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From Hydrogen to Hydro-zen, the Super Fuel for a Sustainable Future

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***Abstract:** Owing to constant endeavor of countries to find a cheap, green, sustainable and easily available natural energy resources it is high time that countries like India should prefer source of energy which is sustainable and having wiser application. compelled to research for a topic close to my heart in sustainability.*

This research outlines the need for a clean and green natural resource due to depletion of fossil fuel reserves and the global warming crossing to alarming levels. In this research hydrogen energy has been chosen as preferred choice in this matter as it is a widely available, clean and natural source of energy.

The research further investigates how different countries are taking the initiative for developing this source of energy and incorporating it in the daily life. In this research some examples from real life application has been taken into account that countries have done in this regards.

With any new development there has to be some pros and cons, so it is being highlighted some advantages and some disadvantages for the use of this energy source. The main challenge to overcome is to get the cost in parity with the traditional energy resources.

It is concluded that still it is a long way to go before hydrogen energy can be used in day to day generation and uses. Still weighing the benefits vs disadvantages, it is still a battle that must be won for a sustainable future.

1. INTRODUCTION

Year 2021 around October, post Covid-19 restrictions being lifted across the world and hope for returning to normalcy- China, a country with unmatched manufacturing capabilities; India, a country with manufacturing facilities to compete with Chinese manufacturing prowess; both came to grinding halt, that threatened to disrupt the production facilities around the world. May it be automobiles, chemicals, telecommunication or a simple thing like children toys, the world saw a shortage like never comprehended earlier in the modern world. The world manufacturing is running through a seamless production dependence that can stop work at Milan if the raw material doesn't arrive from Cairo. Companies and countries are now facing shortage of day to day use products and also are faced with high level of inflation threatening to disrupt Economic balances in developed and developing countries alike.

What is the reason for this? ***Power Shortage***? It could be, yes- it cant not be blamed to the power companies to not be able to maintain and supply continuous power, but the reason lies deep in our relentless or rather lazy approach to solving the global power problem. It is all about sustainable power sources since the inception of Industrial Revolution, but most of the countries are still mostly dependent on perishable power sources like Coal and Fossil fuels yet. Fossil fuels continue to dominate the global energy system, accounting for 81% of primary energy demand.[1]

In this research it will be emphasized the need for using a clean energy resource-Hydrogen Energy for solving the energy crisis and making the world more sustainable.

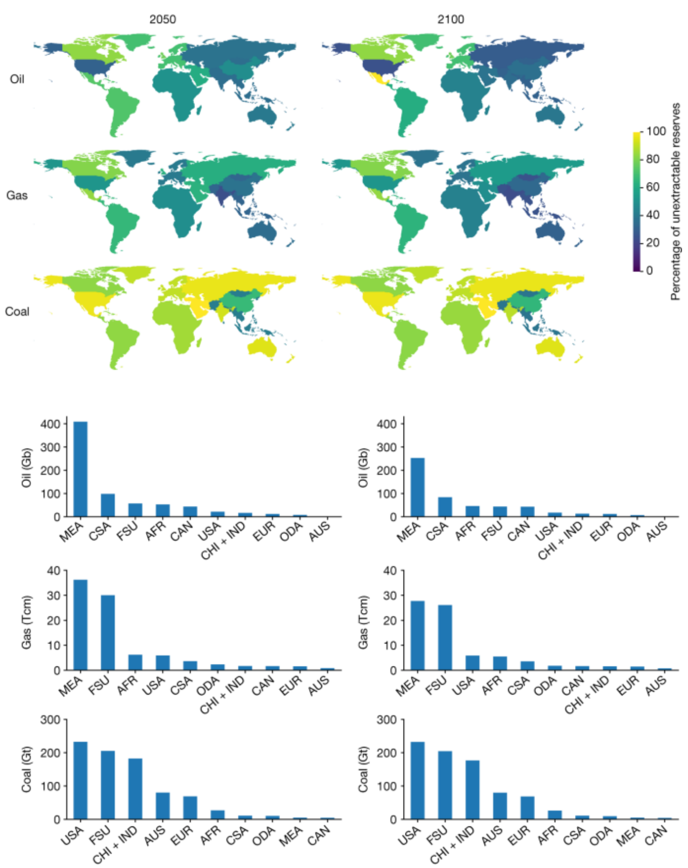
2. THE PROBLEM OF DEPLETING NATURAL RESOURCES

Unextractable oil, fossil methane gas and coal reserves are estimated as the percentage of the 2018 reserve base that is not extracted to achieve a 50% probability of keeping the global temperature increase to 1.5 °C. It is estimated to be 58% for oil, 59% for fossil methane gas and 89% for coal in 2050. This means that very high shares of reserves considered economical today would not be extracted under a global 1.5 °C target, the precedent target set in the latest COP 26 (Conference of the Parties) agreement.

[1] *World Energy Outlook 2019 (IEA, 2019)*

In a research done for this purpose shows continued use of fossil fuels after 2050 sees these estimates reduce by 2100. For oil, the global estimate drops to 43% in 2100. The reduction is smaller for fossil methane gas, reducing from 59% to 50%. The majority of fossil fuels extracted after 2050 are used as feedstocks in the petrochemical sector, and as fuel in the aviation sector in the case of oil. Feedstock use, which has a substantially lower carbon intensity than combustion, accounts for 65% and 68% of total oil and fossil methane gas use, respectively, in 2100 under a 1.5 °C carbon budget. [2] Currently as per COP26 agreement countries "resolve to pursue efforts to limit the temperature increase to 1.5 degrees C," which gives this lower temperature threshold even greater emphasis than in the Paris Agreement. Keeping the above in mind we have a look at the following table:

TABLE 1: Unextractable reserves of fossil fuels by region under the 1.5 °C scenario

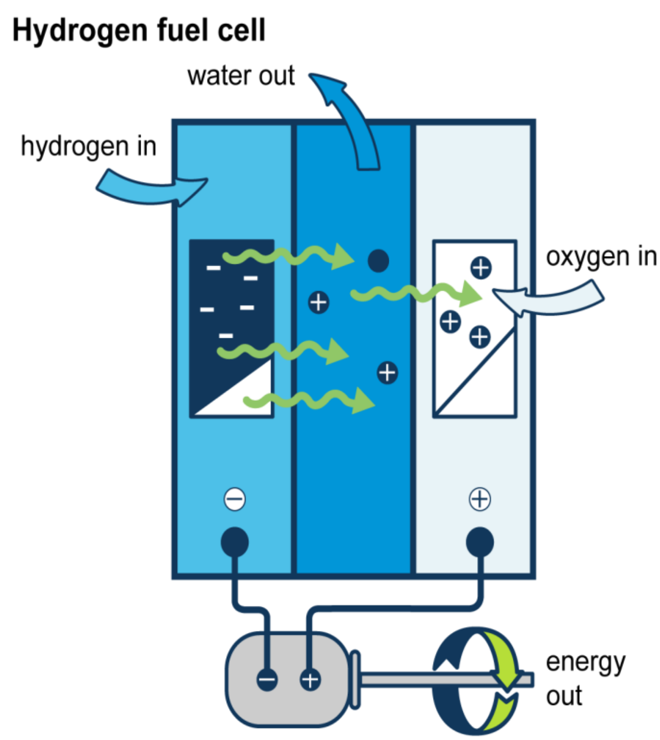


The above table shows unextractable shares vary substantially by region, relative to the global estimates. The largest reserve holders, such as the Middle East (MEA) (for oil and fossil methane gas) and Russia and other former Soviet states have the strongest influence on the global picture, and therefore have estimates close to or marginally above the global average.

3. HYDROGEN ENERGY – INTRODUCTION

The hydrogen energy is based on hydrogen fuel cell, which was invented by the Welsh physicist William Grove in 1842. Grove recombined hydrogen with oxygen – the reverse of the process of electrolysis – to produce electricity with only pure water as a by-product.

The following diagram explains the process of deriving energy from a hydrogen cell. Hydrogen fuel cells produce electricity by combining hydrogen and oxygen atoms. The hydrogen reacts with oxygen across an electrochemical cell similar to that of a battery to produce electricity, water, and small amounts of heat. [3]



Source: Adapted from National Energy Education Development Project (public domain)

[2] *Welsby, D., Price, J., Pye, S. et al. Unextractable fossil fuels in a 1.5 °C world. Nature* ***597,*** *230–234 (2021).*

[3] *National Energy Education Development project (public domain)*

Why hydrogen is called a clean fuel?

Hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water. Hydrogen can be produced from a variety of domestic resources, such as natural gas, nuclear power, biomass, and renewable power like solar and wind. These qualities make it an attractive fuel option for transportation and electricity generation applications. It can be used in cars, in houses, for portable power, and in many more applications. Industrial uses of Hydrogen power are being considered as future option with more and more companies investing in hydrogen infrastructure.

4. PRODUCTION OF HYDROGEN FUEL

Today, hydrogen fuel can be produced through several methods. The most common methods today are natural gas reforming (a thermal process), and electrolysis. Other methods include solar-driven and biological processes. Now I will explain the common methods of generating hydrogen fuel:

A) Thermal Processes

Thermal processes for hydrogen production typically involve steam reforming, a high-temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen. Many hydrocarbon fuels can be reformed to produce hydrogen, including natural gas, diesel, renewable liquid fuels, gasified coal, or gasified biomass. Today, about 95% of all hydrogen is produced from steam reforming of natural gas.

B) ELECTROLYTIC PROCESSES

Water can be separated into oxygen and hydrogen through a process called electrolysis. Electrolytic processes take place in an electrolyzer, which functions much like a fuel cell in reverse—instead of using the energy of a hydrogen molecule, like a fuel cell does, an electrolyzer creates hydrogen from water molecules.

C) SOLAR-DRIVEN PROCESSES

Solar-driven processes use light as the agent for hydrogen production. There are a few solar-driven processes, including photo biological, photoel ectrochemical, and solar thermochemical. Photobiological processes use the natural photosynthetic activity of bacteria and green algae to produce hydrogen. Photoelectro chemical processes use specialized semiconductors to separate water into hydrogen and oxygen. Solar thermochemical hydrogen production uses concentrated solar power to drive water splitting reactions often along with other species such as metal oxides.

D) BIOLOGICAL PROCESSES

Biological processes use microbes such as bacteria and microalgae and can produce hydrogen through biological reactions. In microbial biomass conversion, the microbes break down organic matter like biomass or wastewater to produce hydrogen, while in photobiological processes the microbes use sunlight as the energy source.[4]

The need for clean hydrogen energy

Clean Hydrogen is enjoying a momentum never seen before in the business and political communities. Further acceleration of efforts is critical to ensuring a significant share of hydrogen in the energy system in the coming decades.

Two key developments have contributed to the growth of hydrogen in recent years: the cost of hydrogen supply from renewables has come down and continues to fall, while the urgency of greenhouse gas emission mitigation has increased, and many countries have begun to take action to decarbonise their economies, notably energy supply and demand. The hydrogen debate has evolved over the past two decades, with a shift in attention from applications for the auto industry to hard to decarbonize sectors such as energy-intensive industries, trucks, aviation, shipping and heating applications. Ensuring a low-carbon, clean hydrogen supply is essential. Current and future sourcing options include:

A) Fossil fuel-based hydrogen production (grey hydrogen)

B) Fossil fuel-based hydrogen production combined with carbon capture, utilisation and storage (blue hydrogen) - Blue hydrogen has some attractive features, but it is not inherently carbon free. Fossil fuels with CCUS require carbon dioxide (CO2) monitoring and verification and certification to account for non captured emissions and retention of stored CO2. Such

[4] *https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics*

transparency is essential for global hydrogen commodity trade.

C) Hydrogen from renewables (green hydrogen)- Green hydrogen, produced with renewable electricity, is projected to grow rapidly in the coming years. Many ongoing and planned projects point in this direction. Hydrogen from renewable power is technically viable today and is quickly approaching economic competitiveness. The rising interest in this supply option is driven by the falling costs of renewable power and by systems integration challenges due to rising shares of variable renewable power supply. The focus is on deployment and learning-by-doing to reduce electrolyser costs and supply chain logistics. Policy makers should also consider how to create legislative frameworks that facilitate hydrogen based sector coupling. [5]

5. FIELDS OF APPLICATION

The transport sector - In addition to the first mass-produced hydrogen passenger cars from Toyota, Honda and Hyundai (among others), hydrogen trucks are being developed to decarbonise road transport of goods[6]. At present, mid-size hydrogen FCEVs are offered at a premium cost, around 50% more than similar internal combustion engine (ICE) vehicles, although a significant scaling effect could decrease costs if production grows substantially, according to manufacturers. Battery-electric vehicles are growing much more quickly in the passenger car sector, especially for urban and short-range applications. Long-distance, heavy-duty transport is potentially a more attractive market for FCEVs[7]. Hydrogen buses are already widely deployed, and several hundred are on the roads in certain Chinese cities. A new H2Bus consortium in Europe was also recently announced, aiming for 1000 commercially competitive buses fuelled with hydrogen from renewable power, the first 600 of which are due by 2023. Furthermore, Japan will utilise hydrogen buses for the 2020 Olympics.

Heating of residential areas - In the UK, the role of hydrogen in combination with existing natural gas distribution infrastructure has been thoroughly explored in a region of 5 million inhabitants as a key option for decarbonisation of heating, and a large-scale pilot project is scheduled in the north of England[8].

Production of feedstock for petrochemicals -Ammonia (fertiliser) and iron can be produced using hydrogen. This offers the prospect of growth in the renewables share of the energy use. While ammonia production technology is commercially available today, direct-reduced iron (DRI) production requires further development. DRI, however, is promising and technically feasible: commercial-scale plants have been in operation for decades and are steadily growing in number, with global DRI production reaching 100 million tonnes in 2018[9]. Beyond renewable fuels of the future, current demand for hydrogen has grown to a large extent due to changes in the oil products market. This has led to an increase in hydrogen demand in refineries, in particular for hydrocracking, to increase the refining yield of middle distillates (notably diesel and jet kerosene)[10]. This is because of a shift towards diesel in passenger cars as well as the continuous growth in trade, which relies on (diesel) trucks and airplanes (burning jet kerosene) in addition to ships and trains, which require a lower yield of naphtha (for gasoline), compared to middle distillates (in particular diesel and jet kerosene).

6. THE WAY AHEAD- WORK IN PROGRESS

A) Enhance understanding of the energy system benefits of hydrogen production from electrolysis and of integration of high shares of renewable power. Notably, the economics of seasonal storage and electrolyser demand-side flexibility need to be understood better.

B) Improve understanding of the cost-reduction potential for electrolysers and their potential to operate part-load based on the availability of variable power. This includes the ability to enhance ramp rates, future characteristics of different electrolyser designs and degradation under different operating conditions, which impacts the cost of hydrogen.

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[5] *https://www.weforum.org/agenda/2021/07/clean-energy-green-hydrogen/*
[6] *Forbes, 2019*
[7] *IRENA, 2018a*
[8] *CCC, 2018; Sadler et al., 2018*
[9] *Midrex, 2018*
[10] *US EIA, 2019*

C) Enhance understanding of the transition issues for pipeline systems from natural gas to hydrogen.

D) Improve understanding of hydrogen fuel chain efficiency losses and options to reduce these.

E) Enhance understanding of the potential to reduce greenhouse gas emissions in the production of blue hydrogen.

F) Exchange best practices and engage in international joint research and evaluation of hydrogen's potential, for example for power-to-X, as well as outreach and addressing regulatory barriers, codes and standards.

G) Assess the potential for low-cost, large-scale production of green hydrogen in different regions and countries to make use of best-available renewable resources.

H) Further develop the analysis of potential pathways to a hydrogen-enabled clean energy future, including the use of methanol and ethanol as hydrogen carriers in fuel cells.

I) Explore the potential to enhance energy security and reduce environmental impacts through relocation of manufacturing activities for energy-intensive commodities based on hydrogen and renewable power.

J) Improve understanding of the socio-economic impacts of the hydrogen economy, building on the work of IRENA (International Renewable Energy Agency).

K) Improve understanding of the geopolitics of hydrogen, building on the work of the IRENA commission on the geopolitics of energy transition.[11]

7. CHALLENGES FACED

A) Producing hydrogen from low-carbon energy is costly at the moment. IEA (International Energy Agency) analysis finds that the cost of producing hydrogen from renewable electricity could fall 30% by 2030 as a result of declining costs of renewables and the scaling up of hydrogen production. Fuel cells, refueling equipment and electrolyzer (which produce hydrogen from electricity and water) can all benefit from mass manufacturing.

B) The development of hydrogen infrastructure is slow and holding back widespread adoption. Hydrogen prices for consumers are highly dependent on how many refueling stations there are, how often they are used and how much hydrogen is delivered per day. Tackling this is likely to require planning and coordination that brings together national and local governments, industry and investors.

C) Hydrogen is almost entirely supplied from natural gas and coal today. Hydrogen is already with us at industrial scale all around the world, but its production is responsible for annual CO2 emissions equivalent to those of Indonesia and the United Kingdom combined. Harnessing this existing scale on the way to a clean energy future requires both the capture of CO2 from hydrogen production from fossil fuels and greater supplies of hydrogen from clean electricity. Most hydrogen used today is extracted from natural gas in a process that requires a lot of energy and emits vast amounts of carbon dioxide. Producing natural gas also releases methane, a particularly potent greenhouse gas.

D) Regulations currently limit the development of a clean hydrogen industry. Government and industry must work together to ensure existing regulations are not an unnecessary barrier to investment. 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.

E) And while the natural gas industry has proposed capturing that carbon dioxide — creating what it promotes as emissions-free, "blue" hydrogen — even that fuel still emits more across its entire

[11] *Cardella, U., Decker, L., Klein, H., 2017. Roadmap to economically viable hydrogen liquefaction. Int. J. Hydrog. Energy, Special Issue on The 21st World Hydrogen Energy Conference (WHEC 2016), 13-16 June 2016, Zaragoza, Spain 42, 13329–13338. https://doi.org/10.1016/j.ijhydene.2017.01.068*

supply chain than simply burning natural gas. [12]

F) Dr. Howarth and Mark Z. Jacobson, a professor of civil and environmental engineering at Stanford and director of its Atmosphere/Energy program, examined the life cycle greenhouse gas emissions of blue hydrogen. They accounted for both carbon dioxide emissions and the methane that leaks from wells and other equipment during natural gas production.

The researchers assumed that 3.5 percent of the gas drilled from the ground leaks into the atmosphere, an assumption that draws on mounting research that has found that drilling for natural gas emits far more methane than previously known.

They also took into account the natural gas required to power the carbon capture technology. In all, they found that the greenhouse gas footprint of blue hydrogen was more than 20 percent greater than burning natural gas or coal for heat. Running the analysis at a far lower gas leak rate of 1.54 percent only reduced emissions slightly, and emissions from blue hydrogen still remained higher than from simply burning natural gas.

Such findings could alter the calculus for hydrogen. Over the past few years, the natural gas industry has begun heavily promoting hydrogen as a reliable, next-generation fuel to be used to power cars, heat homes and burn in power plants. In the United States, Europe and elsewhere, the industry has also pointed to hydrogen as justification for continuing to build gas infrastructure like pipelines, saying that pipes that carry natural gas could in the future carry a cleaner blend of natural gas and hydrogen.[13]

8. WHAT IS THE WORLD DOING ON GREEN HYDROGEN?

A) The U.S. – The county had 6,500 fuel cell electric cars on the road in 2019 — the world's largest fleet. President Joe Biden's administration has set a goal of reducing the cost of renewable hydrogen by 80% by 2030. Industry groups, including some fossil-fuel companies, are pushing for tax credits for hydrogen production and for subsidies for converting natural gas pipelines to transport hydrogen.

B) The European Union- They have set the most ambitious goal: building electrolysers that are capable of converting 40 gigawatts of renewable electricity into hydrogen by 2030. It's made hydrogen a central component of its Green Deal plan, envisaging as much as 470 billion euros ($560 billion) of public and private investments by 2050 in the hope of kickstarting a global hydrogen market. Germany has declared that green hydrogen will play a central role in transforming the country's industrial base as it moves to zero emissions by 2045.

C) China -They plan to have 1 million vehicles powered by hydrogen fuel cells on its roads by the end of 2030. The value of its hydrogen production could reach 1 trillion yuan ($155 billion) by 2025, according to the China Hydrogen Alliance.

D) Australia- It will invest $214 million to speed development of four hydrogen hubs with 26 gigawatts of capacity. Japan, where Toyota Motor Corp. has invested heavily in fuel cell technology, is the world leader in hydrogen refueling stations, while South Korea is building fueling and other infrastructure in six cities where it hopes to make hydrogen the main energy source by 2025.

9. OVERCOMING THE CHALLENGES AND MAKING IT A REALITY

Most of the world's energy companies and big industrial groups are involved in hydrogen somehow. Royal Dutch Shell Plc is leading a consortium developing a project to produce up to 10 gigawatts of green hydrogen by 2040. Germany's RWE AG, together with 26 other companies, plans to set up electrolysis units in the North Sea with 10 gigawatts of capacity by 2035. European's Airbus SE is working on designs for hydrogen-powered aircraft.[14]

[12] *https://news.cornell.edu/stories/2021/08/touted-clean-blue-hydrogen-may-be-worse-gas-or-coal*
[13] *https://www.nytimes.com/2021/08/12/climate/hydrogen-fuel-natural-gas-pollution.html*
[14] *https://www.bloomberg.com/news/articles/2021-06-19/why-hydrogen-is-the-hottest-thing-in-green-energy-quicktake*

The time is right to tap into hydrogen's potential to play a key role in a clean, secure and affordable energy future. At the request of the government of Japan under its G20 presidency, the International Energy Agency (IEA) has produced this landmark report to analyse the current state of play for hydrogen and to offer guidance on its future development. The report finds that clean hydrogen is currently enjoying unprecedented political and business momentum, with the number of policies and projects around the world expanding rapidly. It concludes that now is the time to scale up technologies and bring down costs to allow hydrogen to become widely used. The pragmatic and actionable recommendations to governments and industry that are provided will make it possible to take full advantage of this increasing momentum.

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. It can also help improve air quality and strengthen energy security. 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.

Hydrogen is versatile. Technologies already available today enable hydrogen to produce, store, move and use energy in different ways. A wide variety of fuels are able to produce hydrogen, including renewables, nuclear, natural gas, coal and oil. 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 enable renewables to provide an even greater contribution. It 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 Australia or Latin America, to energy-hungry cities thousands of kilometres away.

The recent successes of solar PV, wind, batteries and electric vehicles have shown that policy and technology innovation have the power to build global clean energy industries. With a global energy sector in flux, the versatility of hydrogen is attracting stronger interest from a diverse group of governments and companies. Support is coming from governments that both import and export energy as well as renewable electricity suppliers, industrial gas producers, electricity and gas utilities, automakers, oil and gas companies, major engineering firms, and cities. Investments in hydrogen can help foster new technological and industrial development in economies around the world, creating skilled jobs.

Hydrogen can be used much more widely. 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 also needs to be adopted in sectors where it is almost completely absent at the moment, such as transport, buildings and power generation.

The IEA has identified four near-term opportunities to boost hydrogen on the path towards its clean, widespread use. Focusing on these real-world springboards could help hydrogen achieve the necessary scale to bring down costs and reduce risks for governments and the private sector. While each opportunity has a distinct purpose, all four also mutually reinforce one another.

1) Make industrial ports the nerve centres for scaling up the use of clean hydrogen. Today, much of the refining and chemicals production that uses hydrogen based on fossil fuels is already concentrated in coastal industrial zones around the world, such as the North Sea in Europe, the Gulf Coast in North America and southeastern China. Encouraging these plants to shift to cleaner hydrogen production would drive down overall costs. These large sources of hydrogen supply can also fuel ships and trucks serving the ports and power other nearby industrial facilities like steel plants.

2) Build on existing infrastructure, such as millions of kilometres of natural gas pipelines.

Introducing clean hydrogen to replace just 5% of the volume of countries' natural gas supplies would significantly boost demand for hydrogen and drive down costs.

3) Expand hydrogen in transport through fleets, freight and corridors. Powering high-mileage cars, trucks and buses to carry passengers and goods along popular routes can make fuel-cell vehicles more competitive.

4) Launch the hydrogen trade's first international shipping routes. 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.[15]

A Royal Dutch Shell hydrogen production plant in Wesseling, Germany[16]

10. INDIA INITIATIVE FOR CLEAN ENERGY

India has announced its Climate Action Plan for reduction of emissions by 33-35% by 2030 over the 2005 levels, boosting clean (non-fossil & including renewable) energy in electricity generation to 40% (at least another 150GW), while adding carbon sinks — tree and forest cover to remove carbon dioxide from the atmosphere — amounting to 2.5-3 billion tonnes of CO2 by 2030. Thus, the country has targeted to enhance nuclear power from 5 GW to 63 GW by 2032 and doubling wind capacity to 60 GW by 2022, solar capacity from 4 GW to 100 GW by 2022.

In view of the India's Climate Action Plan, the technologies for hydrogen production may be targeted accordingly. The first target may be focused on the efficient utilization of byproduct hydrogen of the Chlor-Alkali units. At the end of the financial year 2014-15, only 10% of byproduct hydrogen was available. Remaining 90% byproduct hydrogen is being utilized, 40% in chemical industries,37% as fuel in boiler heating for captive use and 13% being bottled for sale. After utilization of surplus un-utilized 10% byproduct hydrogen, next target may be made to utilize ~37% hydrogen efficiently, which is currently being used as fuel in boiler heating for captive use. Alternate sources may be used for heating purpose. In-house stationary power generation may be one of the most effective ways of utilizing hydrogen. The government may consider incentivizing this application of hydrogen for its cost effective utilization.

The present facilities of hydrogen production may be utilized to supply hydrogen for purpose of carrying out the activities on the research, development and demonstration for hydrogen production and its applications for stationary power generation and vehicles.

The Basic / Fundamental Research projects will cover search / development of new materials for the development of components, catalysts and new processes in the area of hydrogen production. These categories may be further elaborated as under

A) Development and demonstration of biological hydrogen production from different kinds of wastes like effluents from distillery, brewery, paper mills, wastewater from city, dairy, tannery, slaughter house, chemical & pharmaceutical industries, agro / food processing industry residues like cane molasses, noodle and potato processing, poultry litter, deoiled algal cakes, food (canteen) waste through dark or/and photo fermentation. Demonstration of prototypes at various levels followed by bench scale and pilot plant. After successful demonstration commercial production may be commenced.

B) Research and development for hydrogen

[15] *https://www.iea.org/reports/the-future-of-hydrogen*

[16] *Friedemann Vogel/EPA, via Shutterstock*

production by gasification of biomass, including demonstration of technology at pilot scale.

C) Hydrogen production by water splitting using photolysis and thermo-chemical route using solar and nuclear heat. Energy balance and process economic aspects may also be studied. (ii) Development & demonstration of 1 Nm3 /h high temperature steam electrolyser (HTSE) and 5 Nm3 /h indigenously developed solid polymer water electrolyser (SPWE). (iii) Development & demonstration of efficient alkaline water electrolyser. (iv) Development and demonstration of clean and sustainable hydrogen production by splitting water using renewable energies such as solar energy, wind energy and hybrid systems. This also includes electrolysis, photo-catalysis and photo-electro-catalysis. 197 c) Basic / Fundamental Research Projects (i) Dissociation of gaseous hydrocarbon fuels to hydrogen using solar energy. (ii) Any other innovative method for hydrogen production, like hydrogen production by non-thermal plasma assisted direct decomposition of hydrogen sulphide, Photo-splitting of Hydrogen Sulphide, including developmental effort for reduction in energy consumption for hydrogen production (d) Projects for Utilization of Byproduct Hydrogen at Chlor-Alkali Units / Refineries Development and demonstration of prototype systems for purification of by-product hydrogen from Chlor-Alkali units / refineries for the use in fuel cells to generate power for captive use or its compression for filing in cylinders to use them onboard in hydrogen fuelled vehicles / material handling systems (based on fuel cell technology). [17]

11. CONCLUSION

A hydrogen-based energy transition will not happen overnight. Hydrogen will likely trail other strategies such as electrification of end-use sectors, and its use will target specific applications. The need for a dedicated new supply infrastructure may limit hydrogen use to certain countries that decide to follow this strategy. Therefore, hydrogen efforts should not be considered a panacea. Also, decarbonisation of a significant share of global emissions will require clean hydrogen or hydrogen-derived fuels. Currently, significant energy losses occur in hydrogen production, transport and conversion. Reducing these losses is critical for the reduction of the hydrogen supply cost. Dedicated hydrogen pipelines have been in operation for decades. Transport of hydrogen via existing and refurbished gas pipelines is being explored. This may reduce new infrastructure investment needs and help to accelerate a transition. However, equipment standards need to be adjusted, which may take time. Whether the way ahead involves radical natural gas replacement or gradually changing mixtures of natural gas and hydrogen mixtures is still unclear. A better understanding is needed. While international hydrogen commodity shipping is being developed, another opportunity that deserves more attention is trade of energy-intensive commodities produced with hydrogen. Ammonia production, iron and steel making, and liquids for aviation, marine bunkers or feedstock for synthetic organic materials production (so-called electrofuels or e-fuels that are part of a power-to-X strategy) seem to be prime markets, but cost and efficiency barriers need to be overcome. This may offer an opportunity to accelerate global renewables deployment with economic benefits.

Hydrogen is a clean energy carrier that can play an important role in the global energy transition. Its sourcing is critical. Green hydrogen from renewable sources is a near-zero carbon production route. Important synergies exist between accelerated deployment of renewable energy and hydrogen production and use. Hydrogen roadmaps and respective opportunities have been elaborated for different countries including: Australia (ARENA, 2018; Bruce et al., 2018), Brazil (CGEE, 2010), Europe (FCH, 2019), France (MTES, 2018), Germany (Robinius et al., 2018; Smolinka et al., 2018), Japan (ANRE, 2017; METI, 2016), the Netherlands (Gigler and Weeda, 2018; NIB, 2017), the UK (E4tech and Element Energy, 2016) the United States (US) (US Drive, 2017). Country's strategies differ in terms of hydrogen production pathways and key hydrogen end uses according to each country particularity (Kosturjak et al., 2019).

[17] *D. Parvatalu. Hydrogen is the Key to Success of Renewable Energy Campaign: ONGC Energy Centre perspective. Invited talk at the National Seminar during 17-18th November 2014 at Univ. Kerala, Trivandrum organized by Indian Association for Hydrogen Energy and Advanced Materials*

The need for climate action now Climate is a main driver for hydrogen in the energy transition. Limiting global warming to below 2 degrees Celsius (°C) requires that CO2 emissions decline by around 25% by 2030, from 2010 levels, and reach net zero by around 2070 (IPCC, 2018). For a reasonable likelihood to stay below 1.5 °C of warming, global net anthropogenic CO2 emissions should decline by around 45% by 2030, from 2010 levels, reaching net zero by around 2050 (IPCC, 2018). In contrast with these ambitions, emissions have recently risen (UNEP, 2018). Energy-related CO2 emissions account for two-thirds of global greenhouse gas emissions. An energy transition is needed now to break the link between economic growth and increased CO2 emissions.

Current hydrogen use and future projections Hydrogen will be part of emissions mitigation efforts in the coming decades. IRENA's Renewable Energy Roadmap (REmap) analysis indicates an 6% hydrogen share of total final energy consumption by 2050 (IRENA, 2019a), while the Hydrogen Council in its roadmap suggests that an 18% share can be achieved by 2050 (Hydrogen Council, 2017). Today, around 120 million tonnes of hydrogen are produced each year, of which two-thirds is pure hydrogen and one-third is in mixture with other gases. This equals 14.4 exajoules (EJ), about 4% of global final energy and non-energy use, according to International Energy Agency (IEA) statistics. Around 95% of all hydrogen is generated from natural gas and coal. Around 5% is generated as a by-product from chlorine production through electrolysis. In the iron and steel industry, coke oven gas also contains a high hydrogen share, some of which is recovered. Currently there is no significant hydrogen production from renewable sources. However, this may change soon. The vast majority of hydrogen today is produced and used on-site in industry. The production of ammonia and oil refining are the prime purposes, accounting for two-thirds of hydrogen use. Ammonia is used as nitrogen fertiliser and for the production of other chemicals. At petroleum refineries, hydrogen is added to heavier oil for transport fuel production. Methanol production from coal has grown rapidly in China in recent years. Hydrogen pipeline systems spanning hundreds of kilometres are in place in various countries and regions and have operated without incident for decades. Similarly, there is a long track record of transporting hydrogen in dedicated trucks. Beyond these conventional applications, which have been around for decades, hydrogen use is very modest. The importance of hydrogen for energy transition has to come from new applications, and its supply needs to be decarbonised. Ammonia production and oil refining dominate hydrogen use. Residential fuel cell applications in the residential sector have constantly increased and comprised 225 000 units installed globally as of the end of 2018. Japan is the global leader with 98% of these applications[18]. According to the IEA (2019a), 380-plus hydrogen refuelling stations are open to the public or fleets, and the global fuel cell electric vehicle (FCEV) stock reached 11 200 units at the end of 2018, with sales of around 4 000 that year. To put these numbers in perspective, 2.5 million electric vehicles (EVs) were sold in 2018. The Hydrogen Council envisions 3 000 refilling stations by 2025, which would be sufficient to fuel around 2 million FCEVs.

As different governments strive to work towards a common goal of reducing the carbon footprint and bring the global warming to lowest levels possible. It is concluded that hydrogen could be a Zen Fuel with capability to give clean, green and low cost energy to keep our future generations pollution free and energy efficient.

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