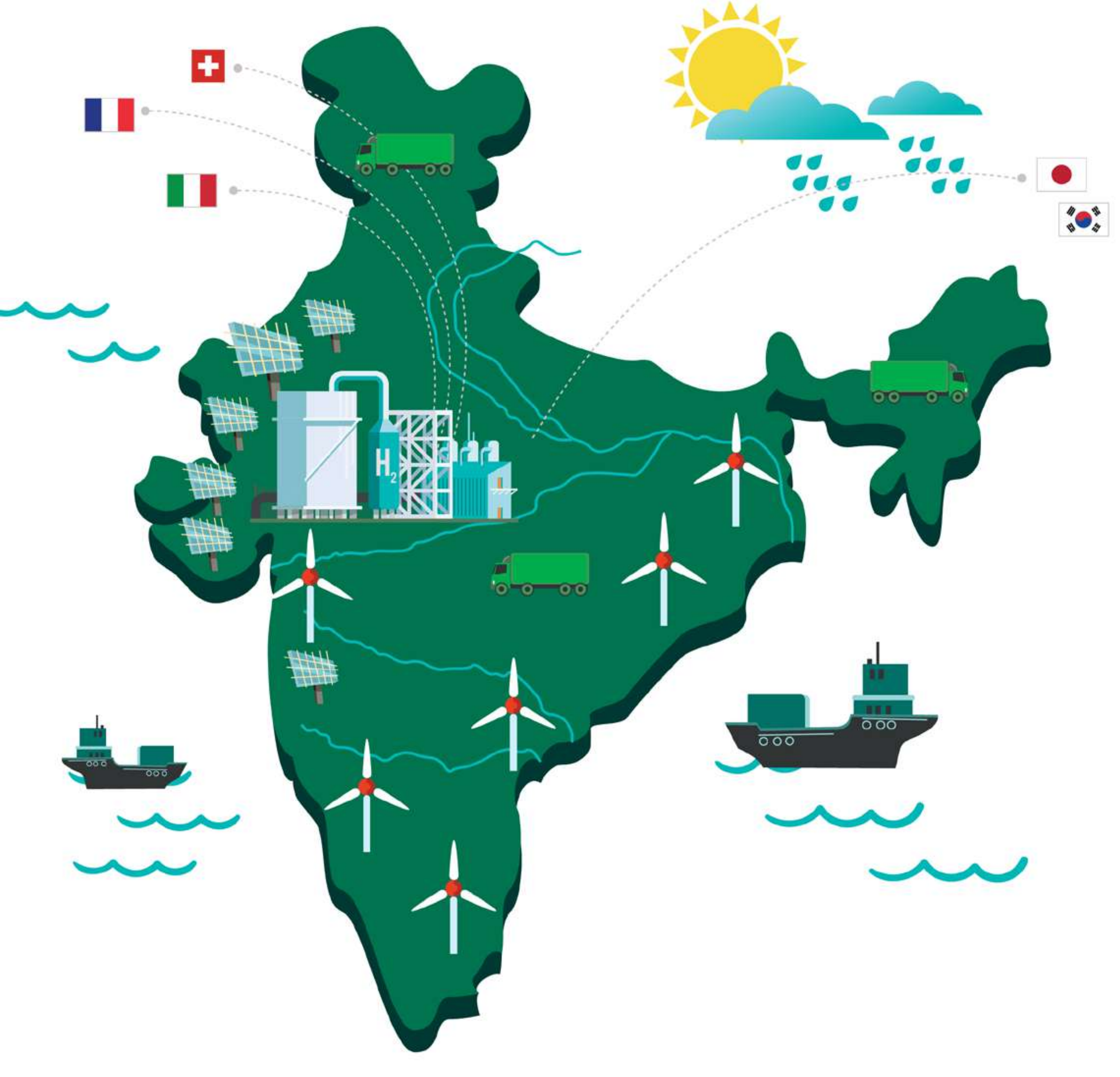
HOW AN AATMANIRBHAR BHARAT CAN BECOME A GLOBAL HUB FOR GREEN HYDROGEN



SMAHI

ABOUT SMAHI FOUNDATION OF POLICY AND RESEARCH

Smahi Foundation of Policy and Research is a non-profit organization based in Bengaluru. The word Smahi stands for progress. Smahi Foundation of Policy and Research (Smahi) works towards forward-looking policy making and harmonization of stakeholder views on issues of public policy to lead India towards progress. We focus on technology-led solutions to spur creation of stronger public digital infrastructure.

AUTHORS

RITU BHANDARI
Head of Research, Smahi

Ritu Bhandari is a Chartered Accountant and Chartered Financial Analyst, with extensive experience in the banking industry.

@Ritu_twt

RAJAT SEKSARIA
Director, Smahi

Rajat Seksaria is the Chief Executive Officer of the solar business at ACME. He is an MBA in major in Finance and Strategy from the Indian Institute of Management, Calcutta, and an Electrical Engineer from Gujarat University. Rajat is presently leading ACME's foray into Green Hydrogen.

@rajatsek

NIMISH JOSHI
Director, Smahi

Nimish Joshi is an engineer and MBA, with experience in conceptualizing, funding and scaling technology businesses.

@nimish_joshi

https://twitter.com/SmahiFoundation

© Smahi Foundation of Policy and Research, 2020. All Rights Reserved.

No part of this report may be copied, reproduced, distributed or transmitted in any form or by any means, including photocopying, recording or other electronic or mechanical methods, without the prior written permission of the Smahi Foundation for Policy and Research.

Contact us: smahifoundation@gmail.com

HOW AN AATMANIRBHAR BHARAT CAN BECOME A GLOBAL HUB FOR GREEN HYDROGEN

January 2022

Contents

Executive Summary

India, being a tropical country has a significant edge in Green Hydrogen production due to its favourable geographic conditions and abundant natural resources.

Producing hydrogen from renewables in India is likely to be cheaper than producing it from natural gas. Cheap solar tariffs mean the cost of powering the electrolysis process through surplus electricity at peak hours to generate hydrogen remains low. With abundant sunlight, it is estimated that India can generate over 1,000 GW of solar energy on just 0.5 per cent of landmass and sea water from the vast coastline can be used for the process of electrolysis.

As the world seeks ways to accelerate the pace of transformation in the energy sector, India with the right policy support, is in a unique position to not only become self-sufficient in green hydrogen but also produce green hydrogen for export markets.

The focus on producing clean energy through Green Hydrogen is in line with the Modi government's goal of producing of producing **450 GW** of RE by 2030 and in the process achieve emission goals under the Paris Agreement and reduce import dependency on fossil fuels.

Hydrogen can be produced by the electrolysis of water i.e. using an electric current to break water, H2O, into its component elements of hydrogen and oxygen. If this electric current is produced by a renewable source (e.g. Solar PV or a wind turbine or Hydropower), the clean hydrogen produced is known as green hydrogen.

The vast majority of industrial hydrogen, about 70 Mt is currently produced from natural gas through a conventional process known as steam methane reforming (SMR) with large quantities of by-product CO2. The dependence on natural gas and coal means that hydrogen production today generates significant CO2 emissions.

Currently, over 80 per cent of India's energy needs are met by three fuels: coal, oil and solid biomass. For India's energy transition to clean fuels, adoption of green hydrogen to generate energy would bring in significant benefits.

No greenhouse gases, particulates, sulphur oxides or ground level ozone are produced from the use of hydrogen. If the hydrogen is used in a fuel cell, it emits nothing but water. The transition to a hydrogen economy will not only reduce India's import dependency on hydrocarbon fuels but also provide clean air to its citizens, reduce green-house gas (GHG) emissions in absolute terms, mitigate carbon emissions and fulfil the Atmanirbhar Bharat vision.

The recent successes of solar photovoltaics (PV), wind, batteries and electric vehicles have shown that policy and technology innovation have the power to build global clean energy industries. Electricity constitutes only about 20 per cent of the primary energy that we as a country consume. RE has been used on the electricity side, but we have not been able to penetrate other 80 per cent of the energy consumption, which is where the hydrocarbons dominate and import dependence happens.

Hydrogen has the potential to help with variable output from renewables, like solar PV and wind, whose availability is not always well matched with demand.

Hydrogen is one of the leading options for storing energy from renewables and looks promising to be a lowest-cost option for storing electricity over days, weeks or even months. Hydrogen and hydrogen-based fuels can transport energy from renewables over long distances – from regions with abundant solar and wind resources, such as India, Middle- East, Australia or Latin America, to energy-deficient cities far away.

Hydrogen is versatile and can act as chemical storage, energy carrier as well as feedstock for industrial production.

Hydrogen's potential role in the power sector extends beyond its use as a fuel to its role as an energy carrier enabling long-term seasonal storage and dispatch flexibility. Green Hydrogen can open up plethora of options such as green Ammonia in the fertilizer sector or blending with natural gas or eventually generating power on a 24x7 basis.

India can decarbonise its energy-intensive sectors such as industry, transport and power by using green hydrogen.

Increased hydrogen use can substantially reduce GHG emissions in hard-to-abate sectors, particularly steel and cement production, heavy-duty transportation, shipping and aviation. Green hydrogen has particular potential in the context of India's industry sector, since it can be used in place of natural gas, coking coal or oil products. This means that steel, ammonia-based fertilisers and methanol – among other products, could all be produced with green emissions.

Transport has been the fastest -growing end-use sector in recent years and India is set for a huge expansion of transportation infrastructure –from highways, railways and metro lines to airports and ports. While transportation, particularly in long-haul, longer-range and high-fuel-consumption applications, will likely be the primary application area for green hydrogen by way of Hydrogen fuel cell electric vehicles (FCEVs), opportunities for the use of green hydrogen exist across the entire economy. This new sector of the economy will not only play a key role in decarbonizing transportation and energy but has the potential to create millions of high-quality, green jobs.

A key step that needs to be taken to speed up the rollout of green hydrogen technology is establishing a strong and sustainable domestic market for the production and use of hydrogen at home. We must create mandate-based hydrogen demand for ensuring scale. A strong domestic market will send an important signal, encouraging other countries to use hydrogen technology as well. By developing the green hydrogen market and promoting green hydrogen as a decarbonisation option, India can make a key contribution to climate change mitigation around the world.

WE EXPECT DEMAND CREATION FOR GREEN HYDROGEN TO HAPPEN IN THE FOLLOWING MANNER:

- Immediate demand for Green Ammonia;
- Gas blending and other industrial applications;
- Round-the-clock power by way of ammonia or hydrogen;
- Automobile fuels;
- Marine fuels by way of ammonia or hydrogen

The recent announcement of the National Hydrogen Mission will help transition India to a green hydrogen economy.

A mutual and co-operative approach within the government, renewable electricity suppliers, industrial gas producers, electricity and gas utilities and industry players along with enabling policy, regulatory and financing push, can make India a pioneer and global hub for green hydrogen.

SMAHI FOUNDATION HAS GIVEN RECOMMENDATIONS FOR INDIA TO ATTAIN LEADERSHIP IN GREEN HYDROGEN UNDER THE FOLLOWING HEADS:

Executive Outlook for Cleaner Energy

According to the WHO, 13 of the 20 most polluted cities are in India and over 50 per cent of the sites studied across India had critical levels of PM10 pollution.

The economic cost of Air Pollution was >5 per cent of GDP in 2018 in India. Air pollution in India causes > 1 million deaths every year that contributes > 10 percent of all deaths in the country, according to a report (2019) released by WHO. Life expectancy in India has gone down by 2.6 years due to deadly diseases caused by air pollution. The report also revealed that outdoor and household air pollution together are causing deadly diseases. "Air pollution is now the third highest cause of death among all health risks ranking just above smoking in India. This is a combined effect of outdoor particulate matter (PM) 2.5, ozone and household air pollution."

Despite very ambitious international climate goals, global energy-related CO2 emissions reached an all-time high in 2018. Outdoor air pollution also remains a pressing problem, with around 3 million people dying prematurely each year. Four-fifths of total final energy demand by end users today is for carbon-containing fuels, not electricity. In addition, much of the raw material for chemicals and other products contains carbon today and generate CO2 emissions during their processing.

The global energy sector has shifted a great deal, particularly in terms of efforts to strengthen policies to tackle the threat of climate change.

The growing number of net-zero emissions pledges by countries and companies reflects the increasing sense of urgency and accelerating momentum around clean energy transition.

Wind and solar produced 9.4 per cent of the world's electricity in 2020, doubling from 4.6 per cent in 2015. In the USA, electricity demand fell 2.5 per cent. The country produced 11.6 per cent of its electricity from wind and solar. Coal power fell 20 per cent in the USA. Europe led wind and solar generation around the world, with Germany producing 33 per cent and the UK at 29 per cent.

China saw a 4 per cent increase in electricity demand, which meant it was the only G20 country to show a large increase in coal generation (+1.7 per cent). The country produced 9.5 per cent of its electricity from wind and solar.

As solar and wind costs become cheaper, their expected share of the future primary energy mix rise. At high proportions of solar and wind power, the variability of their output poses a challenge. Because hydrogen can be stored or used in a variety of sectors, converting electricity to hydrogen can help with the matching of variable energy supply and demand, both temporally and geographically, alongside alternatives such as pumped-storage hydropower, batteries and grid upgrades.

Hard-to-abate emissions sources include aviation, shipping, iron and steel production, chemicals manufacture, high-temperature industrial heat, long-distance and long-haul road transport and especially in dense urban environments or off-grid, heat for buildings.

National Green Hydrogen Mission

Prime Minister Narendra Modi, on August 15 2021, formally announced the launch of a National Hydrogen Mission (NHM) to expedite plans to generate carbon-free fuel from renewables as he set a target of 2047 for India to achieve self-reliance in energy.

India could achieve self-reliance in energy through a mix of a gas-based economy, adding sugarcane extracted ethanol in petrol and electric mobility.

Stressing on the need for energy independence, Modi announced that the government intends to make India a global hub for Green Hydrogen production and exports, by augmenting its capacity in the production and storage of Green Hydrogen.

WHILE THE FINAL DRAFT/ ROADMAP OF THE MISSION IS STILL NOT RELEASED, IT IS EXPECTED THAT NHM WILL BE ON THE LINES OF OTHER SIMILAR NATIONAL-LEVEL MISSIONS LIKE NATIONAL SOLAR MISSION AND WOULD INTER-ALIA LIKELY TO INCLUDE THE FOLLOWING:

- Focus on Green Hydrogen vis-à-vis grey and blue hydrogen;
- Progressive Mandate for use of green hydrogen in refinery, fertiliser application and blending with Natural Gas;
- A roadmap for incentivization of green hydrogen export;
- A scheme to encourage domestic production of capital equipment (such as electrolyzers) which are required for generation of green hydrogen

INDIA'S COMMITMENT TO THE PARIS AGREEMENT

Currently, India has a total power generation capacity of 384 GW as compared to 175 GW, 10 years back. India has crossed a milestone of 100 GW in the total installed renewable energy (RE) capacity, 50 GW is under installation and 27 GW is under tendering.

The focus on producing clean energy through Green Hydrogen is in line with the Modi government's goal of producing 175 GW of RE by 2022.

Green Hydrogen, will help India achieve its emission goals of producing 450 GW of renewable energy by 2030, under the Paris Agreement and reduce import dependency on fossil fuels.

India has committed to reducing the emission intensity of economic activity by 33–35 per cent by 2030 (below the 2005 levels) under the Paris Agreement on climate change. To achieve this goal, the Government of India has drafted policies to reduce emissions from the power, industry and transport sectors, which contribute a lion's share of emissions to the economy.

UN has declared India as the global champion in the theme of energy transition. India is the only country among G-20 nations that is on the path of meeting its climate goals.

India stands at 4th position in the world in terms of installed RE capacity, 5th in solar and 4th in wind.

Solar, wind, biodiversity, land neutrality, climate change or waste recycling, organic farming, India is progressing in all these sectors.

The 195 signatories of the 2015 Paris Agreement on climate change agreed to raise their emissions reduction efforts towards net zero emissions from all sectors over the course of the century. In 2018, the Intergovernmental Panel on Climate Change found that global net anthropogenic CO2 emissions would need to reach net zero around 2050 in a pathway consistent with limited global temperature increases to 1.5°C (IPCC, 2018).

Green Hydrogen today appears to have a tailwind, with the opportunity to successfully build on this unprecedented momentum. ACME Solar group chairman, Manoj K Upadhyay reckons PM's initiative can help industry build a domestic green hydrogen ecosystem worth $2-3 trillion in 20-25 years. Green hydrogen is expected to emerge as a $12-13 trillion global industry by 2050.

INDIA'S SUCCESS IN SOLAR ENERGY

The rise of renewables in India's power sector has been a major success story; wind and solar PV now account for 7 per cent of total generation, twice their share in 2014. In 2015, the Indian government had announced a target of 175 GW of renewables by 2022 (excluding large hydro), which included 100 GW of solar and 60 GW of wind capacity, further expanding the RE capacity to 450 GW by 2030.

Over the past five years, solar PV capacity has grown at an average growth rate of around 60 per cent and wind capacity of around 10 per cent, outpacing the 7 per cent growth in overall installed capacity. India added nearly five times as much solar capacity as it did in 2015.

Solar PV projects are now the cheapest source of new power generation in India and are among the lowest cost in the world.

Ten years since the solar revolution began in the country, prices have dropped to a historic low of Rs 1.99 per kilowatt-hour (kWh).

Solar power is set for explosive growth in India, matching coal's share in the Indian power generation mix within two decades. The National Institute of Solar Energy has estimated that 750 GW of solar PV would need only 3 per cent of India's wasteland areas (TERI, 2017).

Cheap solar tariffs mean the cost of powering the electrolysis process through surplus electricity at peak hours to generate hydrogen remains low. Setting up hydrogen generation plants near solar parks will further reduce transmission costs.

This rapid growth reflects government policy support and falling equipment costs. The solar revolution was made possible by streamlining bureaucratic processes and forward-looking policies for a conducive market to inspire the confidence of private players. A similar approach is needed to increase the contribution of green hydrogen in India's energy mix.

INDIA'S HUGE ENERGY IMPORT BILL

To cater to the present energy demand, India imports petroleum and industrial grade coal. Currently India spends Rs 12 trillion annually to import fuels for its energy needs. At the moment, India imports 85 per cent of its crude oil, 24 per cent of coal and 54 per cent of gas requirements.

India possesses the world's fifth-largest coal reserves and the world's second-largest coal market, but nonetheless is one of the world's major coal importers. Domestic production of coal has been unable to keep pace with demand. Part of the import requirement arises from the steel industry's need for coking coal, which is far less abundant domestically than thermal coal.

India is a major centre for global oil refining, but relies overwhelmingly on imported crude. India has become the second -largest net oil importer after China. Crude oil is brought in by tanker from the Middle East, Latin America and Africa to Indian refineries along the western coast.

How is Hydrogen Generated?

Hydrogen is the lightest and first element on the periodic table. Hydrogen is also the simplest element on earth as it consists of only one proton and one electron. At standard temperature and pressure, Hydrogen is a non-toxic, non-metallic, odourless, tasteless, colourless and highly combustible gas.

The gaseous element is an energy carrier, not an energy source, but can be used to store, move and deliver energy produced from other sources. Hydrogen weighs less than air, hence it rises in the atmosphere and is therefore rarely found in its pure form, i.e. H_2.

There are no natural hydrogen deposits on earth, it has to be extracted from other compounds by a chemical process.

The energy industry refers to different "types" of hydrogen to differentiate how it is produced. Although the production of hydrogen remains primarily "grey" at the moment, the future of hydrogen is "green".

Grey Hydrogen:

The vast majority of industrial hydrogen is currently produced from natural gas through a conventional process known as steam methane reforming (SMR). As natural gas is relatively cheap, the hydrogen produced is also relatively cheap.

The standard SMR process has the considerable disadvantage of releasing large quantities of by-product CO_2 into the atmosphere.

CO_2 is well known to be a highly significant greenhouse gas. Methane itself has a global warming potential that is 85 times higher that CO_2, so any small gas leakage of methane from its source and through the process is also a significant contributor to climate change. The production of hydrogen using SMR is a major issue in our attempts to avoid climate disaster.

Grey hydrogen is produced through SMR without capturing the resulting greenhouse gases.

DEBATE ON GREEN HYDROGEN VS BLUE HYDROGEN

	GREEN HYDROGEN	BLUE HYDROGEN
HOW IS IT GENERATED?	Hydrogen can be produced by the electrolysis of water i.e. using an electric current to break water, H2O, into its component elements of hydrogen and oxygen. If this electric current is produced by a renewable source (e.g. Solar PV or a wind turbine), the clean hydrogen produced is known as green hydrogen.	When hydrogen is produced through SMR and in the process carbon dioxide as a by-product, is integrated with carbon capture and storage (CCS) technology.
CLEAN ENERGY	Green Hydrogen is completely clean, carbon-free and has the highest degree of purity Electrolysis processes take place in an electrolyser and the Hydro - gen gas so obtained is considered clean and carbon-free. As it leaves Oxygen as a by-product, it is beneficial for nature and does not cause any harm.	Blue hydrogen has a lower degree of purity. CCS technology only captures 85 per cent to 95 per cent of carbon emissions at best, so there would still be some level of emissions associated with blue hydrogen. Capture of CO2 may need to be audited as there could be differ- ences in measurement. Methane itself has a global warm - ing potential that is 85 times higher that CO2, so any small gas leakage of methane from its source and through the process is also a significant contributor to climate change.
COST	As per many Indian developers who are working on this, because of drastic reduction in RE cost, we are already close to $2 per kg, on which there is a global consensus, would be tipping point for wides- cale adoption of green hydrogen.	Currently, Blue hydrogen is esti- mated at $3/ kg

	GREEN HYDROGEN	BLUE HYDROGEN
	However, currently Green Hydrogen is considered to be more expensive than blue hydrogen in some regions. As per several academic studies, the cost of green hydrogen is $3-4/ kg or even higher. There appears to be diversion in assumptions of capital cost of the electrolysis process.	
EXISTING INFRASTRUCTURE	Large scale, new infrastructure will need to be put up to generate green hydrogen	Some additional equipment can be added to the existing infrastructure for carbon capture.
TRANSITION ENERGY	Green Hydrogen is looked upon as the clean energy that all countries must ultimately achieve. There is a general momentum towards green hydrogen as it is a completely clean energy.	Blue hydrogen can at best be seen as a transition fuel as there are carbon emissions. There is a view that that there needs to be a transition period in which blue hydrogen, which is cheaper and whose production is more easily ramped up to a commercial scale, should be relied on to provide a bridge to an economy in which the zero-carbon green hydrogen is predominant.

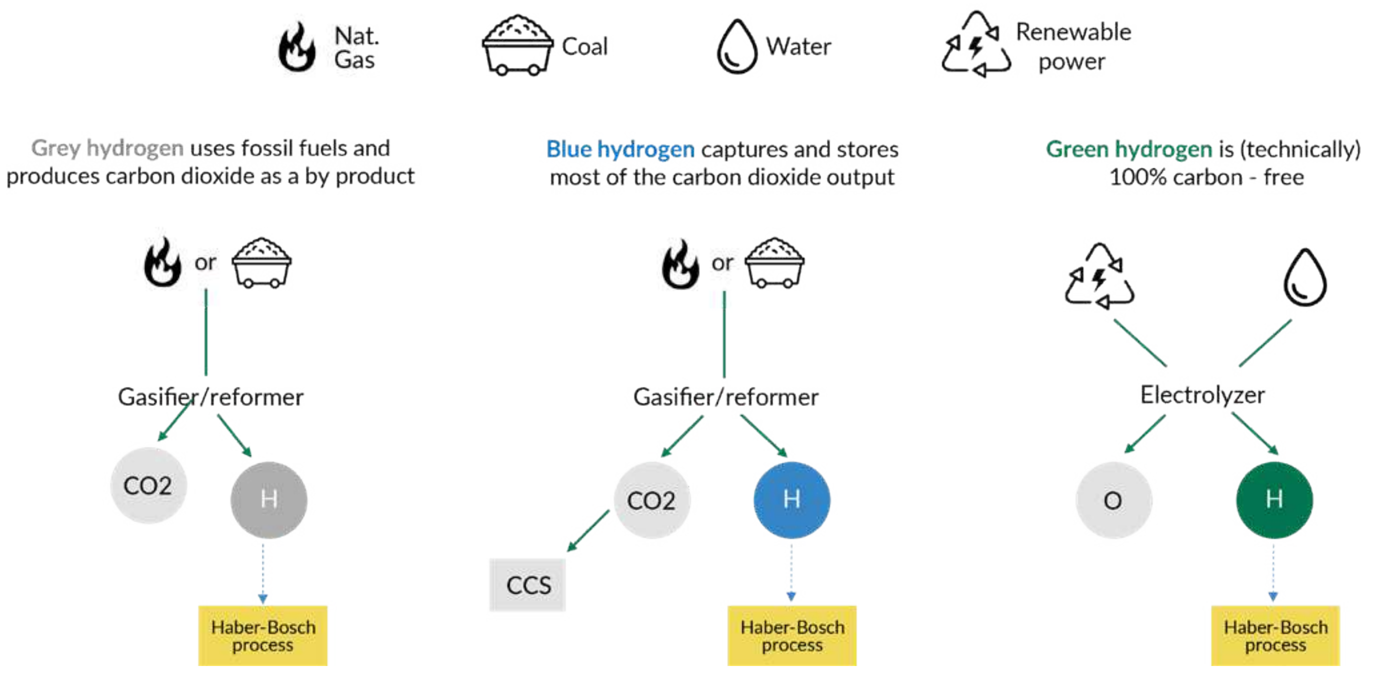
Brown/ black Hydrogen:

Produced from the gasification of lignite or bituminous coal, followed by steam reforming.

Pink/ purple/ red Hydrogen:

Produced through electrolysis powered by nuclear energy.

THE TERMINOLOGY: GREY/BLUE/GREEN HYDROGEN AND AMMONIA



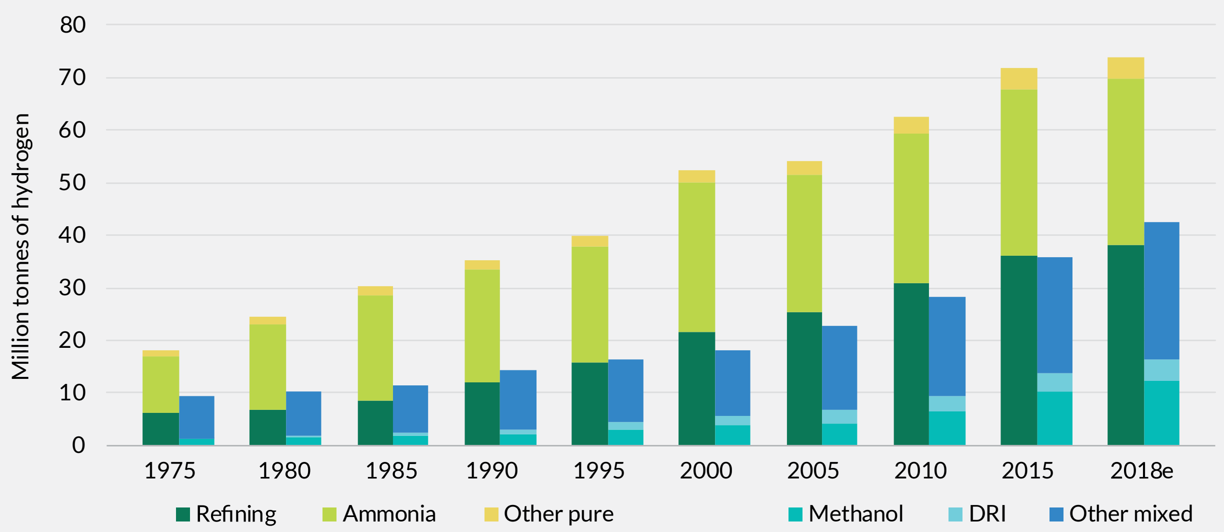
CURRENT HYDROGEN SCENARIO

The dependence on natural gas and coal means that hydrogen production today generates significant CO2 emissions.

According to IEA, most of hydrogen currently used in industrial processes is supplied from natural gas, followed by coal. A small fraction comes from oil and only 0.1 per cent from water electrolysis. Around 70 Mt of dedicated hydrogen are produced today, 76 per cent from natural gas and almost all the rest (23 per cent) from coal. In energy terms, total annual hydrogen demand worldwide is around 330 million tonnes of oil equivalent (Mtoe).

Currently, India consumes about 6 million metric tonnes of grey hydrogen per annum, which is about 8.5 per cent of the global hydrogen demand.

GLOBAL ANNUAL DEMAND FOR HYDROGEN SINCE 1975



Around 275 Mtoe of energy are used for the production of hydrogen today (2 per cent of global total primary energy demand). Annual hydrogen production consumes around 205 billion cubic metres (bcm) of natural gas (6 per cent of global natural gas use) and 107 Mt of coal (2 per cent of global coal use), with coal use concentrated in China.

As a consequence, global hydrogen production today is responsible for 830 MtCO2/yr. Most of this CO2 is emitted to the atmosphere, although in ammonia/ urea plants the concentrated CO2 streams from SMR (around 130 MtCO2 each year) are captured and used in the production of urea fertiliser.

The production of green hydrogen requires about nine litres of water to produce one kilogram of hydrogen, while blue hydrogen production requires about half that amount of water.

If all current dedicated hydrogen production were produced through water electrolysis (using water and electricity to create hydrogen), this would result in an annual electricity demand of 3,600 terawatt hours (TWh). Water requirements would be 617 million m3 or 1.3 per cent of the water consumption of the global energy sector today; this is roughly twice the current water consumption for hydrogen from natural gas.

The combined costs of renewable electricity and electrolyzer technologies makes green hydrogen more expensive to produce than blue hydrogen.

Role of Hydrogen in Abating Emissions

Hydrogen has the potential to help with variable output from renewables, like solar photovoltaics (PV) and wind, whose availability is not always well matched with demand. Hydrogen is one of the leading options for storing energy from renewables and looks promising to be a lowest-cost option for storing electricity over days, weeks or even months.

Hydrogen and hydrogen-based fuels can transport energy from renewables over long distances – from regions with abundant solar and wind resources, such as India, Middle East, Australia or Latin America, to energy deficient cities far away.

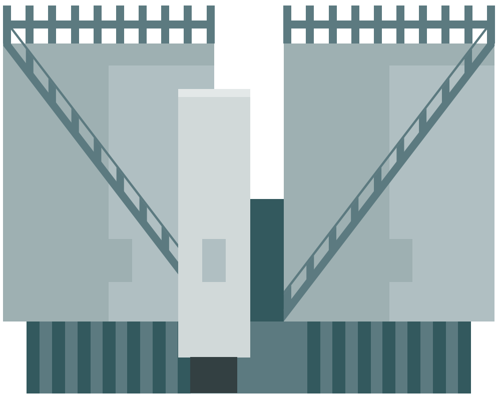
Hydrogen's potential role in the power sector extends beyond its use as a fuel to its role as an energy carrier enabling long-term seasonal storage and dispatch flexibility. Hydrogen is not an energy source but an energy carrier, which means that its potential role has similarities with that of electricity. Both hydrogen and electricity can be produced by various energy sources and technologies. Both are versatile and can be used in many different applications.

Hydrogen is better than electricity because it can be stored, unlike electricity; electricity transmission has limitation i.e. require grid lines for transmission and hence is usually not cross-border. Unlike electricity consequently, countries can source their hydrogen requirements from multiples countries without compromising their energy security.

Without hydrogen a decarbonised energy system based on electricity would be much more flow-based. Flow-based energy systems must match demand and supply in real time, across wide distances and can be vulnerable to disruptions of supply. Chemical energy can add a stock-based element to an energy economy and thus contribute significantly to energy system resilience.

Hydrogen can be used without direct emissions of air pollutants or greenhouse gases. No greenhouse gases, particulates, sulphur oxides or ground level ozone are produced from the use of either hydrogen or electricity. If the hydrogen is used in a fuel cell, it emits nothing but water.

As a low-carbon chemical energy carrier, hydrogen is a leading option for reducing hard-to-abate emissions because it can be stored, combusted and combined in chemical reactions in ways that are similar to natural gas, oil and coal.



If renewable power generation becomes sufficiently cheap and widespread, it can be used not only to provide low-carbon electricity, but also to create green hydrogen that can displace fossil fuels in transport, heating and industrial raw materials and indeed almost any application not susceptible to electrification.

Hydrogen can also be used as a feedstock for industrial production, not just energy. All this makes hydrogen one of a suite of technologies that work well together to support the growth of low-carbon energy at the level of the overall energy system.

As renewable energy costs plummet and reductions of electrolyzer costs look more promising, hydrogen technology powered by renewable electricity is expected to make a significant contribution to the carbon-free economy in the coming decades.

Some operators of natural gas grids are now exploring the opportunity to replace natural gas partially with alternatives that have a lower CO2 intensity, including hydrogen. Transition pathways that make use of existing infrastructure, assets and skills could be easier and cheaper to navigate than the alternatives.

END-USES OF HYDROGEN

THE TOP FOUR SINGLE USES OF HYDROGEN TODAY (IN BOTH PURE AND MIXED FORMS) ARE:

oil refining	ammonia production	methanol production	steel production via the direct reduction of iron (DRI) ore
33%	**27%**	**11%**	**03%**
for desulfurizing petroleum products	mainly for fertilisers	used in vehicle fuel	

Today, hydrogen is used mostly in oil refining and for the production of fertilisers. For it to make a significant contribution to clean energy transitions, it needs to be adopted in sectors where it is almost completely absent at the moment, such as transport, buildings and power generation.

POTENTIAL USES OF HYDROGEN INCLUDE:

- Green Ammonia for production of Fertilizers (Ammonia/ Urea) replacing fossil fuel as feed stock
- Hydrogen Blending with CNG for existing CNG Vehicles (HCNG)
- Hydrogen use for Industrial applications e.g. Steel, Refineries, Fertiliser, Food, Plastic etc.
- Hydrogen for Energy Generation as Energy Storage with Grid Scale Renewable Plants for providing round the clock clean power
- Hydrogen mixing with Carbon Dioxide (Captured from Air) for producing useful products such as – Methanol, Ethanol, Gasoline

POTENTIAL USES OF HYDROGEN INCLUDE:

- Hydrogen use for running Gas based Turbines for Electricity Generation
- Hydrogen Fuel for Fuel Cell Vehicles thus ensuring zero emission from transportation sector
- Oxygen as a by-product: Electrolysis requires water as well as electricity. Around 9 litres of water are needed to produce 1 kgH2, producing 8 kilograms (kg) of oxygen as a by-product, which at smaller scale can be used in the health care sector or at a larger scale for industrial purposes.

Hydrogen can help tackle various critical energy challenges. It offers ways to decarbonise a range of sectors – including long-haul transport, chemicals and iron and steel – where it is proving difficult to meaningfully reduce emissions.

Hydrogen can be used alone or combined with other inputs such as carbon, to produce hydrogen-based fuels and feedstock, such as synthetic methane, synthetic liquid fuels and methanol. Hydrogen can be combined with nitrogen to produce ammonia to be used as chemical feedstock or fuel. Ammonia and synthetic fuels can use existing infrastructure for transport, storage and distribution.

In the meantime, low-carbon hydrogen could be blended into existing processes that are currently based on natural gas and coal to lower their overall CO2 intensity.

Fertilizer

Fertilizers play an important role in agriculture by providing the required nutrients for crops to grow. Currently fossil fuels such as LNG, Coal are used to produce Ammonia/ Urea using Haber Bosch process and this process emits carbon.

Green Hydrogen can be used to produce Green Ammonia by Haber Bosch process with zero carbon emission.

Green Ammonia can be used to make Urea, Ammonia Nitrate and other associated chemicals. This can also reduce import of LNG (natural gas) in India. All the required technologies are readily available to setup Green Ammonia plants. Germany, Norway have already installed pilot plants to produce Green Ammonia. 20 per cent green ammonia procurement shall be mandated across all end user segments.

Why ammonia?

Similar to fossil fuels, ammonia is both a chemical energy carrier and a potential fuel, where energy is released by the breaking of chemical bonds. Crucially, ammonia has the advantage of not releasing any carbon emissions if used as a fuel.

Ammonia can be synthesized from nitrogen and hydrogen via various methods, with the Haber-Bosch process currently the only method used on a commercial scale. The resulting ammonia can be easily transported, stored and the hydrogen can be extracted again at the destination via a thermal decomposition and separation process. There are a number of key features that make ammonia particularly suitable as a green hydrogen carrier.

Ease of storage and transportation:

The energy storage properties of ammonia are fundamentally similar to those of methane. The volumetric energy density of ammonia is 150 per cent of liquid hydrogen and these hydrogen densities can be achieved at near ambient storage conditions. This contrasts with the high pressures or low temperatures needed to achieve useful volumetric hydrogen density with pure hydrogen. Ammonia also has lower explosive limits in air than pure hydrogen. As a result, the storage of hydrogen is more difficult, energy intensive and expensive than storing ammonia.

Established logistics and end-use markets:

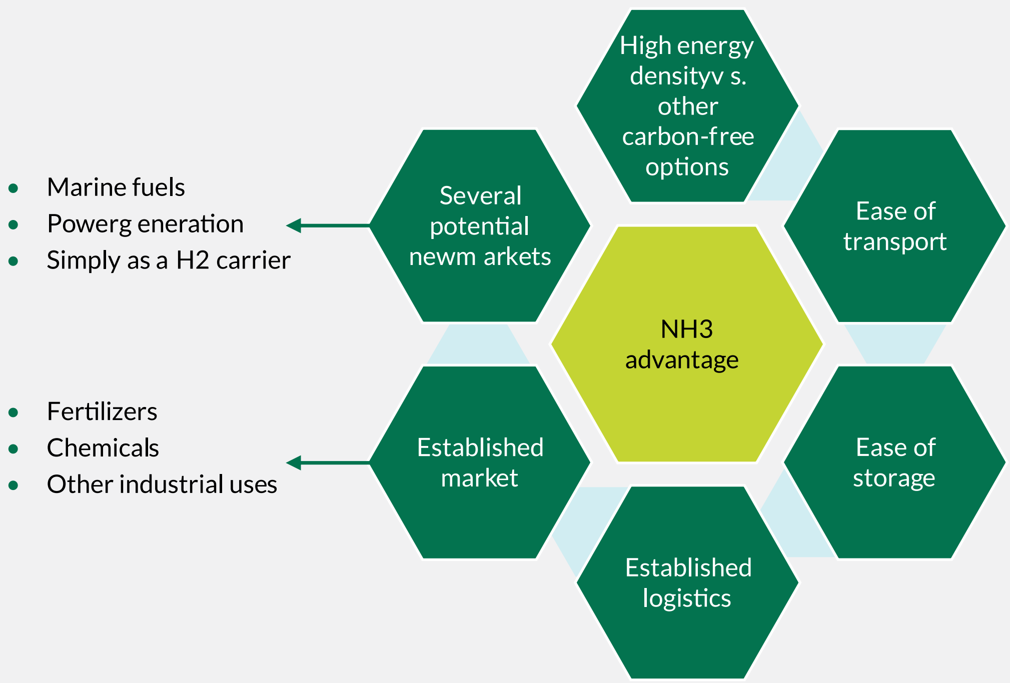
There is a high level of maturity in the ammonia supply chain thanks to its widespread use as a feedstock for inorganic nitrogen containing fertilizers and a variety of other industrial chemicals. Ammonia can count on an established global storage and trading infrastructure.

High hydrogen density compared to other potential hydrogen carriers.

Potential uses as a fuel:

Crucially, ammonia can be used directly in ammonia-fired turbines and engines

AMMONIA AS A HYDROGEN CARRIER-KEY ADVANTAGES



HCNG

Green Hydrogen can be blended (20 per cent) with natural gas for use in transportation and heating application. It can be mixed in the existing gas pipeline or in the cylinders.

There is no modification required in current CNG operated vehicles for use of HCNG. So, it can be implemented with immediate effect. Use of HCNG in vehicles will reduce the carbon emission by 20 per cent immediately caused by CNG vehicles.

USA and UK have already started blending hydrogen in natural gas pipeline for transportation and heating/ cooking application at home.

Hydrogen for Refineries and Industry

There are certain industries like refineries, fertiliser, steel, food processing, chemicals etc that use hydrogen by cracking natural gas which releases carbon dioxide. These are existing applications of Hydrogen and such industries can immediately start using Green Hydrogen produced through renewable sources.

A 20 per cent blending of green hydrogen shall be mandated to be used in refineries.

Power generation and Energy Storage

Hydrogen gas has the largest energy content of any fuel, making it a very good carrier for storing and distributing energy. It can be used in Fuel Cell to produce electricity on demand. Power sector is the largest contributor of carbon emission in India.

Green Hydrogen can be used as energy storage media when integrated with renewable power plants (Solar/ Wind) and can provide power to the grid 24 hrs/ day thereby reducing dependence on conventional power plants and enabling reduction in carbon emission.

Europe and USA have already started to install Fuel Cell based power plants.

Hydrogen Fuel for Power Generation in Gas Turbines

Green Hydrogen can also be used as fuel in the large Gas Turbines (MW range) that can provide 24x7 power to the national grid.

Existing natural gas based power plants which are not operating to the designed capacity, can use green hydrogen to generate power with zero emission.

Green Fuel for Transport Sector

Green Hydrogen can be mixed with Carbon Dioxide to make green fuel (gasoline or methanol) through Fisher Tropsch process.

Currently, various fossil fuels such as Petrol, Diesel and CNG are used as fuel in transportation sector. Transportation is the 2nd largest contributor of carbon emission in India (and also globally).

This process captures carbon from the ambient air or from the carbon emitting industries. This process is completely carbon neutral as no more carbon is added in the environment through this process rather it uses carbon from the atmosphere. This green fuel can be used in transportation sector without any modification in any part of current eco system.

Germany, Norway have already installed pilot plants to produce such green fuel. This solution can be implemented by setting up Fischer Tropsch process integrated with renewable power plants. This will reduce import bill of India significantly thereby becoming self-dependent.

Hydrogen Fuel for Transportation Sector

Green Hydrogen can be used as fuel in vehicles by using it with Fuel Cell Vehicles. These type of vehicles use Fuel Cell Systems (instead of conventional engine) that converts Hydrogen Gas into electrical power and then electrical power is used to operate electric motor to drive Fuel Cell based Vehicles.

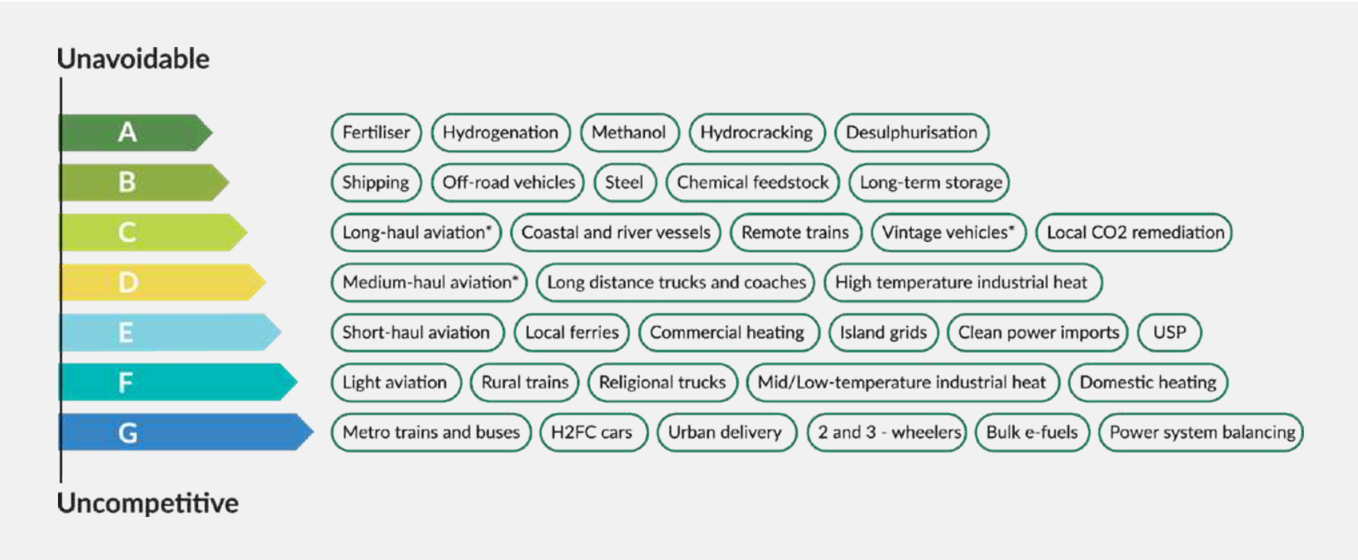
This is a kind of Electric vehicle with zero emission in the whole value chain i.e. from well to wheel. Hydrogen refuelling stations can be installed (like CNG stations) for refuelling of Hydrogen Gas. It takes only 5 – 8 minutes to refill the gas in any fuel cell vehicle (Bus/ Car/ Truck). Introduction of Hydrogen based Fuel Cell vehicles can significantly reduce dependence on imported crude oil. Hydrogen Fuel Cell Vehicles can give range of > 500 km in one gas fill. More than 11,000 nos of Fuel Cell vehicles and 300 nos of Hydrogen Refuelling Stations are operational globally and it is rapidly gaining momentum now.

The leading FCEV car manufacturers are Toyota and Hyundai, both of whom have ambitious plans for scale-up. Toyota's announced target is to produce over 30,000 fuel cell electric cars annually after 2020, from about 3,000 (Tajitsu and Shiraki, 2018). Hyundai also has production capacity of around 3,000 fuel cell systems and aims to increase this to 700,000 by 2030, with 70 per cent for road FCEVs (Kim, 2018).

In the case of trucks, several established truck manufacturers – Hyundai, Scania, Toyota, Volkswagen, Daimler and Groupe PSA – are developing models, as are newer companies such as Nikola Motor Company, founded in 2014.

Green Hydrogen Ladder:

Michael Liebreich has illustrated the use cases of green hydrogen in a merit order by way of a Green Hydrogen Ladder.



HYDROGEN FUEL CELL VS BATTERY ELECTRIC CARS

	Tesla Model 3 Long Range AWD	Toyota Mirai 2
Price	$46,900	$49,500/ $66,000
Curb weight	1,844 kg	1,930 kg
Range	353 miles	402 miles
Number of seats	5	5
Luggage/Cargo space (cubic feet)	15 ft3 (~43 ft3 with seats down)	9.6 ft3 (seats don't fold down)
Acceleration 0-60mph, top speed	4.2 seconds, 145 mph	9.0 seconds. 111mph
Refuel time, petrol station	250 miles (10% - 80%): 20 minutes	402 miles: 5 minutes
Refuel time, home, office, mall	< 1 minute to plug in	Not possible
Drive train moving parts	17	>200
Wind-to-wheel efficiency	>61%	<32%

Challenges of Hydrogen

Low density requiring more storage space

Hydrogen has the highest energy content of any common fuel by weight, but it also has the lowest energy content by volume.

For example, it has around three times more energy content than gasoline by weight, but around four times less energy content by volume, requiring larger volumes and storage space for the same energy content.

Similarly, hydrogen has around three times more energy content than natural gas by weight, but only about a third of the energy density per unit of volume. As a result, hydrogen-natural gas blends would require greater gas volumes to maintain the same energy content of natural gas only. For example, around 3.3 cubic feet of hydrogen would be required to generate the same level of energy as a cubic foot of natural gas. Hydrogen also requires greater pressure for gas compression and lower temperatures for liquefaction relative to natural gas.

Requires Special equipment since it is very light

As a light gas of small molecules, hydrogen requires special equipment and procedures to handle it.

Hydrogen is so small it can diffuse into some materials, including some types of iron and steel pipes and increase their chance of failure. It also escapes more easily through sealings and connectors than larger molecules, such as natural gas.

Highly flammable

Hydrogen is a non-toxic gas, but its high flame velocity, broad ignition range and low ignition energy make it highly flammable. This is partly mitigated by its high buoyancy and diffusivity, which causes it to dissipate quickly.

It has a flame that is not visible to the naked eye and it is colourless and odourless, making it harder for people to detect fires and leaks.

Hydrogen transportation through ammonia, although done for decades, is more concerning for health and safety because ammonia is highly toxic, flammable, corrosive and could leak in gaseous form.

Globally producing hydrogen from low-carbon energy is costly at the moment

As per many Indian developers who are working on this, because of drastic reduction in RE cost, we are already close to $2 per kg for Green Hydrogen, on which there is a global consensus, would be tipping point for widescale adoption of green hydrogen.

IEA analysis finds that the cost of producing hydrogen from renewable electricity could fall 30 per cent by 2030 as a result of declining costs of renewables and the scaling up of hydrogen production.

Fuel cells, refuelling equipment and electrolysers (which produce hydrogen from electricity and water) can all benefit from mass manufacturing.

The development of hydrogen infrastructure is slow and holding back widespread

Hydrogen prices for consumers are highly dependent on how many refuelling stations there are, how often they are used and how much hydrogen is delivered per day.

Tackling this is likely to require planning and co-ordination that brings together national and local governments, industry and investors.

Conversion Losses

There are also significant electricity losses in the conversion of hydrogen into hydrogen-based fuels and feedstock.

In addition to high costs, there are significant efficiency losses associated with its production, which can range anywhere from around 30 per cent to over 70 per cent based on the technology used, making its production more expensive than the electricity or natural gas used to produce it.

STORAGE, TRANSPORTATION AND DISTRIBUTION OF HYDROGEN

The rapidly decreasing cost of renewable power generation is putting "green" hydrogen under the spotlight as a promising energy carrier for a number of applications. However, the storage, handling and transportation of hydrogen is notoriously challenging, and there are a range of mature and emerging hydrogen carrier and storage technologies being studied for potential commercial applications.

Favourable conditions for green Hydrogen include abundant and cheap renewable generation, large water sources, geological formations – such as high-quality deep saline formations that can be turned into salt caves for hydrogen storage, extensive hydrogen pipeline network and regional industrial demand.

Hydrogen is one of the leading options for storing energy from renewables and looks promising to be a lowest-cost option for storing electricity over days, weeks or even months. Hydrogen and hydrogen-based fuels can transport energy from renewables over long distances.

Hydrogen is versatile. Technologies already available today enable hydrogen to produce, store, move and use energy in different ways. It can be transported as a gas by pipelines or in liquid form by ships, much like liquefied natural gas (LNG). It can be transformed into electricity and methane to power homes and feed industry and into fuels for cars, trucks, ships and planes.

Hydrogen can be transported from its point of production via trucks, trains, pipelines or shipping.

The regional distribution of hydrogen through new pipelines or retrofitting current natural gas pipelines is gaining traction. Trains and ships also transport hydrogen, in either liquid or gaseous form, across regions. The choice will depend on the location of the supply centre, costs, the proximity to demand centres and in some cases, the presence or lack of existing dedicated or adaptable infrastructure (i.e. hydrogen pipelines or natural gas pipelines).

Transmission of hydrogen as a gas by pipeline is generally the cheapest option if the hydrogen needs be transported for distances of less than about 1,500 km. For longer distances, transmission as ammonia or Liquid Organic Hydrogen Carriers (LOHC) may well be a more cost-effective option, especially if the hydrogen needs to be moved overseas, even taking into account the costs of converting hydrogen into ammonia or LOHC and back again. For local distribution, pipelines are cost-effective for distributing high volumes of hydrogen over longer distances; in other cases trucks are likely to be the cheaper option.

Hydrogen is much more combustible than natural gas and some of its properties may require significant alteration and refurbishment of existing pipelines, burners and turbines for it to be used safely.

Studies are still underway about the viability of increasing hydrogen into the fuel blend for use in power generation. Producing, transmitting and using hydrogen may require new precision-engineered products, such as storage tank or pipeline materials and burners.

Hydrogen has low energy density, which makes it more challenging to store and transport than fossil fuels. However, it can be converted into hydrogen-based fuels and feedstocks, such as synthetic methane, synthetic liquid fuels and ammonia, which can make use of existing infrastructure for their transport, storage and distribution.

This can reduce the costs of reaching final users. Ammonia is already used today as a feedstock in the chemical industry and could be a hydrogen carrier for the long-distance transport of hydrogen in the future or itself be used as fuel in the shipping sector.

Hydrogen can be compressed or liquefied for storage and transport, a process that is far from ideal due to high capex and opex requirements, as well as significant safety risks. Another method of transporting hydrogen via sea is to chemically convert the hydrogen molecule into an energy carrier such as ammonia, methanol or liquid organic hydrogen carriers. Ammonia is emerging as the most promising carrier owing to a number of factors.

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.

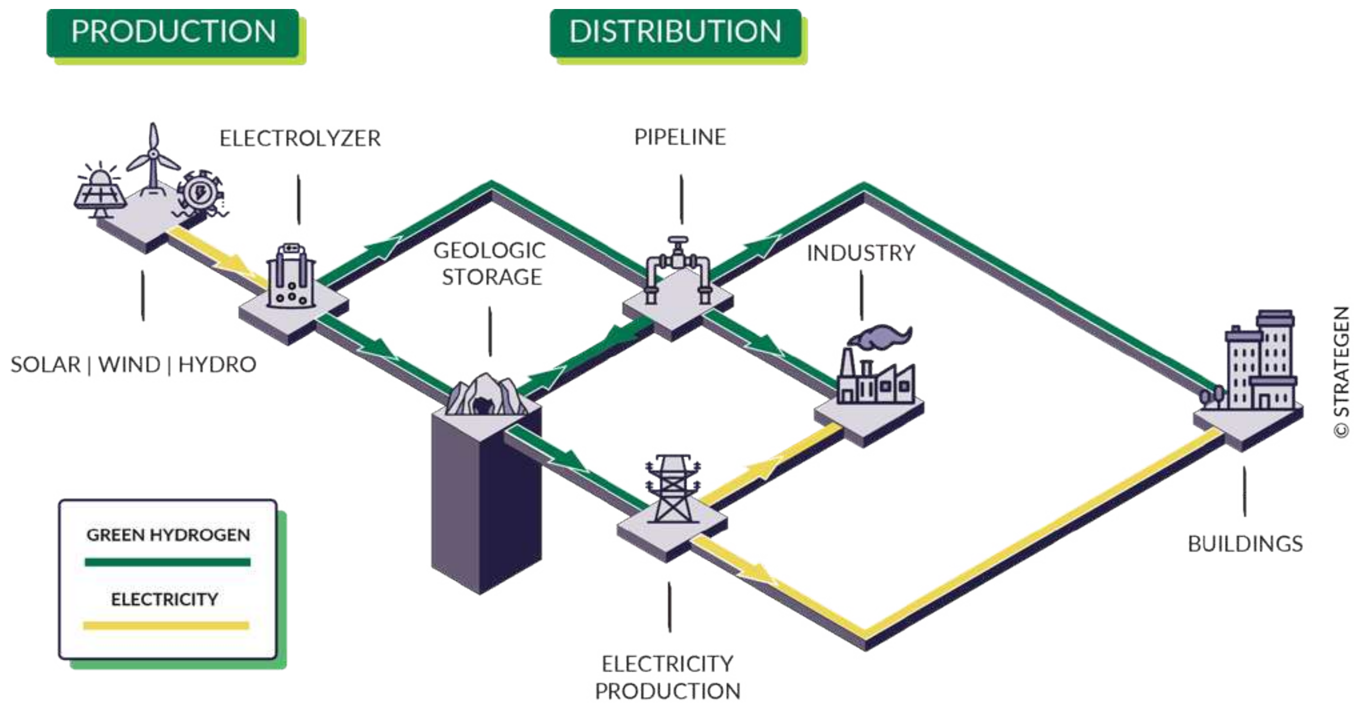
The installation of hydrogen refuelling infrastructure, while relatively limited to date, has picked up momentum in the past few years. Hydrogen refuelling stations for road transport vehicles, including both publicly accessible and private refuelling points, reached a worldwide total of 381 in 2018. Japan (100), Germany (69) and the United States (63) are the three countries with the highest numbers of publicly available hydrogen refuelling stations.

Compressed hydrogen (at 700 bar pressure) has only 15 per cent of the energy density of gasoline, so storing the equivalent amount of energy at a vehicle refuelling station would require nearly seven times the space.

Opportunities for off-grid hydrogen generation and storage systems have emerged from improvements in integrated designs of electrolysers, hydrogen storage and fuel cells.

Containerised systems are in development that can be paired with off-grid energy supplies to provide backup power for important facilities such as hospitals and electricity storage for longer periods than battery-based systems.

PRODUCTION AND DISTRIBUTION PATHWAYS OF GREEN HYDROGEN - ELECTROLYSIS EXAMPLE



TECHNOLOGY

Three main electrolyser technologies exist today: alkaline electrolysis, proton exchange membrane (PEM) electrolysis and solid oxide electrolysis cells (SOECs).

There has been a surge in projects for producing hydrogen for energy and climate purposes in recent years. Since 2000, around 230 projects have entered operation around the world to convert electrical energy to hydrogen for a range of energy and climate applications.

Among these projects, both alkaline and PEM electrolysers are commonly used: recent projects have tended to favour PEM, possibly reflecting the fact that many of them test environments for less mature technologies that have high potential for cost reduction.

SOECs which promise higher efficiencies, are also beginning to enter this market.

There is a debate on which would be the eventual global technology for electrolysis whether alkaline or PEM. Though alkaline is cheaper, there could be some issues of integration with variable power supply of renewables.

To date, electrolyser sizes for these installed projects have been no higher than 10 megawatts (MWe) (with modules of 2–4 MWe), and generally much smaller. However, a 20 MWe project is currently under construction and several project proposals are above the 100 MWe milestone. A number of the projects have demonstrated the further conversion of hydrogen to synthetic methane, methanol, ammonia and other hydrogen-based fuels and feedstocks.

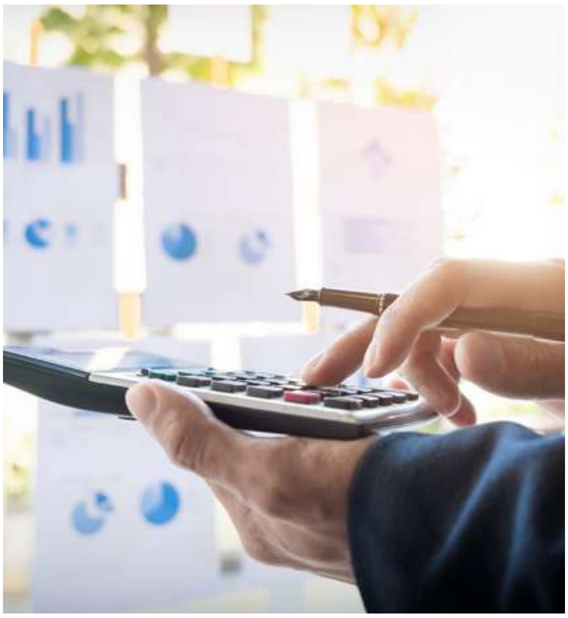
Electrolysers share technical attributes with batteries and fuel cells, creating opportunities to co-locate research hubs and exploit synergies.

Many stakeholders today share the opinion that technologies such as fuel cells, water electrolysers, hydrogen refuelling and hydrogen turbines are now mainly waiting for large-scale demand and standardisation and not further technological development. Fuel cell costs, in particular, are expected to greatly benefit from mass manufacturing

Hydrogen fuel cells provide instantaneous power generation and also aid in demand response. The latter is especially relevant as hydrogen bridges the gap between fluctuations in power generation for renewable energy systems (RES) and a grid powered solely by renewables.

Hydrogen fuel cells solve demand response problems by acting as a power source as well as reserve energy for months. Fuel cells are also in use for marine, land and aviation operations, as well as in ships, trains, planes, drones, cars, trucks and buses.

HYDROGEN ECONOMICS



The price of hydrogen varies widely between regions and end uses (different end uses require different volumes, pressures and purity levels of hydrogen); it also varies according to the way that hydrogen is transported.

As per many Indian developers who are working on this, because of drastic reduction in RE cost, we are already close to $2 per kg for green Hydrogen, on which there is a global consensus, would be tipping point for widescale adoption of green hydrogen. Currently, Green hydrogen and green ammonia can be produced in India, at a cheaper cost than grey hydrogen and grey ammonia as shown in the table below.

Cost of Production of Blue Hydrogen with CCUS	$3/ kg
Cost of Production of Grey Hydrogen	$1.3/ kg and with carbon tax $3 /kg (as per Red II Act)
with carbon tax $3 /kg (as per Red II Act)	with carbon tax $3 /kg (as per Red II Act)
Cost of Production of Green Hydrogen	$2-2.5/ kg (assuming energy cost of 2-2.5/ kwh tariff)
Historical market price of Grey Ammonia	~ $300 - $350/ tonne
Present market price of Grey Ammonia	$600/ tonne+
Blue Ammonia with CCUS	$520/ tonne
Cost of production of Green Ammonia	$400-450/ tonne (assuming energy cost of 2-2.5 cents/ kwh tariff)

Source: Industry feedback
Note: As per RED II, a carbon tax of € 50/tonne is currently being levied on carbon emissions

However as per several academic studies, the cost of green hydrogen is $3-4/ kg or even higher. There appears to be diversion in assumptions of capital cost of the electrolysis process.

Cost estimation for onsite - green Hydrogen production

The cost of Renewable Energy and Electrolyzer Capex & Opex are the key parameters to decide Green Hydrogen Production cost. Currently, no company manufactures Electrolyzers in India and it needs to be procured from Global market till India creates its manufacturing capability.

An Electrolyzer requires 60 KWH (55 KWH for power + 5 KWH for compression @ 200 Bar, approx) energy to produce 1 kg of Green Hydrogen by water electrolysis. It is quite possible to achieve Green Hydrogen Production cost <= $2/ Kg even today under certain assumptions as explained below

- If we continue to buy PV Modules & Inverters from global market and with import duties waived off on Solar equipment, it is possible to achieve renewable energy tariff < Rs 2/ KWH and another Rs 60 - 70/ Kg on account of Electrolyzer Capex & Opex, (assuming zero import duty on Electrolyzers), the estimated cost of green hydrogen production comes at ~ $2.5/ kg currently.

- With the generally declining prices of solar equipment, notwithstanding, the recent increase due to supply disruptions, it is quite possible that Renewable Energy tariff will further fall in the range Rs 1.4 to 1.6/ Kwh in near future.

In addition, if the Green Hydrogen also is pegged in $ in India like oil & gas, then the Green Hydrogen Production cost can go below in the range of $ 1.6 to 1.75/ kg in the near future

- Green Hydrogen can be used to synthesis Green Ammonia and it requires 178 – 180 kg of Green Hydrogen to make 1 Ton of Green Ammonia. Green Ammonia is easy to transport in bulk and required transportation infrastructure already exists in India. Assuming green hydrogen cost to be ~ $1.75/kg, the cost of production of green ammonia can be approx $ 400/ tonne locally.

- **If Green Ammonia is also pegged in $ in India and taxes are waived off, then the Green Ammonia cost can go below in the range of $ 350 – 375/ MT. With the declining renewable energy tariff, when the cost of Green Hydrogen further reduces to < $1.5/ kg, then the Green Ammonia price will go below $300/ MT.**

The price of Grey Ammonia in the global market varies from $250 – 500/ MT. Currently EU, Japan & many other nations have shown interest in buying green ammonia at a price of ~ $500 - 600/tonne currently itself whereas resulting in green ammonia cost of ~ $300/tonne which may support India's emergence as an export hub for green ammonia in the international markets and accrue corresponding trade benefits.

» Green Ammonia can also solve India's energy security needs by providing a cost-effective means to not only store energy but also provide 24X7 electricity to its citizens.

Assuming cost of oil @ $ 80/ barrel (~$ 45/barrel crude oil x refining cost + corresponding energy losses) and energy content of 1,628 KWH/ Barrel, it translates to $ cents 5/ KWh storage cost. Ammonia could be an alternate for large energy reserve, assuming Ammonia @ < $ 300/ MT the cost of storage will be around 5.7 $ cents/ KWH.

» Battery Storage:

Indeed, the Battery cost has reduced by over 80 per cent in last 10 years and battery can be a storage alternate only for certain applications like peaking power, frequency regulation or short duration energy backup (2 to 4 hrs max.) with renewable power plants.

Battery may not be economically viable and technically feasible for long duration GW scale storage and especially when it comes to achieve 24 x 7 renewable grid, Ammonia can be economically viable option to meet such requirement.

» Assuming current battery cost of around $ 150/ KWh in the global market, it translates to finally USD 270 – 280/KWh installed cost including it's de-rating & other associated BOP cost. This leads to storage cost in the range of Rs 10 – 11/ Kwh + cost of renewable energy on account of battery charging.

So the total battery storage cost comes to Rs 14 – 15/KWH. Even if the battery cost further goes below $ 80/KWH, the total battery storage cost will still be in the range of Rs 10 – 11.

On the other side, Ammonia can be an economical option especially for 14 – 18 hrs long storage to provide renewable power 24x7 to the grid. It is easy to store and transport in bulk quantity. Assuming Ammonia cost <$300/ Mt, it can be used for power generation through engine/ gas turbine and the cost of stored energy will be in the range of Rs 9-10/ Kwh

» Considering above scenario, the average renewable energy cost @ 24x7 operation using ammonia storage can be in the range of ~ Rs 5/kwh, whereas the average renewable energy cost with battery storage will > Rs 8/kwh. Therefore, the cost of renewable power with ammonia storage is going to be less than upcoming new thermal power plants per unit cost of generation resulting in economic benefits for the country.

Transport and storage costs will play a significant role in the competitiveness of hydrogen.

If hydrogen can be used close to where it is made, these costs could be close to zero. However, if the hydrogen has to travel a long way before it can be used, the costs of transmission and distribution could be three times as large as the cost of hydrogen production. The costs of providing hydrogen to FCEVs can be brought down by building larger refuelling stations as long as expected hydrogen demand allows.

Costs could be further reduced in the future through research-driven advances in technology. It may be possible to increase catalyst activity and thus reduce the platinum content, which is one of the expensive components of the fuel cell. It may also be possible to develop a platinum-free catalyst. Research is also needed to optimise the design and integration of fuel cell components in the membrane electrode assembly and to decrease the costs of the bipolar plates (which are expected to account for an increasing share of the future costs) and balance of plant components (e.g. compressors and humidifiers).

India's Energy and Emissions Scenario

Energy consumption in India has more than doubled since 2000, propelled upwards by agrowing population– and a period of rapid economic growth.

Prior to the pandemic, India's energy demand was projected to increase by almost 50 per cent between 2019 and 2030, but now the growth over this period has slowed down to 25-35 per cent.

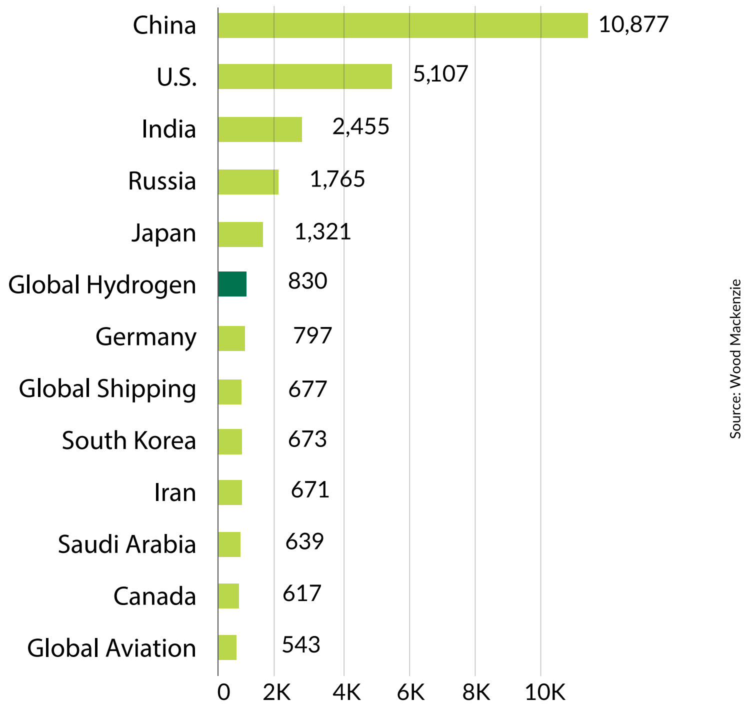
India is likely to witness a huge surge in energy demand in a post-pandemic world to realise rapid economic growth. Until now, India's economic growth has been driven mainly by the services sector, rather than the more energy-intensive industry sector.

An expanding economy, population, urbanization and industrialization mean that India sees the largest increase in energy demand of any country up to 2040.

As India develops and modernises, it's rate of energy demand growth can be estimated to be three times the global average.

The World Energy Outlook 2018 estimated that India's industrial and transport emissions, as a share of its total energy emissions, will rise from 37 per cent in 2017 to 50 per cent in 2040 (International Energy Agency [IEA] 2018).

2017 CO_2 EMMISSIONS BY COUNTRY & SECTOR IN MEGATONS OF CO_2 PER YEAR



PER CAPITA BASIS

Energy use on a per capita basis in India is well under half the global average

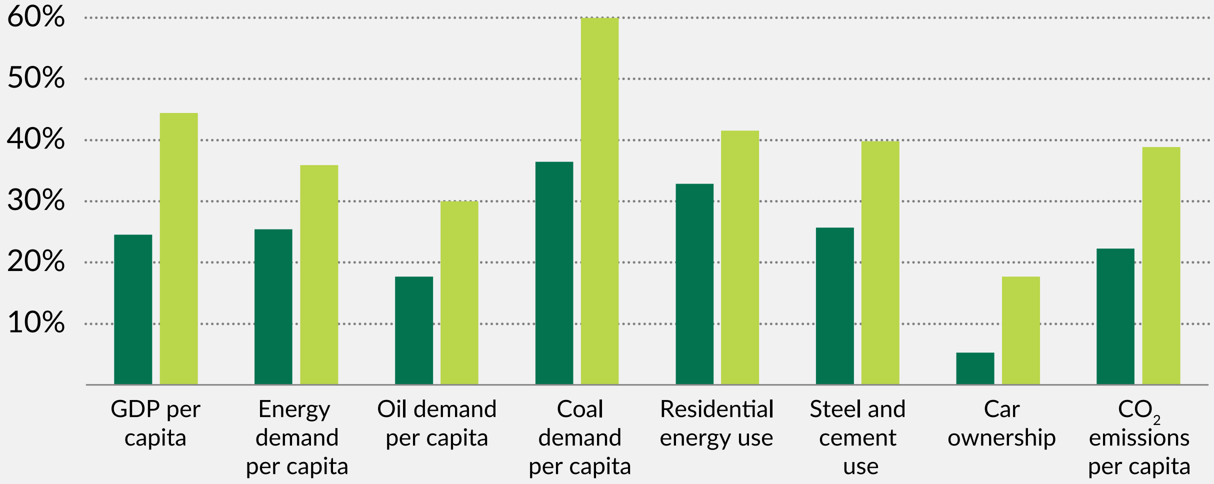
India's emissions per capita rank among the lowest in the world today and it accounts for only about 3 per cent of historic energy sector and industrial process CO2 emissions since 1850 (compared to 30 per cent for Europe, 25 per cent USA and 15 per cent China).

India is the third-largest global emitter of CO2, despite low per capita CO2 emissions. Though Coal meets 44 per cent of India's primary energy demand, it is responsible for 70 per cent of India's energy sector CO2 emissions.

The carbon intensity of its power sector in particular is well above the global average at 725 gm of CO2 per kilowatt-hour (g CO2/kWh), compared with a global average of 510 g CO2/kWh, underlining the predominant role of inefficient coal-fired generation.

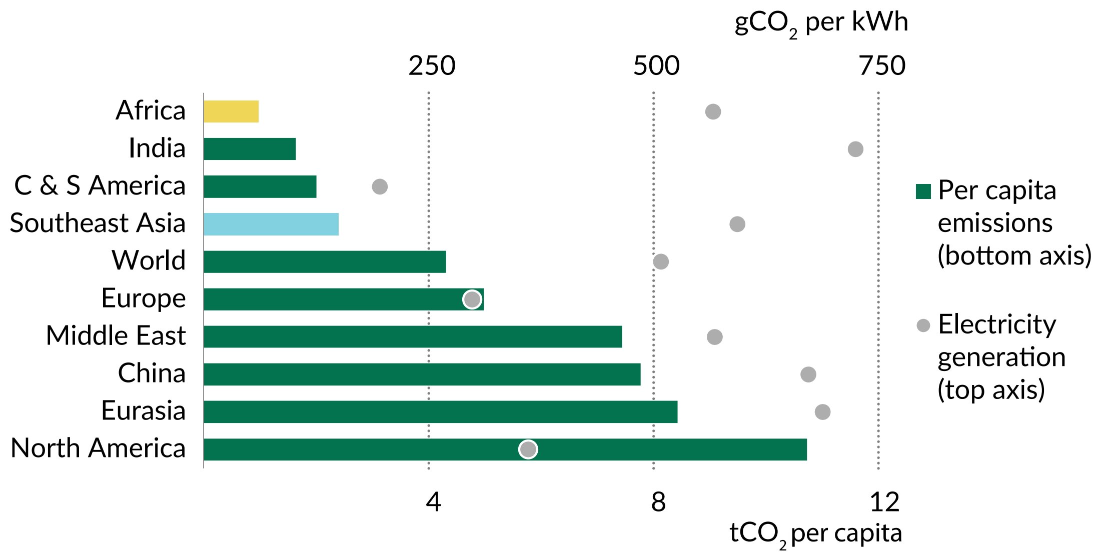
Coal demand per capita increased from 25 per cent of the world average in 1990 to 60 per cent in 2019 and mainly for this reason, CO2 emissions per capita increased from 20 per cent to around 40 per cent over this period.

KEY INDICATORS IN INDIA AS A PERCENTAGE OF GLOBAL AVERAGES



Key energy and economy indicators of India are well below the global average, although they have been steadily rising.

CO_2 EMISSIONS PER CAPITA AND EMISSIONS INTENSITY OF ELECTRICITY GENERATION BY REGION, 2020



India's per capita CO2 emissions are 60% lower than the global average, but the emissions intensity of its electricity generation is among the highest of any country.

INDIA'S ENERGY RESOURCES

Currently, over 80 per cent of India's energy needs are met by three fuels: coal, oil and solid biomass. Solar accounts for less than 4 per cent of India's electricity generation and natural gas 6 per cent.

Coal

Coal is the dominant energy source, in power generation and for many industries (especially heavy industries such as iron and steel). Coal demand nearly tripled between 2000 and 2019. Today, coal meets 44 per cent of India's primary energy demand, up from 33 per cent in 2000.

Oil

Oil demand has more than doubled since 2000 as a result of growing vehicle ownership and road transport use. Oil demand for road freight transport in India has tripled since 2000, highest after China. More than 45 per cent of emissions from road transport in India come from trucks. India's heavy- freight trucks have a relatively high level of fuel consumption per tonne kilometre compared with other countries.

Emissions from passenger road transport in India have also quadrupled since 2000. India has a high share of two- and three-wheelers in its vehicle fleet (four-fold of passenger cars) and this helps to explain why passenger cars in India accounts for only 18 per cent of its overall transport emissions (merely 36 per cent even if two- and three-wheelers is added). This is lower than many other countries; in USA, for e.g. passenger cars account for 57 per cent of total transport emissions.

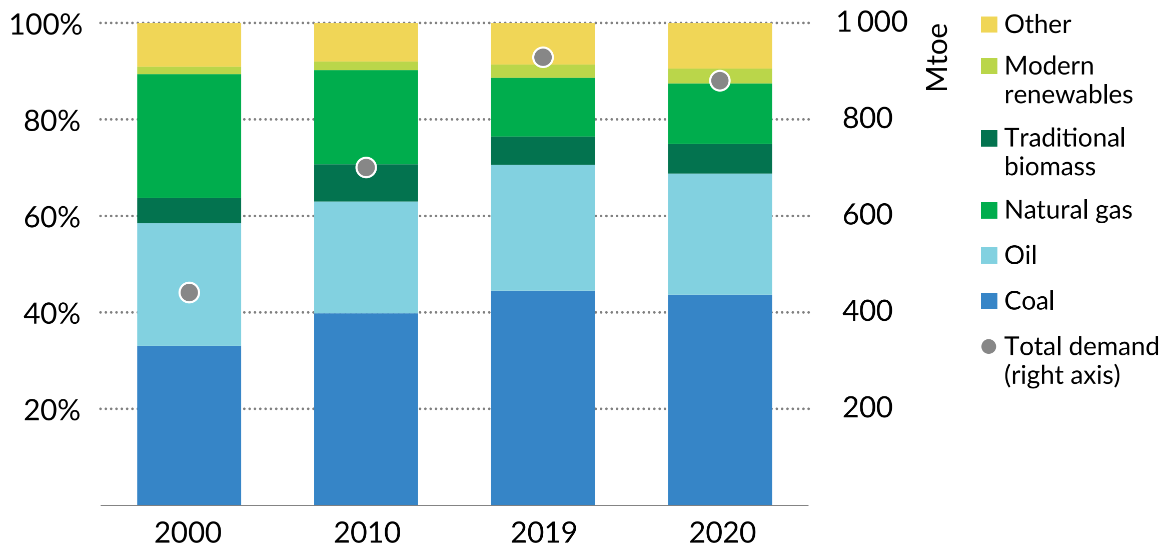
Biomass

Traditional biomass – primarily fuelwood but also animal waste and charcoal – was the largest energy source in India in 2000 after coal, constituting about one-fourth of the primary energy mix. Overall energy demand has doubled since then, but the share of traditional biomass in the energy mix has been decreasing: it fell to 12 per cent in 2019, largely as a result of efforts to improve access to modern cooking fuels, in particular LPG, which has been subsidised and promoted by the government.

Natural Gas

While the share of natural gas in India's primary energy mix has largely remained flat in recent years at around 6 per cent, overall energy demand has risen rapidly. The use of natural gas as a fuel in industry has increased about tenfold since 2010, against the background of an overall 50 per cent increase in energy use in the sector. This has increased the share of natural gas in industry from less than 2 per cent to nearly 10 per cent. Similarly, natural gas use in buildings has tripled over the past decade, albeit from a low base. These increases have, however, been partly offset by a fall in the use of natural gas for power generation. India has a stated ambition to increase the share of natural gas in its primary energy mix to 15 per cent by 2030, up from 6 per cent in 2019.

TOTAL PRIMARY ENERGY DEMAND IN INDIA



India's energy demand has tripled over the last three decades: the share of traditional biomass has fallen, leaving coal and oil dominant.

END-USE SECTORS OF ENERGY IN INDIA

Industry is the end-use sector that currently uses most energy and its share in total final consumption is 36 per cent today.

Industry

India's industry sector has been the main source of energy demand growth since 2000, around half of which was met by coal.

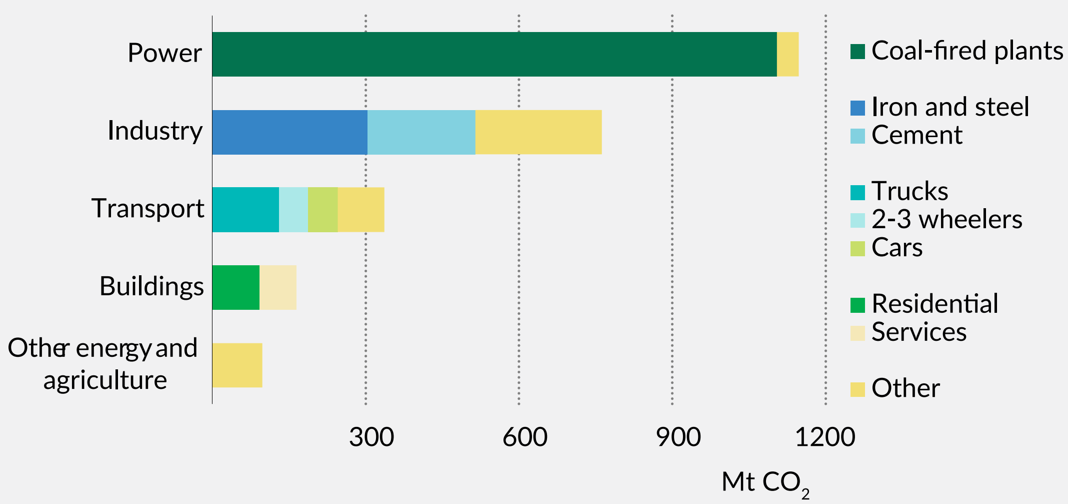
Coal provides around 85 per cent of the energy used for iron and steel and the sector makes relatively little use of recycled scrap. This means that India's steel industry is more emissions-intensive than its counterparts in many other countries.

Iron and steel sector is the largest industrial subsector in terms of emissions: it is responsible for around 30 per cent of India's industrial energy consumption.

Cement production is the second-largest emitting industrial sub-sector.

Although coal and oil are the main fuels used to provide heat for its cement industry, a number of energy efficiency measures have been introduced at Indian cement plants and total emissions per tonne of production is nearly 15 per cent lower in India than in China.

CO_2 EMISSIONS FROM THE INDIAN ENERGY SECTOR, 2019



India's power sector is the largest contributor to its CO_2 emissions, and coal-fired power plants are responsible for the great majority of power sector emissions.

Transport

Transport has been the fastest-growing end-use sector in recent years where energy demand grew 3.5 times and India is set for a huge expansion of transportation infrastructure – from highways, railways and metro lines to airports and ports.

Transport is heavily reliant on oil, with 95 per cent of demand being met by petroleum products. Just under half of India's oil demand is accounted for by transport.

Vehicle ownership per capita has grown five-fold since 2000, with particularly significant growth in the fleet of two- and three- wheelers. With a stock of just over 200 million, there are five times more of these vehicles than passenger cars, complementing a relatively low stock of 2 million buses that serve public transport needs. Freight activity also quadrupled between 2000 and 2019, alongside a fivefold increase in the stock of light commercial vehicles and a thirteen-fold increase in the stock of heavy freight trucks.

India's per capita distance travelled on rail increased from 430 km in 2000 to nearly 860 km in 2019. With over 8 billion trips annually, rail continues to be one of India's most preferred ways to travel (Ministry of Railways, 2019). Freight activity similarly more than doubled on India's vast railway network, reaching 740 billion tonne kilometres (tkm) in 2018, although the share of freight that moves on railways has been falling.

The Ethanol Blended Petrol (EBP) programme was launched in 2003 with an ambition to blend an average of 5 per cent ethanol into petrol, but it eventually fell short of this target owing to supply chain and procurement difficulties and a lack of attractive pricing. A more comprehensive National Policy on Biofuels (NBP) was approved in 2018 that envisages a target of 20 per cent blending of ethanol in petrol and 5 per cent blending in diesel by 2030 (MoPNG, 2018).

India's push for CNG in transport over the past decade has resulted in the doubling of CNG use in transport since 2010. There are now over 3 million CNG- fuelled vehicles registered in India. These vehicles are largely three-wheelers, buses and cars, most of which are used for shared mobility, for example as taxis or for public transport.

Electrification of road transport substantially reduces air pollution from this sector: a conventional car can emit more than 10 times the NOX produced by an electric car. The number of electrified two-and three-wheelers has grown by more than 60 per cent each year on average since 2015 and there were 1.8 million such vehicles by 2019. Despite this rapid rise, they still constituted only 3 per cent of overall two-and three- wheeler sales in 2019. The electrification of transport has accelerated in other modes of transport too.

The share of electrified tracks has increased in recent decades, rising from 24 per cent in 2000 to just over 50 per cent in 2019. India's railway network now has a target of 100 per cent electrification of its tracks by 2022, up from 51 per cent of the railway network (in route kilometres) in 2019. In parallel, there is aspiration for rail transport to become "net zero" emissions by 2030 by drawing its entire electrical load from renewable energy.

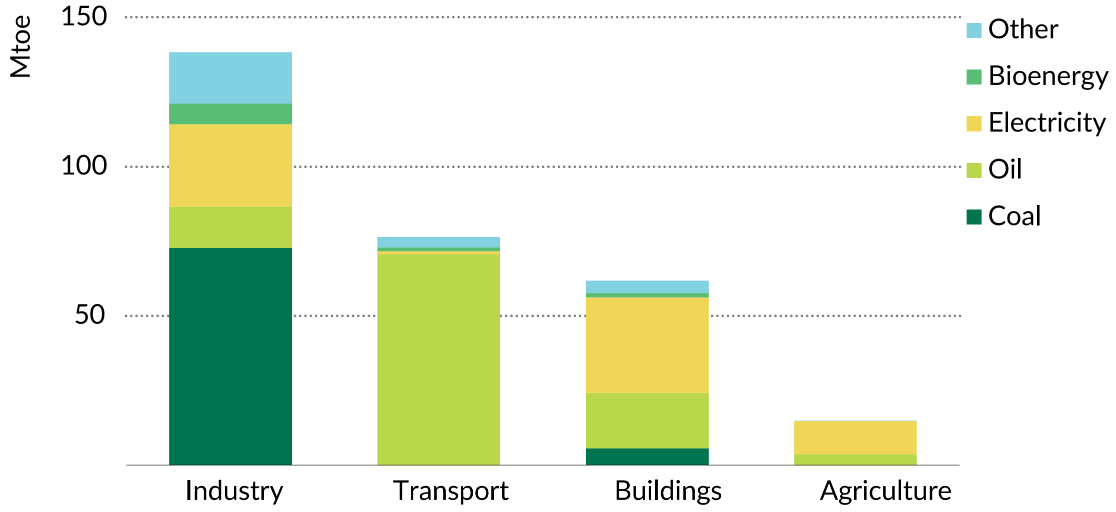
Buildings

Demand in buildings has grown by 40 per cent since 2000, largely as a result of growing appliance ownership and increased access to modern cooking fuels.

The direct use of fossil fuels in the buildings sector resulted in just over 160 Mt of CO2 emissions in 2019 with a further 460 Mt of indirect emissions coming from the use of electricity. India has been seeking to improve the energy efficiency of its buildings through mandatory building energy codes and voluntary rating schemes, as well as through programmes to improve the efficiency of appliances and equipment.

India is set to more than double its building space over the next two decades, with 70 per cent of new construction happening in urban areas. Urbanisation will lead to a massive increase in total residential floor space from less than 20 billion square metres today to more than 50 billion in two decades' time.

CHANGE IN ENERGY DEMAND BY FUEL IN SELECTED END-USE SECTORS, 2000-19



Among end-use sectors, the growth in energy demand has been larger in industries than in transport and buildings, and this growth has largely been fuelled by coal.

INDIA'S ELECTRICITY NEEDS

Synchronisation of the grid was achieved in 2013 in India, making it one of the world's largest. Near- universal household access to electricity was achieved in 2019, through the Saubhagya Scheme and more than $200 billion has been spent on transmission and distribution networks over the last ten years. Over 900 million citizens have gained an electrical connection in less than two decades. As a consequence, India has become the fourth-largest electricity market in the world, after the USA, China and EU.

Electricity consumption has nearly tripled over the past two decades- faster than total energy demand– as urbanisation and rising incomes push up the use of household appliances. Industry has also contributed to the increase in electricity demand through its increasing use of electrical motors and other machinery.

Urbanisation has also led to an increase in household energy use away from solid biomass and towards electricity. Rising ownership of appliances and demand for air conditioners mean that the share of energy demand taken by electricity in India's buildings sector rises sharply.

The government's flagship Unnat Jyoti by Affordable LEDs for All (UJALA) scheme,launched in 2015, has led to the deployment of 366 million LEDs (Minister of Power, 2020), while the LED Street Lighting National Programme has led to the installation of over 10 million LED smart streetlights. The government estimates that energy savings of about 54 terawatt-hours (TWh) per year have been achieved through these measures (PIB, 2020).

HOWEVER, THERE ARE WIDESPREAD DIFFERENCES IN ENERGY USE, THE QUALITY AND RELIABILITY OF SERVICE ACROSS STATES AND BETWEEN RURAL AND URBAN AREAS. KEY CHALLENGES FOR INDIA INCLUDE

- A lack of reliable electricity supply for many consumers
- Despite recent success in expanding coverage of LPG in rural areas, a continued reliance on solid biomass, mainly firewood, as a cooking fuel for some 660 million people, who have not fully switched to modern, clean cooking fuels
- Financially ailing electricity distribution companies
- Air quality that has made Indian cities among the most polluted in the world

Developments on Hydrogen Projects in India

India will meet its incremental demand from RE only. Most of the capacity addition in energy sector is happening only through renewables. No capacity addition is happening in coal sector.

We have a huge market, due to which so much investment is happening in India. We have very good standardized bidding documents, which gives a lot of comfort to the international investors and we are following a transparent bidding process.

CEEW estimates hydrogen demand in India to reach 1 million tonnes by 2030, a $44 billion investment opportunity. IEA estimates that global demand would be 200 MT by then.

Reliance Industries Ltd, Adani group, ACME Group, Indian Oil, JSW Energy, GAIL and NTPC have already announced green hydrogen projects. NTPC has floated a tender for hydrogen blending of CNG.

Reliance Group

Reliance Industries has announced that it will create or enable capacity to generate at least 100 GW of electricity from renewable sources by 2030, which can be converted into carbon-free green hydrogen, as per a 1-1-1 vision to bring down the cost of hydrogen to under $1 per 1 kg in 1 decade.

They have started developing the Dhirubhai Ambani Green Energy Giga Complex over 5,000 acres in Jamnagar. It will be amongst the largest integrated renewable energy manufacturing facilities in the world.

This complex will have four Giga Factories, which cover the entire spectrum of renewable energy and offer a fully integrated, end-to-end renewables energy ecosystem to India. The four Giga factories will include an integrated solar photovoltaic module factory, an advanced energy storage battery factory, an electrolyser factory for the production of Green Hydrogen and a fuel cell factory for converting hydrogen into motive and stationary power.

Over the next three years, they will invest Rs 75,000 crore in these initiatives. They will also create a pan-India network of kilowatt and megawatt -scale solar energy producers who can produce green hydrogen for local consumption.

ACME Group

ACME Group currently holds a solar portfolio of 5.25 GWp, spread across 12 states in India. This includes 2.2 GWp of operational capacity and another 3.05 GWp under construction. ACME Group has taken lead in the area of Green Hydrogen/Ammonia and has already set up semi commercial scale green hydrogen/ammonia plant in Bikaner. They claim that, this 5 tonnes per day Green Ammonia plant is the world's first such integrated facility.

ACME Group is also setting set up a global scale facility in Oman with an investment of $3.5 billion to produce Green Hydrogen and Green Ammonia for export to Europe and Asia. The Oman plant will be an integrated facility using around 3 GWp of solar energy to produce 2,400 TPD of green ammonia with an annual production of 0.8 million tons.

GAIL

GAIL has a 75 per cent market share in gas transmission and more than 50 per cent share in gas trading in India. GAIL currently has around 13,700 km of natural gas pipeline network and is laying a further 6,000 km of pipeline, including a west coast to east coast pipeline.

GAIL has a current RE portfolio of about 130 MW which they are targeting to scale up to 1 GW through acquisitions in the next 3-4 years.

GAIL will bid for a 400 MW solar power capacity being auctioned by SECI in Rewa, Madhya Pradesh. GAIL has also signed up with state-run power gear maker BHEL for RE project.

IOC

Indian Oil Corporation (IOC) is all set to build a green hydrogen plant with a 1 tonne per day capacity pilot plants at Mathura Refinery, with the support of Petroleum Ministry. IOC has a wind power project in Rajasthan and the management intends to use the power produced there to its Mathura refinery.

IOC recently shared a Statement of Intent with the Norwegian company Greenstat, to set up a Centre of Excellence on hydrogen in India to accelerate a gradual transition from fossil fuels to renewable energy.

IOC's hydrogen compressed natural gas (HCNG) experiment in Delhi, wherein it converted 50 CNG BS-IV buses to run on HCNG fuel, has revealed benefits in reducing exhaust emissions and improving the fuel economy. IOC intends to seed hydrogen mobility by commoditising the surplus quantities of hydrogen available at the Gujarat refinery with a hydrogen dispensing facility for fuel-cell electric vehicles. Initially, this facility will be refuelling 25 buses per day with a ramp-up capability to refuel 75 fuel-cell buses per day. The project is likely to be operational soon, running the first set of buses from Gujarat Refinery to the Statue of Unity and other iconic sites in the vicinity.

Adani group

In March 2021, Adani Enterprises declared a collaboration with Italian conglomerate Maire Tecnimont, to develop green hydrogen projects in India.

The Adani group has announced plans to invest $20 billion over the next 10 years in renewable energy generation, component manufacturing and will produce the world's cheapest green electron.

They plan to triple their renewable power generation capacity over the next four years, foray into green hydrogen production, power all data centres with renewable energy, turn its ports into net carbon zero by 2025, and spend over 75 per cent of capital expenditure until 2025 in green technologies.

R&D IN INDIA

Ministry of New and Renewable Energy (MNRE) has been supporting a broad-based R&D programme on Hydrogen Energy and Fuel.

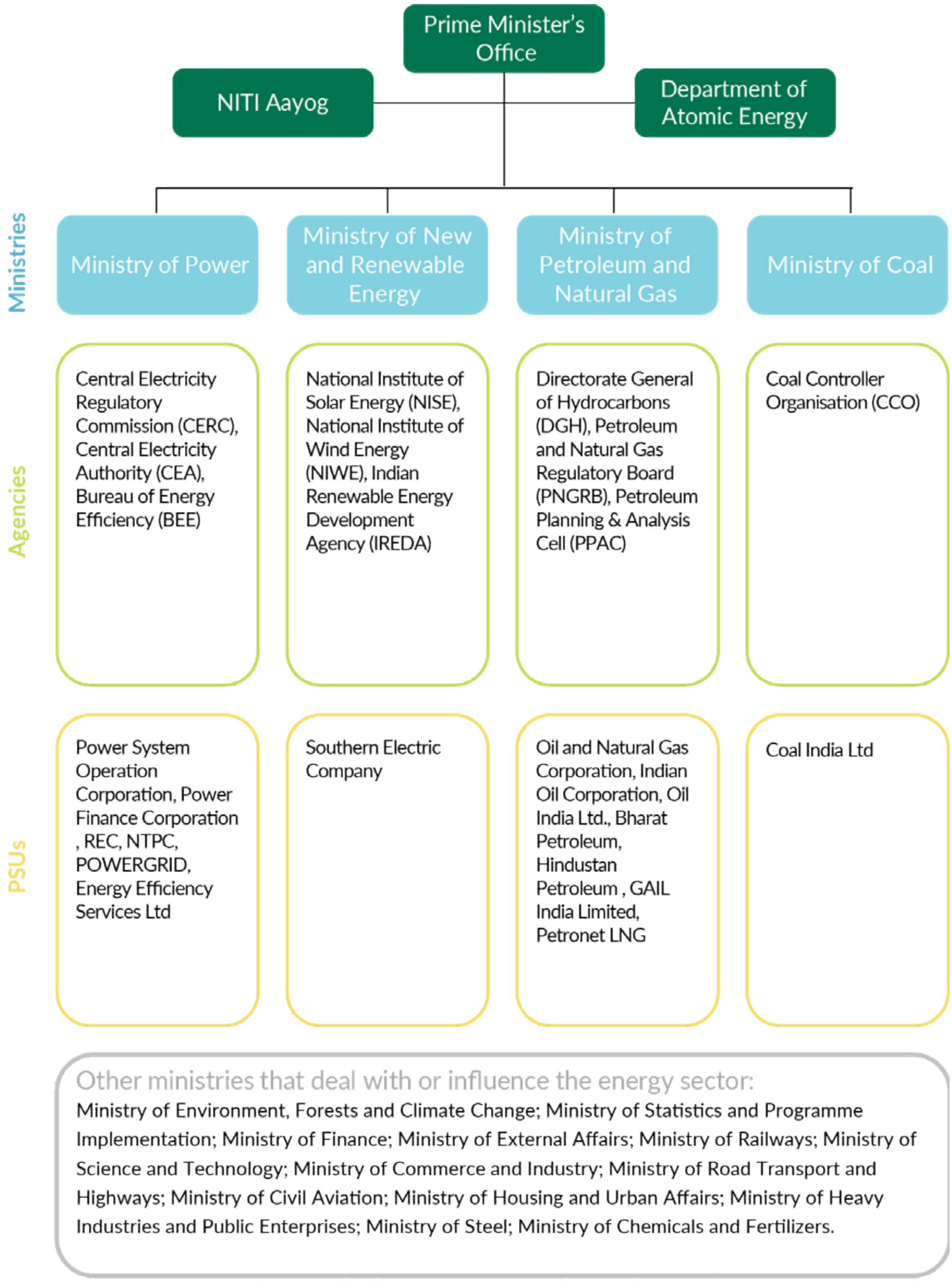
Projects are supported in industrial, academic and research institutions to address challenges in production of hydrogen from renewable energy sources, its safe and efficient storage and its utilization for energy and transport applications through combustion or fuel cells.

With respect to transportation, major work has been supported to Banaras Hindu University, IIT Delhi and Mahindra & Mahindra. This has resulted in development and demonstration of internal combustion engines, two wheelers, three wheelers and mini buses that run on hydrogen fuel. Two hydrogen refuelling stations have been established (one each at Indian Oil R&D Centre, Faridabad and National Institute of Solar Energy, Gurugram).

The Department of Science and Technology (India) is also working on a Hydrogen Valley Platform to create an ecosystem along the lines of the existing hydrogen valleys in Europe, to concentrate the production, transportation and end use of green hydrogen in a single region. Once the efficacy of closed-circuited pilot projects has been established, such local hydrogen economies will pave the way for the expansion of the supply chain at a macroeconomic level.

Researchers at the IIT Bombay have devised a method that increases hydrogen production up to three times while significantly lowering the energy required for water electrolysis. The research team, led by Prof. C. Subramaniam, demonstrated that a water electrolysis system that produced 1 ml of hydrogen gas, required 19 per cent less energy to produce 3 ml of hydrogen in the same time, when electrolysis was carried out in the presence of an external magnetic field. The team achieved this by synergistically coupling the electric and magnetic fields at the catalytic site.

GOVERNANCE OF THE ENERGY SECTOR BY THE CENTRAL GOVERNMENT



India has multiple bodies in central government with a range of energy-related competencies and functions.

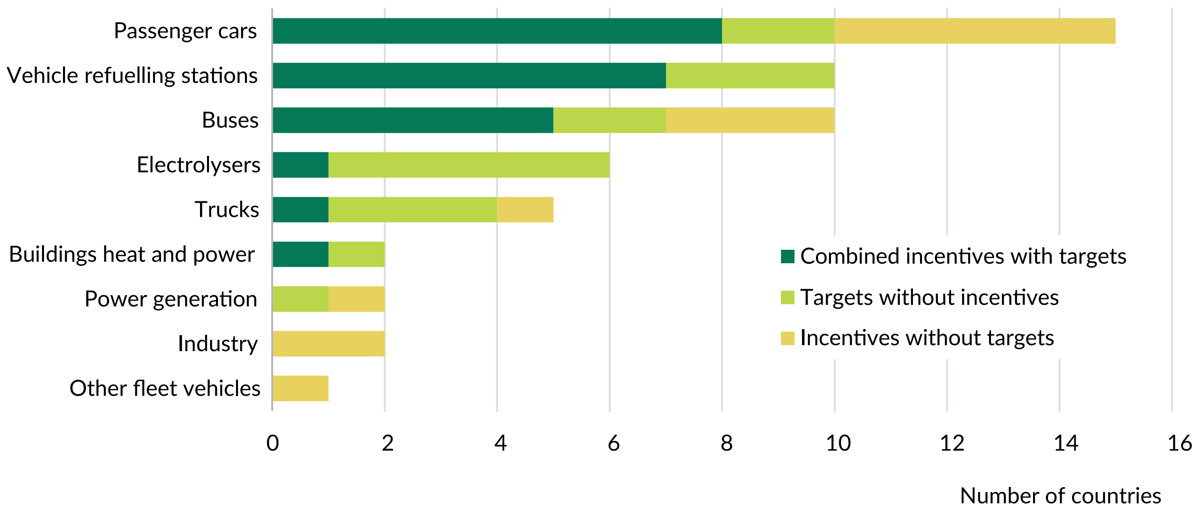
EMERGING GLOBAL TRENDS IN HYDROGEN ECONOMY

Globally, green hydrogen, a source of clean energy, is becoming the key focus of international climate agenda as the cumulative of all the Nationally Determined Contributions fall short of the required reductions in global GHG emissions needed to limit global warming below 2°C by the end of the century.

EHB initiative report estimated hydrogen demand could reach 2,300 TWh (213 Bcm) in 2050 across the EU and UK, representing 20-25 per cent of final energy consumption.

In 2017, the Hydrogen Council was formed to bring together relevant private-sector players. According to the Hydrogen Council, there are 228 announced hydrogen projects across the globe, the majority of which are in Europe, Middle East, Asia and Australia. 18 countries accounting for over 70 per cent of global GDP have already developed or are in the process of developing hydrogen strategies. Among the Group of Twenty (G20) and EU, 11 have such policies in place and 9 have national roadmaps for hydrogen energy.

POLICIES DIRECTLY SUPPORTING HYDROGEN DEPLOYMENT BY TARGET APPLICATION



Note: Based on available data up to May 2019.
Source: IEA analysis and government surveys in collaboration with IEA Hydrogen Technology Collaboration Programme; IPHE (2019), Country Updates

---

Developed economies such as EU, Australia and Japan have already drawn hydrogen roadmaps and set ambitious targets for hydrogen development for 2030 to achieve green economic growth.

Governments in Asia and Europe have announced targets for hydrogen use in transport, heating and power generation. UK, Germany and Japan have also outlined specific strategies and funding, with many countries having joined collaborative efforts, particularly within the EU.

Through the EU Green Deal, member countries are pursuing a range of hydrogen strategies focused on green or blue hydrogen, or both. Although its policies have mainly focused on hydrogen for transport, the EU is eyeing a dramatic expansion of its current installed electrolyzer capacity of about 250 megawatts (MW). It is targeting the construction of six gigawatts (GW) by 2024 and 40 GW by 2030, with another 40 GW to be built outside of the EU, possibly in North Africa and Ukraine.

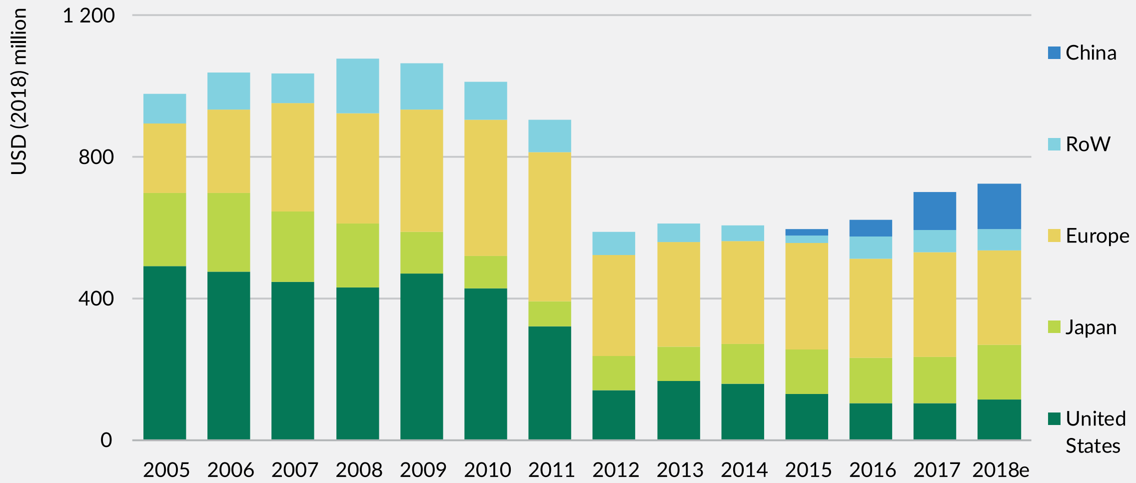
Further, broader goals such as decarbonizing the electric grid by 2035 will indirectly promote the use of hydrogen in the power sector.

Countries across the globe vary greatly in terms of availability of renewable energy resources needed to meet the expected demand for green hydrogen.

According to Bloomberg New Energy Finance (Bloomberg NEF), China, Japan, the Republic of Korea, South East Asia and most European countries are likely to face a deficit of renewable power generation capacities due to the lack of sites for further expansion of renewables.

At the same time, many countries with vast territories and abundant renewable resources such as Australia and Saudi Arabia could have a surplus of green hydrogen, which could help to meet the demand in other countries. Germany and Japan have already initiated pilot projects and partnerships for intercontinental shipping of hydrogen. McKinsey and the Hydrogen Council estimate the potential size of the global hydrogen market at USD 2.5 trillion by 2050.

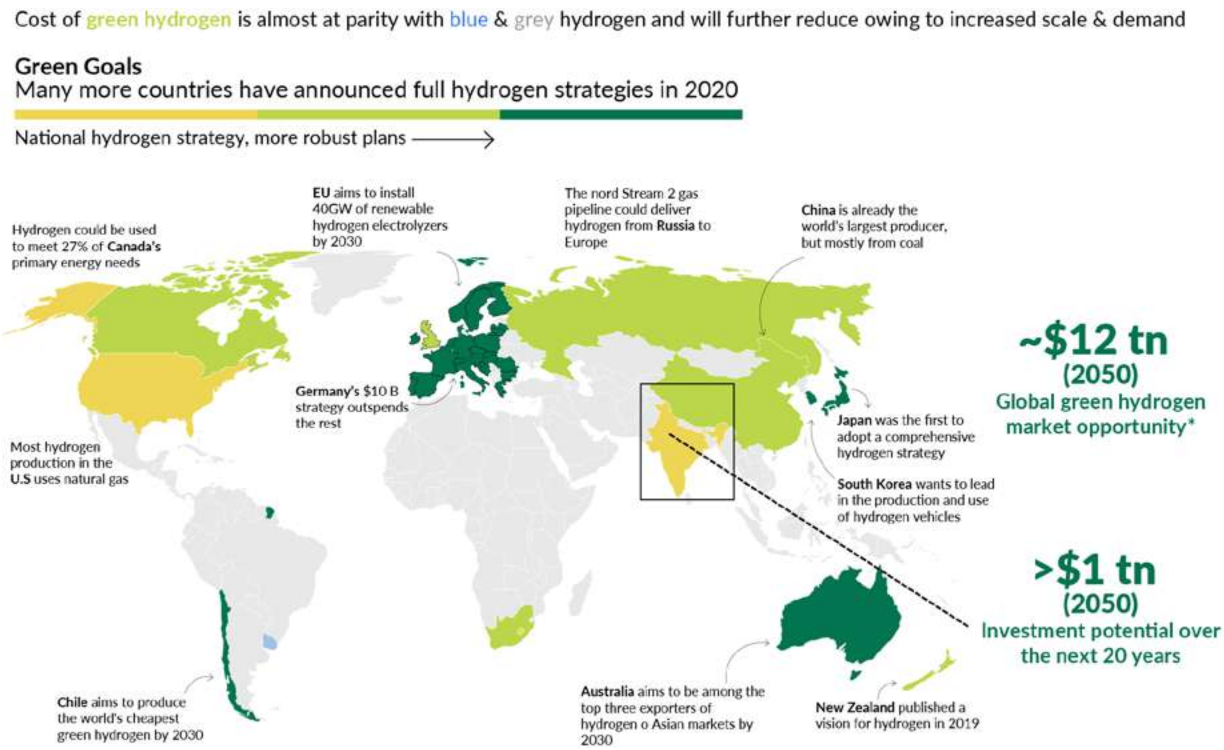
GOVERNMENT RD&D BUDGETS FOR HYDROGEN AND FUEL CELLS



Notes: Government spending includes European Commission funding, but does not include sub-national funding, which can be significant in some countries. 2018e = estimated; RoW = rest of world.
Source: IEA (2018a), RD&D Statistics.

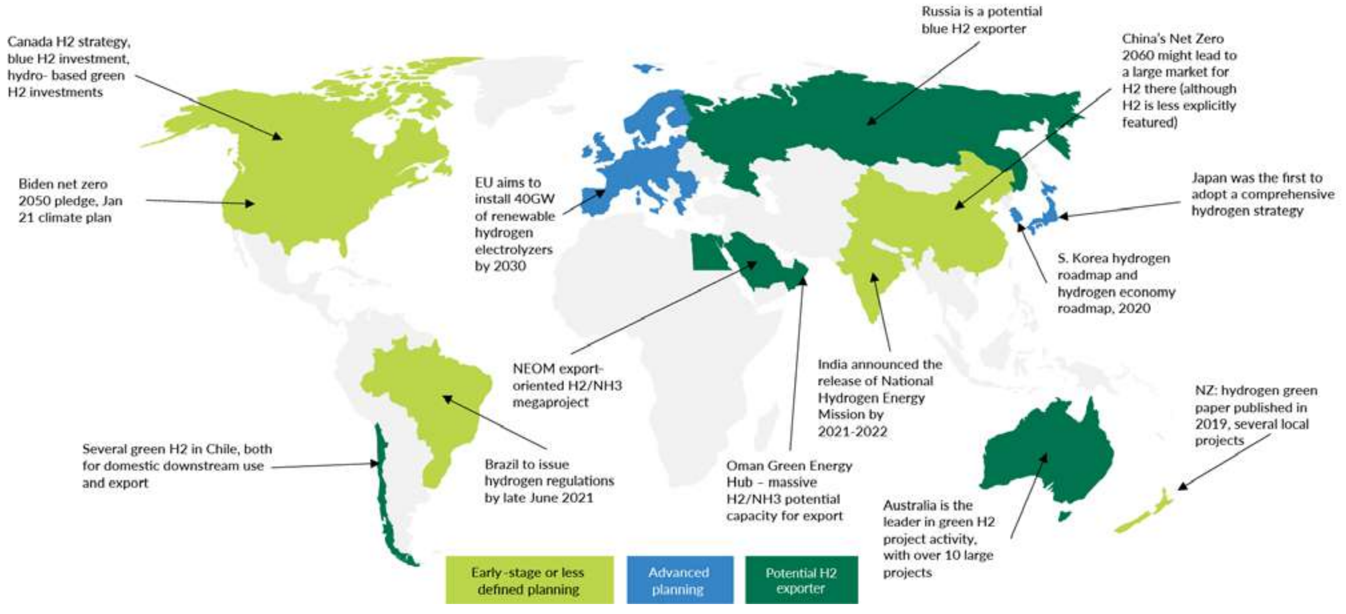
Refer Annexure 1 for an indicative list of hydrogen-related government announcements across jurisdictions since early 2018- mid 2019

GLOBAL FOCUS-HYDROGEN ECOSYSTEM-OVER TRILLION DOLLAR OPPORTUNITY



Sources: Eurasia Group; International Energy Agency; BloombergNote: Black outlines demarcate EU countries, and don't necessarily indicate a national strategy exists

REGULATORY DRIVERS FOR HYDROGEN AND GREEN AMMONIA - AMBITIOUS NET ZERO TARGETS ARE DRIVING POTENTIAL DEMAND FOR HYDROGEN AND AMMONIA



Smahi View and Recommendation

India's energy demand is expected to double by 2040 and India is taking giant strides towards harnessing solar and wind energy.

The recent initiatives of the Government of India, such as the announcement of a National Hydrogen Mission by the Prime Minister and the proposed introduction of green hydrogen consumption obligations for fertiliser and petroleum refining industry, indicate the country's resolve to transition towards an economy fuelled by green hydrogen. It is worth noting that the India has decided to directly leap frog into Green Hydrogen unlike many countries who are devising the policy to use a mix of Blue and Green Hydrogen.

Green hydrogen has the potential to decarbonise the sectors, which currently have the largest carbon footprint in the world. With the capability to provide a zero-emission fuel, green hydrogen is well placed to be integrated into the transport sector and replace the use of coal and coke in the industrial sector.

The GoI, therefore, must strongly pursue the objective of making India a global manufacturing hub of green hydrogen and place itself as the leading green hydrogen user and exporter.

In the past few years, we have done 10 GW of solar a year. Doing 40-50 GW a year is a steep target. Reaching the 450 GW target by 2030, will require a much more flexible system, with increased investments in grids and storage, a stronger focus on demand-side measures and tenders that provide appropriate compensation for flexibility services provided to the system. India has a higher requirement for flexibility in its power system operation than almost any other country in the world.

OUR KEY OBJECTIVES FOR GREEN HYDROGEN ECONOMY COULD INCLUDE:

- Quick scale-up: India is at the forefront of adopting green hydrogen economy and we must provide immediate policy support to be a pioneer and hub for green hydrogen
- Aatmanirbhar India/ Make in India: Unlike in the solar sector, where we ended up importing modules, we need to ensure that the majority of the capital value chain is in India
- Green hydrogen to be cost competitive globally
- Balanced focus between domestic market creation and international opportunity
- Attracting investment in the sector

GHE hinges upon the creation of a supply chain, starting from the manufacture of electrolysers to the production of green hydrogen, using electricity from a renewable energy source, for its eventual transmission to the end-users. Each of these activities carries risks that can have a cascading effect on the entire supply chain.

For instance, a hydrogen plant may not be of any value unless it is tied-up with a renewable energy plant that can supply electricity for conducting electrolysis and an off-taker to whom the green hydrogen can be delivered for transmission to the end users. A smooth implementation of the supply chain may, therefore, require development of back-to-back projects.

According to estimates, around $ 300 billion will be invested worldwide in the green hydrogen energy sector by 2030. Given the nascent nature of the industry and the magnitude of inter-dependence in the supply chain, banks and lending institutions may be wary of financing such projects, unless each link of the supply chain is adequately tied up with other links. Green hydrogen is produced using electrolysers, a technology for which the performance standards are yet to be established.

The lenders may require robust manufacturer warranties, backed by insurance to ringfence the technological risks associated with a green hydrogen project. The multiple end-uses of green hydrogen, such as providing feedstock to chemical industries or fuel for the transportation sector, will further require the lenders to develop tailor-made financing packages for each project, based on the risk analysis of the industry of the intended end-use.

The regulatory support provided by the GoI will be key to the take-off and the subsequent scaling-up of the green hydrogen energy in the country. While the stakeholders are awaiting the formulation of guidelines under the National Hydrogen Mission, it is imperative that the measures adopted by the GoI are aimed at lowering the production cost to enable green hydrogen to compete with fossil fuels and other renewable resources in terms of pricing.

This may be achieved by the grant of time-bound and targeted subsidies for the equipment required to be deployed at each stage of the supply chain or in the form of fiscal incentives to promote the demand for green hydrogen. Once the necessary infrastructure is in place, a carbon emissions tax to disincentivise the use of fossil fuels may also be considered by the GoI to support the green hydrogen energy sector.

Pro-active industry collaboration with the government is key to creating a hydrogen economy in India.

This will help bring best-in-class hydrogen technology, equipment and know-how to create a hydrogen supply chain in India — in many cases, these could be "Made in India". By prioritising national hydrogen demonstration projects, innovations to further reduce the cost of hydrogen will become prominent locally.

Government and industry must work together to ensure existing regulations are not an unnecessary barrier to investment.

Hydrogen, a versatile fuel, has applications across sectors. This means several ministries need to be involved in the framing of policies and increase adoption of green hydrogen in their respective segments.

Achieving a low hydrogen production cost in the future crucially hinges on scaling up of global annual manufacturing capacities, which would drastically bring down equipment costs.

Trade will benefit from common international standards for the safety of transporting and storing large volumes of hydrogen and for tracing the environmental impacts of different hydrogen supplies.

Overall, scaling up investment for utility-scale renewable projects will require policy reforms, as well as an expansion of the availability of low-cost financing.

Government needs to promote R&D expenditure and harmonize standards.

We need to address the distribution reforms, we need policy certainty- there should not be different policy for state and national and there should not be indiscriminate termination of PPAs. Reforms could lead to greater utilisation of forward contracts to increase the options for hedging, which are currently not available in India.

India's ambitious renewable capacity deployment targets, accompanied by falling tariffs and the ever-increasing energy demand from the industry and transport sectors are ideal for making a switch to hydrogen economy.

A robust policy framework akin to the one that guided the country's solar revolution could lead to an increase in production and demand of this green fuel. Hydrogen's growth trajectory depends on policy support, lower costs, new infrastructure, creation of markets and hubs. Low solar prices coupled with pragmatic policies can help India take a leadership position in driving the global hydrogen economy.

01 DEMAND CREATION

Nudge end-use sectors on green hydrogen. Hydrogen purchase obligation for companies using Hydrogen through Fossil Fuel feed stock. There are certain industries like refineries, fertiliser, steel, etc that use hydrogen by cracking natural gas which releases carbon dioxide. These industries may be given a target of, say 20 per cent to begin with, using green hydrogen. This could be called Hydrogen Purchase Obligation.

Green Hydrogen mandated to be blended up to 20 per cent with natural gas to make for use in transportation and heating application

Like a Smart City, create a Green City Program; with criteria on green power generation, green fuels in transportation, higher blending of green hydrogen with Natural Gas etc.

We should have a specific growth trajectory for 2030 and 2040. Establish a role for hydrogen in long-term energy strategies. National, regional and city governments can guide future expectations. Companies should also have clear long-term goals. Key sectors include refining, chemicals, iron and steel, freight and long-distance transport, buildings, power generation and storage

RATIONALE:

Green Hydrogen purchase obligation by all the hydrogen consuming industries will create a sizeable demand for green hydrogen. For solar power promotion, a similar concept was used. The Discoms were mandated to purchase a percentage of their total demand from solar power. This created a market for solar without the need for any subsidy. Initially the Discoms paid high price but as demand grew the solar power acquired economy of scale, prices dropped.

Upstream facilities (sourcing critical minerals, electrolyser production, hydrogen supply) would struggle if downstream end-use sectors don't signal sufficient demand.

02 MAKE IN INDIA

PLI for high-tech and critical components like electrolyser should be rolled out immediately in the short run so that we scale up our electrolyser capacity along with green hydrogen capacity

All taxes and duties should be rationalized on RE equipment to help further tariff reduction, for next 5 years till the industry becomes self-sustainable. For e.g. waive off GST or have a lower GST rate of 5 per cent for Green Hydrogen and Green Ammonia; waive off Custom Duty (for import of Electrolyzer, Refuelling Station, Fuel Cell Vehicles) for accelerating capacity building and to make industry competitive in the short term

Policy measures like FAME for electric vehicles should be extended to fuel-cell electric vehicles.

Exemption of Electricity Transmission and Wheeling Charges for the use of renewable energy for Hydrogen Generation

Limited Grid Banking facility of Renewable power for one year

Provide export parity for green hydrogen & ammonia like oil & gas refineries

RATIONALE:

From the beginning, when sector is relatively nascent, we must target for supply side localization. We must learn lessons from EVs (battery) and solar energy (solar panels), where we did not localize and tie-up the critical supply side value chain. By scaling up supply chains, these investments can drive cost reductions. Currently, India has 50-60 per cent localization of the supply chain, while we must target to reach 70-75 per cent over a period of time.

03 FINANCING

India's specialized institutional financing agencies should be mandated to fund projects in this space, such as PFC for power sector

Should encourage funding for Green Hydrogen projects to be part of priority sector lending by RBI

The purchase for hydrogen or its derivatives (like Green Ammonia, Green Methanol etc) to be undertaken in 'USD' similar to other hydrocarbon energy like oil & gas. This will enable lower cost project borrowings which in turn would make the end product globally more competitive.

GoI should extensively lobby with developed nations during the upcoming Glasgow summit and on other forums that in view of India adopting a faster trajectory towards Green Hydrogen, long- term very low-cost financing to be made available for such projects in India. Such financing can be done through a specialized government-controlled financing institution.

Concept of Green Bank can be evaluated. Green bank raises money globally and invests in green projects

Accelerated depreciation for capital investment for the initial years.

04 ADMINISTRATION

A project administrative authority should be formed (on the lines of Solar Energy Corporation of India or NHAI in roads) that can help promote sector development

Provide/Aggregate on lease large-scale land banks for establishing giga-scale green hydrogen projects

Make the most of existing industrial ports to turn them into hubs for green hydrogen

Provide single-window clearance mechanism to deliver projects in plug-and-play mode

INTERNATIONAL COLLABORATION

India should consider sponsoring a Global Green Hydrogen Alliance like India's Solar Alliance, along with other leading hydrogen countries, as a multi-country, multi-institutional network to assess, develop and design affordable green hydrogen technologies that can be deployed at scale

Establish and share global best practices in market and policy development, technology innovation and applications and business models

Areas that would benefit from international harmonisation and common standards include hydrogen purity and pipeline specifications for industry, comparable to ISO standards in the transport sector, safety protocols for the use of hydrogen and hydrogen-based fuels and feedstocks and "guarantees of origin". Among other things, standards are needed for refuelling nozzles for vehicles; hydrogen supply pressures; refuelling station permitting; and safety protocols for high-pressure hydrogen and liquid hydrogen transport by trucks. There is also a case for looking at whether current limitations on the use of hydrogen vehicles on bridges and in tunnels could safely be amended.

Kick-start the first international shipping routes for hydrogen trade. Lessons from the successful growth of the global LNG market can be leveraged. International hydrogen trade needs to start soon if it is to make an impact on the global energy system.

RATIONALE:

Growing hydrogen demand in major industries offers the opportunity to create hubs that bring down the cost of green hydrogen pathways and kick-start new sources of demand. Developing cross-sectoral roadmaps and committing to deployment targets can be instrumental to bringing all stakeholders on board and to ensuring that visions for different industries are aligned in scale and timing.

Research and development on green hydrogen will require collaborations. While dozens of countries have announced hydrogen programmes, most research is concentrated in advanced economies. Individually, countries will struggle to bring down the prices of electrolysers.

Research and development on green hydrogen will require collaborations. While dozens of countries have announced hydrogen programmes, most research is concentrated in advanced economies. Individually, countries will struggle to bring down the prices of electrolysers.

Pooling resources can accelerate the process and test technologies in markets that will drive demand. The alliance can build on existing platforms by increasing transparency on green hydrogen research, assessing technologies periodically, pooling resources across countries/ firms, designing IPR that facilitate technology co-development and setting standards and safety protocols.

Trade in hydrogen will benefit from common international standards. The harmonisation of standards at global level would help to stimulate cost reductions. International co-operation is vital to accelerate the growth of versatile, clean hydrogen around the world. If governments work to scale up hydrogen in a co-ordinated way, it can help to spur investments in factories and infrastructure that will bring down costs and enable the sharing of knowledge and best practices.

In Europe, the CertifHy organization has set the first standard for renewable hydrogen Guarantees of Origin (GO). As certification and standard organizations helped grow the renewable electricity market in the 1990s, baseline rules and standards will do the same for the green hydrogen market today

Shipping hydrogen between countries could emerge as a key element of a future secure, resilient, competitive and sustainable energy system. There is future potential to use port facilities to support both international hydrogen trade by ship and the use of hydrogen and hydrogen-based fuels for trucks and fleet vehicles and as maritime and inland shipping fuel.

05 REGULATION

Green Hydrogen should come under Ministry of New and Renewable Energy (MNRE) for ease of administration and creating a clear chain of authority. Create a proper regulatory framework for consistent implementation of policy. Appoint a regulator and appellate tribunal for adjudication of issues cropping up.
Currently India has multiple bodies in Central government with a range of energy related competencies and functions such as MNRE, Ministry of Power, Ministry of Petroleum and Natural Gas etc, which could have conflicting elements for regulating green hydrogen.

After all stakeholder consultation, we need to have a sector law on the lines of Electricity Act to cover full legal framework

Create a collaborative regional green hydrogen task force composed of state and local leadership. This can provide momentum for accelerated deployment of green hydrogen at scale and provide a platform for advancing new technology innovation. It also supports creating a regional green hydrogen roadmap that identifies broad opportunities to re-purpose existing infrastructure, develop storage, enhance reliability and realize the development of new markets and products to drive investment, jobs and decarbonization.

RATIONALE:

Having a clear mid-term and long-term target inspires confidence in the private sector to make their investments in a new energy source. Hydrogen's complex supply chains mean governments, companies, communities and civil society need to consult regularly.

06 R&D

Government of India needs to play a central role in setting the research agenda for early-stage high-risk projects, taking early-stage risks and crowding in private investment in projects in the following areas:

- Demand, adoption and impacts analysis
- Hydrogen-based fuels/ feedstocks
- Renewable hydrogen production technology and feedstock supply
- Supply-chain forecasting and optimization
- Electrolysers: efficiency; lifetime; manufacturing and installation costs; recyclability; oxygen production
- Fuel cells: precious metals content; efficiency; recyclability; manufacturing costs; storage tank costs
- Safety of hydrogen, ammonia, toluene: understanding of implications of new uses; management techniques
- Storage: solid-state; lightweight tanks; porous media
- Renewable hydrogen fuel production and electric grid integration

Research is needed for developing alternative membranes and alternative materials. Industry should also collaborate with DRDO, BARC and CSIR laboratories, which have been developing electrolyser and fuel cell technologies

The economic viability of laying large-scale pipelines to transport the hydrogen from renewable-rich production site to the far-off demand centre has to be clearly worked out.

The Department of Science and Technology and academic research institutions to take up hydrogen storage as one of the strategic research priorities. Explore commercialisation of alternate storage technologies like metal hydrides and liquid organic carriers

Skill development- Some of the specialized institutes to have modified curriculum to include Green Hydrogen. Specialized accreditations for Green Hydrogen.

Public awareness campaigns in schools, colleges, local communities for creating momentum and acceptability for green hydrogen for the general public.

RATIONALE:

Alongside cost reductions from economies of scale, R&D is crucial to lower costs and improve performance, including for fuel cells, hydrogen-based fuels and electrolysers (the technology that produces hydrogen from water). Government actions, including use of public funds, are critical in setting the research agenda, taking risks and attracting private capital for innovation.

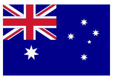
Publicly funded research efforts might focus primarily on key cost components, such as fuel cell durability and recycling, on-board storage options and electrolyser efficiency, as well as on earlier-stage technologies likely to be important for shipping and aviation, including use of ammonia in ships, lower-cost means of sourcing "low-carbon" CO2 and producing synthetic fuels.

The smooth operation of large-scale and intercontinental hydrogen value chains will depend on the availability of adequate storage capacity and functionality. Lack of low-cost storage solutions can become a potential barrier for green hydrogen production in India. The cost of storage also plays a very critical role in reducing the overall production costs. While large-scale geological storage is the focus in economies such as the EU and Australia, India is yet to carry out an extensive analysis to map the prospective sites for storing hydrogen.

The proton exchange membrane accounts for about 25 per cent of total electrolyser costs. DuPont holds the exclusive IP on membrane technology. Developing alternative membranes should be prioritised to lower costs and manufacture in India. Electrolysers use iridium, a by-product of platinum, which in turn is primarily used in conventional vehicles. As auto demand shifts to EVs, there will be excess platinum supply if iridium has to be produced for electrolysers.

Annexure 1: Hydrogen-related Government Announcements

INDICATIVE LIST SINCE EARLY 2018- MID 2019

Country	Announcements and developments since early 2018
 Australia	Announced more than AUD 100 million to support hydrogen research and pilot projects. Published a technical roadmap for hydrogen in Australia produced by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Has set up a government working group to develop a national hydrogen strategy for completion by the end of 2019.
 Austria	Announced that a hydrogen strategy based on renewable electricity would be developed in 2019 as part of the Austrian Climate and Energy Strategy for 2030.
 Belgium	Published a government-approved hydrogen roadmap in 2018, with specific targets set for 2030 and 2050 and an associated EUR 50 million regional investment plan for power-to-gas
 Brazil	Included hydrogen in the Science, Technology and Innovation Plan for Renewables and Biofuels. Hosted and supported the 22nd World Hydrogen Energy Conference in 2018.
 China	Announced that the Ten Cities programme that launched battery electric vehicles in the China would be replicated for hydrogen transport in Beijing, Shanghai and Chengdu, among others. Announced that Wuhan will become the first Chinese Hydrogen City, with up to 100 fuel cell automakers and related enterprises and up to 300 filling stations by 2025. Announced targets of 5,000 fuel cell electric vehicles (FCEVs) by 2020 and recommitted to the 2015 target of 1 million FCEVs by 2030, plus 1 000 refuelling stations. Exempted FCEVs (and battery electric vehicles) from vehicle and vessel tax.

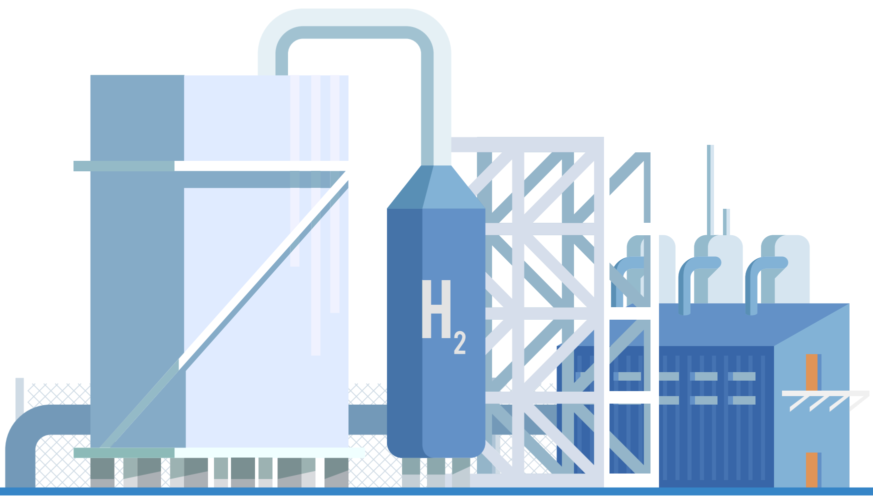
Country	Announcements and developments since early 2018
EU	The European Commission published a long-term decarbonisation strategy that included hydrogen pathways for achieving carbon neutrality; recast the directive on the promotion of the use of energy from renewable sources, enabling hydrogen produced from renewable sources with guarantees of origin to be counted against 2030 renewables targets; and set up a "Hydrogen Energy Network" as a platform for discussion of hydrogen among EU member states. Twenty-eight European countries signed the Linz Declaration "Hydrogen Initiative" promoting co-operation on sustainable hydrogen technology, alongside around 100 businesses, organisations and institutions.
France	Unveiled a Hydrogen Deployment Plan and EUR 100 million funding and 2023 and 2028 targets for low-carbon hydrogen in industry, transport and for renewable energy storage, including for islands
Germany	Approved the National Innovation Programme for Hydrogen and Fuel Cell Technologies for another ten years with EUR 1.4 billion of funding, including subsidies for publicly accessible hydrogen refuelling stations, fuel cell vehicles and micro co-generation purchases, to be complemented by EUR 2 billion of private investment. Supported the first commercial operation of a hydrogen-powered train, and the largest annual increase in refuelling stations in the country, though the H2mobility programme.
India	The Supreme Court asked Delhi to explore use of fuel cell buses in the city to counter air pollution and the government published an Rs 60 million call for research proposals on hydrogen and fuel cells. Prime Minister Narendra Modi, on August 15 2021, formally announced the launch of a National Hydrogen Mission (NHM) to expedite plans to generate carbon-free fuel from renewables as he set a target of 2047 for India to achieve self-reliance in energy.
Italy	Issued regulations to overcome barriers to the deployment of hydrogen refuelling stations by raising the allowable pressure for hydrogen distribution and enhancing safety, economic and social aspects.
Japan	Hosted the first Hydrogen Energy Ministerial Meeting of representatives from 21 countries, plus companies, resulting in a joint Tokyo Statement on international co-ordination. Updated its Strategic Roadmap to implement the Basic Hydrogen Strategy, including new targets for hydrogen and fuel cell costs and deployment, and firing hydrogen carriers in power plants. The Development Bank of Japan joined a consortium of companies to launch Japan H2 Mobility with a target to build 80 hydrogen refuelling stations by 2021 under the guidance of the Japanese central government's Ministerial Council on Renewable Energy, Hydrogen and Related Issues. The Cross-Ministerial Strategic Innovation Promotion Program (SIP) Energy Carriers initiative concluded its 2014–18 work programme and a Green Ammonia Consortium was launched to help support the next phase.

Country	Announcements and developments since early 2018
Korea	Published a hydrogen economy roadmap with 2022 and 2040 targets for buses, FCEVs and refuelling stations, and expressed a vision to shift all commercial vehicles to hydrogen by 2025. Provided financial support for refuelling stations and eased permitting. Announced that it would work on a technological roadmap for the hydrogen economy.
The Netherlands	Published a hydrogen roadmap and included a chapter on hydrogen in the Dutch Climate Agreement. Spearheaded the first meetings of the Penta-lateral Energy Forum of Belgium, the Netherlands, Luxembourg, France, Germany and Austria in support of cooperation on hydrogen in north-west Europe
New Zealand	Signed a memorandum of co-operation with Japan to work on joint hydrogen projects. Began preparing a New Zealand Green Hydrogen Paper and Hydrogen Strategy. Set up a Green Investment Fund to invest in businesses, including those commercialising hydrogen.
Norway	Awarded funding for development of a hydrogen-powered ferry and a coastal route vessel.
Saudi Arabia	Saudi Aramco and Air Products announced they are to build Saudi Arabia's first hydrogen refuelling station
South Africa	Included fuel cell vehicles as part of Green Transport Strategy to promote the use of fuel cell public buses in metropolitan and peri-urban areas of the country
UK	Set up two GBP 20 million funds for innovation in low-carbon hydrogen supply and innovation in storage at scale including Power-to-X. Published a review of evidence on options for achieving long-term heat decarbonisation, including hydrogen for buildings. Is testing blending of up to 20% hydrogen in part of the UK natural gas network. Announced decarbonising Industrial Clusters Mission supported by GBP 170 million of public investment from the Industrial Strategy Challenge Fund.
USA	Extended and enhanced the 45Q tax credit that rewards the storage of CO_2 in geological storage sites, and added provisions to reward the conversion of CO_2 to other products, including through combination with hydrogen. California amended the Low Carbon Fuel Standard to require a more stringent reduction in carbon intensity by 2030, incentivise development of refuelling stations and enable CCUS operators to participate in generating credits from low-carbon hydrogen. California Fuel Cell Partnership outlined targets for 1 000 hydrogen refuelling stations and 1 000 000 FCEVs by 2030, matching China's targets

Source: The Future of Hydrogen, Report prepared by the IEA for the G20, Japan, June 2019
Note: Co-generation refers to the combined production of heat and power

References

- A Green Hydrogen Economy for India- by Tirtha Biswas, Deepak Yadav, and Ashish Guhan Baskar, CEEW, Shakti Sustainable Energy Foundation, December 2020
- India Energy Outlook 2021, IEA
- The Future of Hydrogen, Report prepared by the IEA for the G20, Japan, June 2019
- Indian Oil to build India's first green hydrogen plant at Mathura Refinery- by The Hindu Business Line Bureau, July 24 2021
- Policy must pave the path for a green-hydrogen economy in India- by Arunabha Ghosh, Financial Express, July 21 2021
- Making Green Hydrogen a Global Trade Commodity for Enhanced Climate Ambition, April 12 2021- By Yuliia Oharenko, Associate, IISD Energy Program, and Richard Bridle, Senior Policy Advisor, IISD
- Hydrogen Projects Database, IEA Fuel report, June 2020
- Top 10 Hydrogen Economy Trends & Innovations in 2021
- View: India must address key issues to transition into a green hydrogen economy- By Ajay Sawhney, ETHealthWorld, July 20, 2021
- PM Modi announces National Hydrogen Mission: Here is how clean energy is produced through Hydrogen, August 15 2021,
- The path to a hydrogen economy- By OP Agarwal, Ravi Pandit and Pawan Mulukutla, June 21 2021, Indian Express
- Indian researchers increase hydrogen yield three-fold through carbon-cobalt catalyst interface, August 11 2021, PV Magazine
- Sector In-depth, Moody's Investor Service, August 11 2021
- Industry can buy green hydrogen to meet renewable obligation, Sanjay Dutta, August 16 2021, TOI
- GAIL scouts for acquisition to augment renewable portfolio, to foray into hydrogen, August 22 2021, Economic Times
- ACME Group signs land deal for green ammonia project in Oman, August 23 2021, Economic Times
- Roadmap for the Deployment and Buildout of Renewable Hydrogen Production Plants in California, June 2020
- The National Hydrogen Strategy- Nationale Wasserstoff- Strategie
- Green Hydrogen Guidebook- Green Hydrogen Coalition
- Reliance aims at 100 GW renewable energy by 2030, bring hydrogen cost under $1: Mukesh Ambani- September 3 2021, TOI
- Adani takes on Ambani, to invest $20 bn in renewable energy; foray into hydrogen- Mint, September 21 2021



SMAHI