainable way as used by our ancestors. Though the current development cannot be stopped but it can be harmonized through several ancient practices for sustainable and mutual growth of nature and everything that exists. Some of these techniques or practices could be organic farming to lower the land pollution and air pollution caused by emission of harmful pesticides and chemicals used in their production. Rainwater harvesting was one of the major practices used in ancient civilizations and even now in some parts of Rajasthan to ensure availability of potable water.

In modern day lifestyle there has been a lot more use of vehicles. In some families, number of cars exceed the family members. Number of clothing are far more than what is needed. Number of houses are more than the family members. That is lifestyle-greed-based and not need-based, If we look at Ancient India and even today in Indian villages, people use motor vehicles only when they must travel exceedingly long distances. For covering short distances walking is preferred, which not only saves environment but also keeps the human body fit and healthy. Materialistic possessions were bare minimum, just what were needed. Used ones were reused and recycled. Entire life style was based on circular economy.

Yoga practice empowers changing behavior to safeguard the community and environment. Yoga helps to change, on both an individual and a community level. Yoga is all about working with nature's forces, which are more than simply physical energies; they are also spiritual forces, at both internal and outward levels, harmonizing you with nature. We must balance the energies of our own, such as body, mind, breath and spirit, on an internal level. We must reconcile ourselves with the natural world and the Cosmic Spirit that underpins it from the outside. Each of us is a manifestation of the entire universe, and we can only utterly understand our purpose in life when we discover the universe within ourselves.

## SPIRITUAL AND CULTURAL TRANSFORMATION

- Yoga emphasizes principles such as expressive thought, non-violence, discipline, and even honesty when it comes to developing ethics. These factors contribute significantly to the development of diligent people who are deeply engaged to both the socio-political and physical environments. Individuals value simplicity and make long-term environmentally friendly decisions.

- Through yoga, body and mind come together in the pursuit of inner peace and understanding. Spiritual transformation is seen in yoga practitioners.

- Yoga relieves stress and trauma, and induces relaxation. It strives to reach an inner tranquilly unlike any other, in which negativity is expelled from our bodies and positive energy is diffused throughout our surrounding area.

- The physical benefits of yoga should not be overlooked. You can get a lot more fit and strong, and assist your systems to work at their best.

- Regular practice of yoga induces a dedication and a sense of respect for mother earth, and this helps a person to act in a specific way at home and work toward a better future. Individuals who work cooperatively, on the other hand, play a key role in gaining public support. Furthermore, living on a small budget, volunteering locally while thinking worldwide, and so on, to help lessen carbon footprint, resulting in innumerable advantages to the planet around us.

- Yoga and meditation help to bring harmony and peace to society and even can stop exploitation of natural resources. The aim of a practitioner's life was not earning a lot of money or to collect physical facilities but to work for the betterment of self and society, this created a sense of responsibility, which made them aware of their environment and surroundings.

- In ancient India, people were more dependent on fresh materials (foods) but nowadays, because of increased demand of processed materials, there has been a significant increase in population level (Like polyethene left after taking food items out are a major source of pollution). Apart from that the machinery used for processing foods produces a lot of pollution.

There has always been a race for happiness and pleasures in the modern society. This race filled humans with greed and jealousy. To fulfil their unwanted needs, people started exploiting nature in their own ways. Ancient wisdom never focused on storing and accumulating things and materials for the future and never gave much importance to material things (like money, physical facilities). It only focused on having what is required. The human-caused climate change is the result of human greed rather than human necessities and ancient wisdom has rituals and components that have the ability to inspire the global community beyond that. Stress and depression have become silent killers of today's society. In Circular economy, Yoga is a practical way to relieve stress and find peace.

All corporate houses should go for small cars, small and simple offices and small houses. To show off wealth should be seen as sin and this will make an important shift. Similarly, all politicians and leaders should lead a very simple life, as they interact with public. This will be a message, which India can convey to international community. Khadi woven clothes should be used, this will reduce consumption of polythene and Rayon fibre.

## CIRCULAR ECONOMY

DR J P GUPTA

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

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

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

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

Plastic industry is another important sector for circular economy. Globally, 8.3 billion tons of plastic was produced between 1950-2015. Out of 6.3 billion tons, which became waste, 4.9 billion tons reached the dumpsites. With the increasing trend of plastic manufacturing, an estimated 12 billion tons of plastic will be dumped in the environment by 2050. Circular strategy in the closed-loop system encourages its reuse, recycle, remanufacturing and finally safe disposal. Waste plastic can be used for thermal insulation of houses. In India, major industries dealing with plastic have come together last year, to form an alliance against plastic waste. India recycles or reuses over 90 per cent of all the PET (polyethylene terephthalate plastic) manufactured in the country. India has also shown improved electronics recycling. By signing 'extended producer responsibility' more than 700 electronics producers have come together to reduce e- waste.

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

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

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

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

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

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

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

## CARBON MARKET

UMESH SAHDEV

# India's expedition to 2070 Net Zero – Case for Carbon Pricing & Emissions Trading Instruments

India has let the world know its disquiet and approach towards Climate Change by Hon. PM of India announcing India's Climate Change commitments at the Glasgow COP26.

Under the 'Panchamrit' strategy – the Five Elixirs for Climate Change mitigation commitment announced, are:

- Achieve Non-Fossil/Renewable Energy capacity of 500GW by 2030.
- 50% of its energy demands to be met through renewable sources by 2030.
- Reduce Total Projected Carbon emissions by 1 billion tons till 2030.
- Reduce Carbon Intensity of its Economy by 45% by 2030.
- Achieve 'Net-Zero' by 2070.

This is the first time that India has taken any climate targets in terms of absolute emissions, that brackets India as a responsible nation with the mandating developed countries of the world.

It's a very bold and laudable step by a country that has only been responsible for 4% of global emissions but with huge need to grow its economy needing low-cost energy.

The rationale behind these bold commitments has been India' perceived vulnerability for loss of GDP growth due to Climate change effects and to share the commercial benefits from global net zero transition. Transition of the global economy to net zero emissions is history's biggest commercial opportunity. And India would benefit with active participation through suitable investments to reap advantages in technologies of the new economy across the entire value chain of renewable energy, electric mobility, hydrogen transport, e-diesel, sustainable industry and agriculture, smart and green cities.

## SOLUTIONS TO FACILITATE NET ZERO- A FIT CASE FORCARBON PRICING INSTRUMENTS

As for the implementation of India's commitments, the year 2070 may seem a long way off, but actions have to begin now. Major transformations will be needed in many spheres, including identifying prime drivers and major hurdles for this transition.

Designing appropriate national policies will be the prime initiative and requirement to support achievement of such goals. Global experiences have shown that an effective Market mechanism is one of the most cost effective and self-sustaining components of suite of policies designed to achieve climate change goals.

> It is proposed to government through appropriate policy interventions, to develop such market mechanism on a national level as soon as possible.

This proposed policy intervention would require development of **Carbon Pricing** instruments in India. Carbon pricing can take the form of Carbon Tax or Crediting, or a Carbon Emission Trading scheme =- a cap-and-trade system that depends on government allotments or permits.

- Carbon pricing is the instrument that captures the external costs of greenhouse gas (GHG) emissions that public has to pay such as damage to crops, health care costs from heat waves and droughts, and loss of property from flooding and sea level rise—and ties them to their sources through a price, in the form of a price on the carbon dioxide (CO2) emitted.

- A price on carbon helps shift the burden for the damage from GHG emissions back to those who are responsible for it and who can avoid it. A carbon price provides an economic signal to emitters and allows them to decide to either transform their activities and lower their emissions or continue emitting and paying for their emissions.

These are increasingly popular market mechanisms that harnesses market forces to address climate change by creating financial incentives for companies to lower their emissions by switching to more efficient processes or cleaner fuels.

In this way, the overall environmental goal is achieved in the most flexible and least-cost way to society. Placing an adequate price on GHG emissions is of fundamental relevance to internalize the external cost of climate change in the broadest possible range of economic decision making and in setting economic incentives for clean development.

Carbon pricing is a valuable instrument in the policy toolkit to promote clean energy transition. It can help to mobilize the financial investments required to stimulate clean technology and market innovation, fueling new, low-carbon drivers of economic growth, investments in low-carbon technological innovations, foster multilateral co-operation and create synergies between energy and climate policies.

## CARBON PRICING- OPTIONS

The main routes for carbon pricing are emissions trading, crediting and carbon taxes. The choice of approach will be important for government looking to create a carbon price indicator to drive emissions abatement within a sector or multiple sectors of the economy (e.g. industrial, commercial, residential, agriculture, transport). Emissions trading options, Crediting and carbon taxes can each be cost-effective and efficient ways to realize emissions reductions.

## EMISSION TRADING SCHEME (ETS)

- Emissions trading involves tradeable units that are used to represent emissions or emissions savings. It can take the form of a cap-and-trade ETS or a crediting mechanism. In an ETS, emissions are capped at predetermined level and the market establishes an emission price necessary to meet that cap.

- In an ETS, the main policy lever available to regulators is control of the volume of emission allowances. This is formulated as a cap and translated into emission allowances that are released to the market either for free or at a charge. Mandated participants are required to acquire emission allowances equal to their determined emissions over a compliance period and surrender these back to the system administrator

### CARBON TAX:

- A carbon tax allows regulators control over the price of carbon emissions; however, it shall have less direct control over the emissions reductions that are actually achieved. It creates a fiscal liability for the emission of GHG, and taxed entities may either incur the liability or reduce it by investing in abatement measures.

- In the same way as for emissions trading, regulated entities are incentivized to abate emissions where it is cheaper than the carbon price, but not where it is more expensive.

- A carbon tax creates a stable price signal for investment in emissions abatement, in so far as the tax rate is known and can be relied upon not to change.

### CREDITING MECHANISM

- In crediting mechanisms, emission reductions relative to a baseline or target are credited, which can be for specific projects, sector performance, or the result of policies. The price of credits is determined by demand/supply balance.

- Crediting may occur at the project or the programme level or involve the development of sectoral or policy-based approaches

- It's an important mechanism to enable financial and technology transfer and can be an effective tool to stimulate the growth of the low-carbon economy.

- Actors may purchase credits either for compliance (targets within the system) or voluntary purposes.

- For carbon taxes the key difference is that the price of emissions is set by policy makers rather than by a market mechanism. The price level determines the level of economically viable abatement and the emissions result that is achieved.

### PARAMETERS AFFECTING SELECTION OF RIGHT INSTRUMENT

Following parameters need to be factored in to decide the right instrument for our country:

- **Stakeholders Adaptability** ease of use and understanding of the stakeholders for each one of the instruments.

- **Infrastructure** and adaptability

to existing infrastructure. While Carbon tax can be much easily programmed to utilize existing infrastructure, Emission Trading needs market infrastructure.

- **Monitoring and reporting**. ETSs and carbon taxes require the establishment of robust systems for the monitoring and reporting of emissions, and use of emission reduction credits to ensure compliance.

- **Verification**: Both instruments create the requirement for high-quality confirmation of determined emissions, such as third-party verification. This may require access to a pool of suitably qualified and experienced independent and accredited verifiers.

- Priority **Sectors** that need to be targeted and Priority development objectives for our country will also drive policy decision.

## WAY FORWARD–CREATING INDIAN EMISSIONS TRADING SCHEME

Considering the various variables, existing market infrastructure of India' matured commodity trading markets like NCDEX (as Futures contract), which is already trading Carbon Credits, are well set to adapt to any similar system if started in India. Under Kyoto Protocol, India's carbon trading market bagged the second highest transacted volumes in the world by generating 30 million carbon credits in recent past.

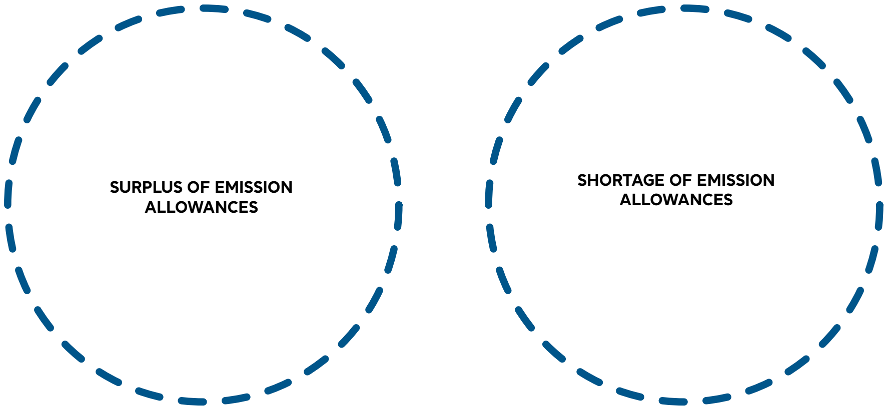
As such we propose that the best approach for our country to achieve rapid decarbonisation would be to start **INDIAN EMISSIONS TRADING SCHEME (Indian ETS)**, as key financial instrument to benefits investment flow in technology and to stakeholders.

The EU ETS has distinctly shown that EU ETS has been the cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. It is the world's first major carbon market and remains the biggest one so far.

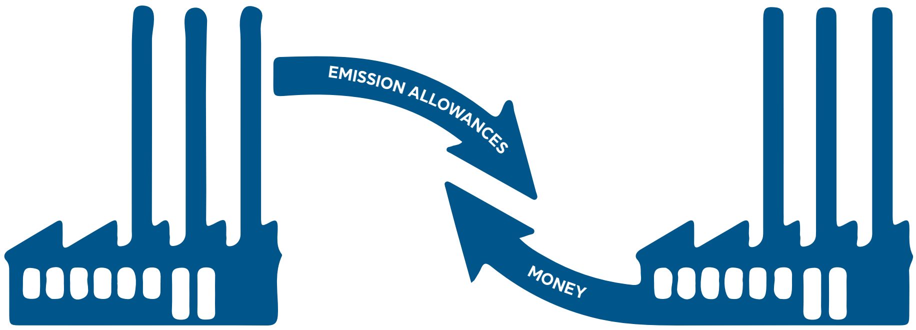
Emissions trading systems create incentives to reduce emissions where these are most cost-effective. Various global jurisdictions have shown increasing interest in emissions trading systems as a policy instrument to achieve climate change mitigation goals

Emissions trading, also known as 'cap and trade', is a cost-effective way of reducing greenhouse
gas emissions. To incentivize firms to reduce their emissions, government sets a cap on the maximum level of emissions and creates permits, or allowances, for each unit of emissions allowed under the cap.

Given below is brief introduction and key aspects of an ETS for the kind consideration of the government.




EMISSION TRADING




## BENEFITS OF NATIONAL EMISSIONS TRADING SCHEME

- Through ETS it's possible to achieve Climate Change mitigation objectives in terms of emission reductions at the lowest cost.
- ETS would incentivize Technology Innovation for lowest cost technology and processes to enable businesses to be more sustainable.
- ETS could be a more effective and potent tool to combat economic fluctuations.
- EU ETS has shown that Cap and Trade is better policy choice to combat climate change.
- With world-wide spread of Emission Trading schemes large opportunities would be presented to the stakeholders for further benefits.

## KEY COMPONENTS OF GHG CAP & EMISSIONS TRADING SCHEME:

The cap is a limit on the total GHG emissions for obligated participants covered by the system over a given period. Emissions allowances are created that represent, normally, one ton of carbondioxide (tCO2) or ton of carbondioxide equivalent (tCO2e).

## CAP & TRADE

A cap-and-trade programme can work in a number of ways, but as the basics, government issues a limited number of annual permits that allow companies to emit a certain amount of carbon dioxide. The total amount permitted thus becomes the 'cap' on emissions. Companies are taxed if they produce a higher level of emissions than their permits allow. Companies that reduce their emissions can sell, or 'trade,' unused permits to other companies.

## KEY ELEMENTS OF EMISSION TRADING SCHEME

The enabling structure for an Emissions Trading Scheme consists of three main elements.

- **System design or Framework**
  Functional rules that govern what it will cover and how it will function. These further include:
  - Coverage
  - Target and Cap
  - Allocation Methodology
  - MRV – Monitoring, Reporting and Verification
  - Compliance and Enforcement
  - Flexible Measures
- **Institutional infrastructure**
  It covers the implementation systems and regulatory oversight arrangements.
  - Registry
  - Trading Platform
  - Market Oversight
  - Regulation and Enforcement
- **Legal basis** for the system.
  - Emission Trading System Legal Foundation.

Thus, an ETS is structured with certain key elements, such as sector and GHG coverage; the cap; allocation of allowances; the monitoring, reporting, and verification (MRV) regime; compliance and enforcement regulations, and flexible measures that support participants or non-participants in managing costs and improving the robustness of the system in the case of unforeseen events such as economic downturns.

## INDIA' EXISTING INFRASTRUCTURE FOR EASE OF IMPLEMENTATION:

India has existing well-developed complementary infrastructure including fully developed latest technology within the country to implement ETS at quite minimal additional infrastructure inputs. It, however, requires detailed framework for allocation methodology, implementation, compliance enforcement and legal aspects.

Government can consider various relevant aspects to decide to plan and implement an Indian Emission Trading Scheme for the entire Industry to achieve required Climate Change and Net Zero by our targeted 2070.

While government may take time

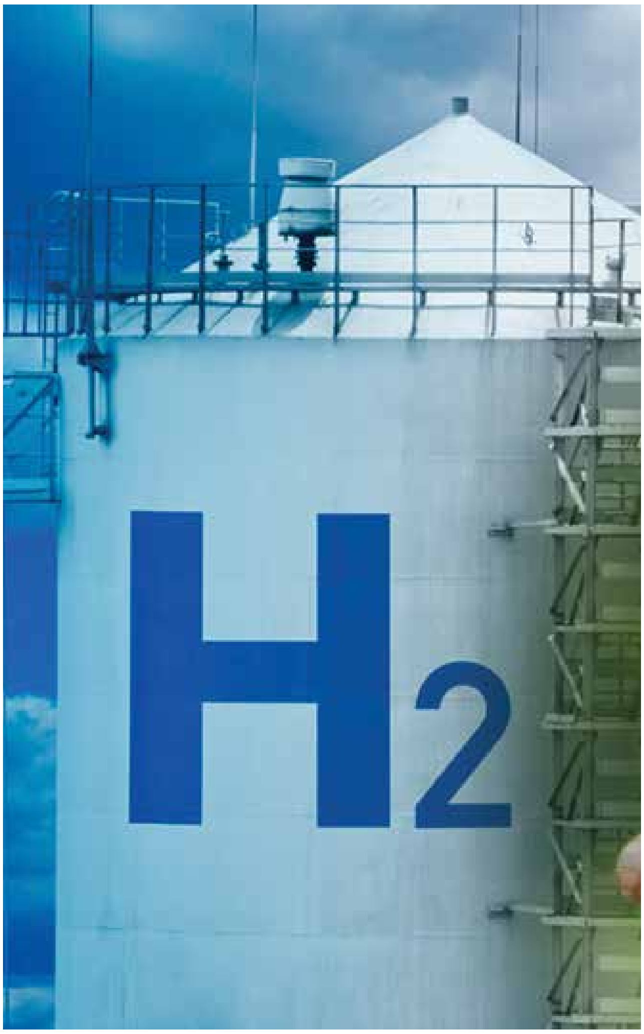
for planning, and implementing comprehensive Indian ETS, it is suggested that a pilot ETS for Hydrogen Offset Trading Scheme be started under National Hydrogen Missions at the earliest. It's due to the fact that low carbon hydrogen industry is just getting started and as such would be easier to initiate the scheme as hydrogen-based Carbon Offset base line identification would be easier to define at this time.

## HYDROGEN OFFSET TRADING SCHEME

A consensus is fast emerging that hydrogen will play a key role as an energy vector and will be a pillar in the ongoing energy transition to fulfil our commitments to climate change mitigation. Hydrogen is uniquely clean. It promises to accelerate transformative changes across many sectors, help decarbonize industrial processes & economic sectors, where reducing carbon emissions is both urgent and hard to achieve. Fertilizers, oil-refining, heavy industry like steel and heavy-duty transport are some hard sectors that likely will need hydrogen to decarbonize. Transport mobility is one of the major applications of low carbon hydrogen to reduce emissions.

Hence, it is critical for India to take steps to harness the hype of hydrogen to achieve our COP26 Net zero commitment. Through initiation of its National Hydrogen Mission, India has shown its intent and resolve to develop and utilize low carbon hydrogen as one of the major components of its transiting energy mix for a sustainable and successful tomorrow.

Key to developing low carbon Hydrogen as part of India' net zero transition will require effective cost reducing technologies, hydrogen distribution infrastructure and large investments. For good measure it requires strong well-devised regulatory direction and government's financial support, and thus Hydrogen Offset Trading Scheme will be in the right direction for the benefit of developing holistic Hydrogen Ecosystem.



## ENVIRONMENT, SOCIAL AND GOVERNANCE (ESG)

MAHENDRA RUSTAGI

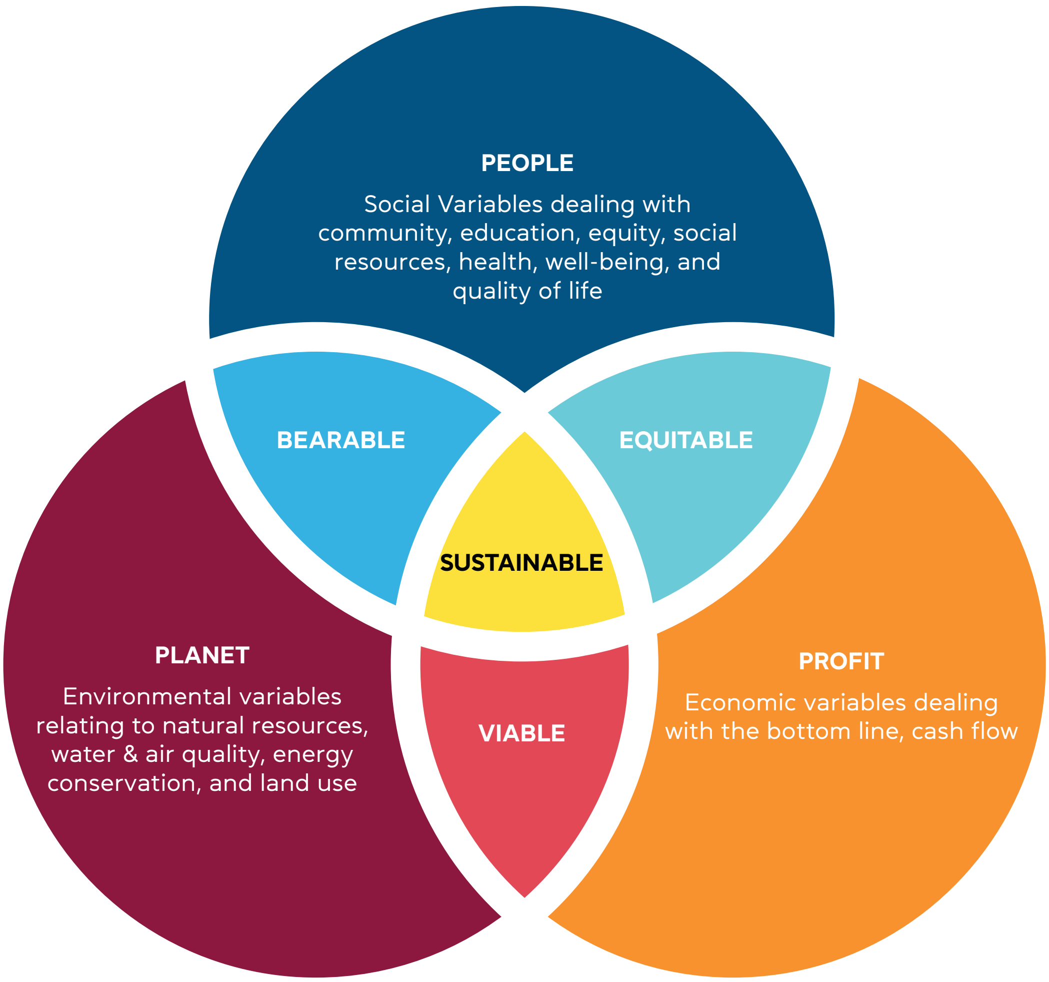
The landscape is charged, the horizon is tainted, and the sun never quite touches the surface. World over, there is realization about the importance of meeting ESG and Net Zero Goals.

There are three Postulates of creation; Environment, Society and Business. ESG is an interwoven matrix for doing business having due consideration for environment and society. ESG matrix helps in a more equal / fair distribution of benefits to the society at large without compromising the business objects of the organisation.

Environmental, Social and Governance are a set of standards devised to structure the organisation'sbehaviour toward Environment, communities and all the stakeholders affected by the organisation's activities. It is an approach to evaluate the working of the organisation on these parameters.

Business world over is assessed not only on the basis of its economic performance but also on the basis of how responsibly business is behaving on 3 pillars of ESG. ESG and Sustainability are generally misunderstood to be the same. Its therefore important to understand these 2 terms clearly. ESG is a matrix which is mainly used by the Investors to assess how responsibly the business behaves on Environmental, Social and Governance for the purpose of taking investments decisions. Sustainability on other hand is how the world sees a business / organisation on 3 parameters namely Economic, Environment and social. And most importantly on the top of it how is the Governance structure. **Sustainability is about development that meets the needs of the present without compromising the ability of future generations to meet their own needs.**

Sustainability in the business means creating balance between 3 Ps namely People, Planet and Profit. All these 3 elements need to co-exist for sustainable development. It can only be when business is Equitable to the People / Society, bearable for the Planet and also most importantly viable / profitable at the same time.



The organisations are being rated by rating agency on the basis of ESG Score. Rating though not mandatory presently, is done by rating agencies on the basis of Sustainability Report, Annual report and other materials available in public domain.

## ESG JOURNEY AND RECENT TRENDS

In India, the journey of ESG is much more recent. It started in 2011 with the framing of **National Voluntary Guidelines on Social, Environmental & Economic Responsibilities of Business (NVGs)**. BRR disclosure were mandatory for Top 1000 companies by market capitalization from Financial Year 2018-19. The name was changed to Business Responsibility and Sustainable Reporting (BRSR) from 2020. BRSR was voluntary for Financial Year 2021-22 but has become mandatory for Top 1000 listed

In EU ESG journey started in 1987, realizing that development is not a development unless it's a sustainable means development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The evolution journey remained normal till 2015 Paris agreement which gave birth to 17 SDGs setting specific aims for dimensions of Sustainability towards 2030.

2019 was a key milestone for EU when it came out with The European Green Deal with a plan to mobilize 1 trillion Euros to finance the transition with laying out the key policies and measures making it the largest efforts in the world.

In the Year 2020, EU introduced EU Taxonomy, a green classification system listing the economic activities that can be classified as Sustainable, making it easier for the banks and investors to identify the green and sustainable opportunities. In 2021, EU introduced decade 2021-30 plan which includes many action plans including CSRD Corporate Sustainability Reporting Directives. Under CSRD, Sustainability information would be made available and verifiable for a larger number of companies. All large companies, whether listed or not, meeting any two of the following criteria 250 Employees / Turnover 40 Million Euros / Assets 20 Million Euros. It will be effective in the year 2024 for the FY 2023. SMEs will get 3 years to comply. Reporting under CSRD would also need limited degree of verification which will be increased to reasonable degree in the year 2027. Over 50,000 companies are expected to be covered under CSRD.

EU has undertaken clean energy drive under which EU is targeting 40% energy through renewable source (its 22% in 2020) , 40 GW renewable Hydrogen Elecrolysers by 2030, and 10 Million MTs of Hydrogen by 2030.

Since 2019, **European investors poured Euro 120 billion into**

**sustainable investment** and investors are increasingly interested in how existing companies and startups are scoring on their ESG policies and practices, demonstrating the rising importance of ESG in Corporate Planning.

At the United Nations Framework Convention, COP 21, the Paris Agreement is brought to life, and at the United Nations General Assembly the Sustainable Development Goals, 17 in numbers were created. These Goals are common for all the countries for a sustainabledevelopment, these goals inter alia include Poverty, hunger, education, health, peace, justice, gender equality etc.

To assess and communicate the impact of organisation on parameters of environmental, society and corporate governance Global Reporting Initiative (GRI) was founded in Boston to provide independent standards, in 1997.

In 2000, another initiative -The United National Global Compact was initiated. This pact is 'a call to companies to align strategies and operations with universal principals on human rights, labour, environment, and anti-corruption. Four years later, through the UN Global Compact, the report 'Who Cares Wins– Connecting Financial Markets to a Changing World' provided guidelines for companies to incorporate ESG into their operations in 2004.

In 2015, at the United Nations Framework Convention, COP 21, the Paris Agreement was brought to life, and at the United Nations General Assembly the Sustainable Development Goals were created. The 2021 United Nations Climate Change Conference, COP26 was the 26th United Nations Climate Change conference. The result of COP26 was the Glasgow Climate Pact, negotiated through consensus of the representatives of the 197 attending parties.

According to the **European Green Deal, by 2050**, all member states will have circular economies, having achieved net zero emissions. While the European Union (EU) has a head start, the United States also has bold plans to decarbonize the economy and aim for net-zero emission target by 2050.

Assets under professional management that take ESG factors into account in the United States increased 42 percent between 2018 and 2020 from $12.0 trillion to $17.1 trillion, which is 1 out of every 3 dollars.

The United Nations Conference on Trade and Development (UNCTAD) estimates that the value of sustainability-related investment instruments (such as green bonds) reached between $1.2 trillion and $1.3 trillion in 2019. Greenfield FDI in renewable energy totaled $85.5 billion globally in 2020, hitting new highs and eclipsing FDI in fossil fuels for the first time.

During the last COP 26 held in November 2021 at Glasgow, India has given commitment to be carbon neutral by 2070. Bringing up the share of Renewable energy to 50% of the total energy usage by 2030 is also one of the major commitments given.

Commitments given by the Government is backed by numerous action points for the Government has been issuing guidelines and notifications on many fronts including regulating business impact on environment and society.

One of the many initiatives towards environment protection is allowing up to 20% ethanol – petrol mix. In fact 10% ethanol petrol mix is already achieved 5 months before the deadline of November 2022. This has reduced the carbon emission by 2.7 Million Tons which has saved the country 5.5 Bn $ on oil imports and also boosted the farmers income by over 5 Bn $ in last 8 years.

The Government of India has also taken many initiatives to save the soil by focusing on 5 factors.

Businesses can develop sustainability and ESG Strategies that achieve net-zero and circularity goals in compliance with 2050 targets remain profitable while maintaining access to financing through banks and capital markets.

The government of India has taken various steps to safeguard the environment. Some of the steps are Swachh Bharat Mission, Green Silk Development Programme, Namamigange Programme, Compensatory Afforestation Fund Act (CAMPA), National Mission for Green India,National River Conservation Programme, Conservation of Natural Resources and Eco-systems.

## ESG MUCH MORE THAN A STATUTORY NEED

ESG need is established beyond the statutory requirement. Business Responsibility and Sustainability

Report which top 1000 listed companies are required to issue every year is an initiative towards ensuring that investors have access to standardized disclosures on ESG parameters. Proven effects include smoother operations, positive morale and market enthusiasm for the ethical stance of the company. Making investments in ESG can produce positive results beyond solid financial performance.

ESG Compliance and Reporting creates a good public relations story and helps in building a stronger corporate brand. A robust ESG programme can open up access to large pools of capital. Fund managers use ESG considerations to identify risks and opportunities that could affect a firm's long-term sustainability. Many Corporates put ESG Compliances as a precondition to business relationships and tie-ups. Also, the Government is likely to provide incentives to businesses in form of subsidies and differential interest rates for achieving ESG goals and committed by our Prime Minister in COP 21 summit.

ESG has become an integral part of business operations and an important part of all future investment decisions. With more and more organisations adopting strict ESG Polices for investing and vendor selection, it will become very difficult for organisations, not adopting ESG, to compete and survive.

Further, a strong ESG proposition helps companies to:

- tap new markets and expand the existing ones leading to strong growth. When governing authorities trust corporate, they are more likely to award them the access, approvals, and licenses that afford fresh opportunities for growth.

- attract and retain quality employees, enhance motivation and increase productivity overall. Employee satisfaction is positively correlated with shareholder returns.

- better brand appreciation and loyalty towards products of ESG compliant companies thereby allowing them better pricing and valuations.

- better customer loyalty and premium pricing of product and organisations pursuing good ESG Practices can help companies achieve higher profits and consumer satisfaction.

- achieve greater strategic freedom, easing regulatory pressure. In fact, in case after case across sectors and geographies, we've seen that strength in ESG helps reduce companies' risk of adverse government action. It can also engender government support.

- **enhance investment returns** by allocating capital to more promising and more sustainable opportunities (e.g. renewables, waste reduction etc.). It can also help companies avoid stranded investments that may not pay off because of longer-term environmental issues.

- **Lower energy and water consumption** contributes to cost reduction and profit maximisation.

## ESG RATING ANALYSIS OF INDIAN CORPORATES BY CRISIL

An analysis by CRISIL research reveals that 20% of 586 Indian companies assessed come under strong and leadership matrix. And nearly 80% companies got placed as weak/below average. However, the silver lining is that most companies saw improvement in their ESG scores, driven by better disclosure and improved performance on various parameters. Leaders on ESG demonstrated a clear commitment towards sustainability, and have continuously delivered superior performance. In contrast those in the weak category have poor disclosure and inadequate ESG risk management practices.

The consideration of ESG in the decision making is very low because of lack of fiduciary commitment for ESG quotient. For ESG to be truly embedded and practiced in spirit, all the stakeholders will have to work collaboratively. A mindful shift is necessary to transform from merely complying to creating value. The performance of companies on the environmental parameter are weaker, compared with social and governance, as per the study by Crisil.

On social aspects, public sector undertakings fared better than private companies. PSUs fared better on key parameters, such as gender diversity, attrition and pay disparity. On Governance practices, especially board composition (women directors / independent directors) and functioning, Private sector companies fared better.

ESG is for business organisation what ECG is for heart. ESG is now becoming a measure of health and pulse of business organisations and a must for survival of the business ■

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## INDO-NORWEGIAN INITIATIVE TO MAKE INDIA SELF RELIANT IN GREEN HYDROGEN

GREENSTAT Norway    GREENSTAT Hydrogen India PVT LTD

GreenStat was established by Christian Michelsen Research (now a part of NORCE) in Bergen in 2015 and has evolved to become an independent player with nearly 1200 unique shareholders. GreenStat Hydrogen India Pvt Ltd is a Norwegian energy company with a specific focus on green hydrogen, solar, wind, and zero emission maritime solutions. The organizations collaborate to set up a Norwegian Centre of Excellence on Hydrogen in India and to support the development of Green Hydrogen Technologies in India.

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Gexcon is a world-leading company in the field of safety and risk management and advanced dispersion, explosion and fire modeling. Their experience arises from detailed knowledge of explosion phenomena built up through years of extensive research projects, carrying out safety assessments, performing accident investigations and conducting physical testing at the company's facilities. Their team of experienced engineers and specialists assists in identifying hazards, understanding risks and contributes to improving company's overall safety performance.

*India is an Attractive Destination for Green Hydrogen,* a knowledge book by the PHD Chamber of Commerce and Industry, India, documents the important initiatives taken by India, as the world slowly moves towards a Hydrogen economy.

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