# MODEL OF TRANSFORMATION TO GREEN HYDROGEN ECONOMY IN EMERGING COUNTRIES

by

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## Dedication

Dedicated to my spiritual Guru Sri Sri 108 Swami Birajananda Maharaj Ji, who has not only guided me throughout my life but also blessed my family through the journey of their progress. His teachings have inspired me all through and given a new dimension to my purpose of life. I also dedicate my research thesis to my late parents, mother- Karuna and father- Saradindu Narayan, for their constant encouragement to my studies which has brought me to the present position in my pursuance of higher studies. I will ever remain indebted to my Guruji and my parents.

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ABSTRACT

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## 1.1 Introduction

Green hydrogen holds significant promise in meeting our planet's energy demands. This research paper searches for avenues and will offer a model of making the green – hydrogen transformation in the emerging countries of Asia, Europe and Africa, economically viable, less costly, environment friendly and lead to a contributor to a more sustainable economy.

## 1.2 Objective

1.2.1 This research paper will offer a model of making the green –hydrogen transformation in the emerging countries of Asia, Europe and Africa, less costly and environment friendly.

1.2.2 This research paper will also explore and suggest necessary steps to be taken so that green hydrogen contributes to 25% of the total world economy by 2035.

## 1.3 Methodology

1.3.1 Critical analysis of the literature review papers on the subject was undertaken, to draw conclusions on what more needs to be done to achieve a Green Hydrogen Economy of about 25% of the world economy by 2035, in the emerging countries.

1.3.2 Based on the feedback on the questionnaire, a statistical model has been projected to suggest the requirements based on the following five parameters: Cost of production, Expenditure / Investments, Innovation on tech expansion, Time and Stakeholders (private, public) participation

## 1.4 Conclusions and Results

1.4.1 The responses from 75 persons on the questionnaire, supports our findings from our research model and our conviction that a “Green Hydrogen Economy is possible by 2035” is confirmed. The cost reduction to about USD 2 per Kg by 2035, predicted by our model is also supported by the survey.

1.4.2 For emerging nations of Asia, Africa & Europe to have a 25% contribution from green hydrogen of their total energy requirements, they would spend about USD 500-600 billion on green hydrogen and other renewable energies during 2030-2040. Support from developed countries in this matter is also a must.

1.4.3 The survey also supports that a larger public-private participation is required in all the emerging nations, to contribute to enhanced production of electrolyzers and for funding of a larger infrastructure to enable green hydrogen production , storage and transportation

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LIST OF ABBREVIATIONS

| | |
|---|---|
| PwC | Pricewaterhouse Coopers |
| kg | Kilogram |
| m | Metre |
| ppm | Parts per million |
| GHG | Green House Gases |
| IEA | International Energy Agency |
| CO2 | Carbon Dioxide |
| GW | Giga Watt |
| Twh | Tera Watt |
| km | Kilometre |
| PV | Photo-Voltaic |
| RE100 | Renewable Energy 100 |
| R&D | Research & Development |
| NEX | Global Innovation Index |
| S&P 500 | Index |
| MSCI | Index |
| RES | Renewable Energy Sources |
| Mt | Metric ton |
| NUTS2 | One European Region of Renewable Energy |
| EU27 | European Union 27 |
| UK | United Kingdom |
| Bar | Unit of Pressure |
| Deg-C | Degree Celsius |
| TERI | The Energy and Research Institute |
| CES | Clean Electricity Standard |
| H2 | Hydrogen |

| | |
|---|---|
| $CO_2$ eq | Carbon Dioxide equivalent |
| $CH_4$ | Methane Gas |
| Mt $CO_2$/YR | Metric ton of Carbon Dioxide per year |
| SMR CSS | Gray Hydrogen Production Plant |
| m/s | Metres per second |
| Cf | Capacity Factor |
| USD/KG | US Dollars per Kilogram |
| WT | WInd Turbine |
| CHP | Combined Heat and Power |
| G20 | Group of 20 Nations |
| Solar-PV | Solar Photo-Voltaic |
| CoP-26 | Confederation of 26 Nations |
| INDC | Intended Nationally Determined Contributions |
| SADC | South African Development Corporation |
| IT | Information Technology |
| UNEP | United Nations Energy Program |
| EV | Electric Vehicle |
| Bloomberg NEF | New Energy Unit of Bloomberg |
| USD | US Dollars (currency of The United States of America) |
| GAIL | Gas Authority of India |

CHAPTER I:

# INTRODUCTION

## 1.1 Introduction

Green Hydrogen is fast replacing the conventional forms of energy obtained from fossil fuels, atomic power, electrical power & biofuels. Advanced countries have already made huge investments on Hydrogen manufacturing units, be it normal, gray, blue or green hydrogen. Developing or emerging economies like India have just started on the hydrogen manufacturing units with a vision to replace fossil fuels in the next 15-20 years. Normal hydrogen is in abundance in the world around us but to extract hydrogen from renewable sources such as solar and wind to make it a “green” one, makes the task more challenging and economically stressful for the emerging countries who have to shell-out a large percentage of their budget in the process. However green hydrogen holds significant promise in meeting our planet’s energy demands.

## 1.2 Purpose of Research

This research paper searches for avenues and will offer a model of making the green –hydrogen transformation in the emerging countries of Asia, Europe and Africa, economically viable, less costly, environment friendly and lead to a contributor to a more sustainable economy where the goals of many countries towards reducing the carbon-footprints in the next 15-20 years is fulfilled. Author will study the different processes of Green – Hydrogen production, its transportation & end-usage where cost optimization would be the primary objective and lead to reducing carbon-footprints of the emerging economies of our planet. Author will also study the various parameters leading to production and storage of green hydrogen on a mass scale, so that the transformation from fossil-fuels to a cleaner energy source may be encouraged and made possible with optimization of resources available in those countries.

## 1.3 Specific Aim of the Research

The main aim is to suggest ways and means to promote green-hydrogen projects in the emerging economies, so that they themselves benefit and it is beneficial to the world economy as well. Thus, the research project would focus on the micro-economics of developing/emerging countries and the macro-economics of our planet as a whole, based on transforming the energy usage from the present fossil-fuel dependence to a green-hydrogen dependence, which would ultimately help reduce the carbon-footprints of the whole world. The present research paper will endeavor to predict a model for the necessary modifications required in infrastructure, stake-holder participation, investments, tech innovations and finally the cost involved in all the above to enable a transformation to a Green Hydrogen Economy in the Emerging countries.

## 1.4 Significance of the Model and other studies on the Subject

Recently, PwC, analyzed the green hydrogen market worldwide and identified potential demand growth, cost trajectories per country and the most promising export and import markets. The results give policymakers and industry leaders guidance on how the future market for green hydrogen could evolve. PwC evaluated the production cost trajectory of green hydrogen worldwide, giving us a better understanding of early movers and potentially large suppliers across countries and regions.

The key results of their findings are:

- Through 2030, hydrogen demand will grow at a moderate, steady pace through many niche applications across the industrial, transport, energy and buildings sectors.
- Through cross-sector collaborations, new alliances will form to develop hydrogen projects.
- Hydrogen production costs will decrease by around 50% through 2030, and then continue to fall steadily at a slightly slower rate until 2050.
- By 2050, green hydrogen production costs in some parts of the Middle East, Africa, Russia, China, the US and Australia will be in the range of EUR 1 to EUR 1.5/kg.
- Over the same time period, production costs in regions with limited renewable resources, such as large parts of Europe, Japan or Korea, will

be approximately EUR 2/kg, making these markets likely importers of green hydrogen from elsewhere.

- Even regions with good renewable resources but densely populated areas will import hydrogen, as land constraints limit the production of green electricity for direct use and conversion to hydrogen.
- Many large countries—such as the US, Canada, Russia, China, India and Australia—have regions for both competitive and non-competitive hydrogen production, which could prompt them to develop in-country trading.
- Export and import hubs will develop around the world, similar to current oil and gas hubs, but with new players in renewable-rich regions.

## 1.5 Analysis of the Research Problem

The need for cheap hydrogen storage will grow exponentially over time. Salt caverns can provide this cheap hydrogen storage solution. Europe has still many empty salt caverns available for large scale hydrogen storage, but dedicated salt caverns for hydrogen storage capacity can be developed in the different salt formations in Europe. Salt caverns today are ‘left over’ from salt production units. A typical salt cavern has a height of 300 m and a diameter of 60–70 m. Shifting from fossil fuels to renewable energy can contribute to achieving ambitious emissions-reduction targets and big strides in energy efficiency. To reduce emissions to a level that would keep the concentration of GHGs at 450 ppm in 2050, the IEA projects that renewable energy would need to account for 27% of the required $CO_2$ reductions. A major part of the $CO_2$ reductions resulting from the promotion of renewable energy technologies would take place in developing countries. The use of fossil and traditional energy sources in both developed and developing countries also impacts global biodiversity and ecosystems. Countries are forecasting future targets based on their resource capabilities. To achieve the targets for 2020, solar grid expansion method is applied as the lowest cost option in urban areas and more densely populated rural areas. Successful expansion has been achieved recently on a large scale in China, South Africa and Vietnam. An estimated USD 194 billion in green stimulus funding had been allocated to support clean energy globally, including renewable energy technologies, energy-smart technologies, carbon capture and storage, and transport. The transition to the green economy involves no less than a technological revolution and will have deep impacts on production structures as well as on consumption patterns.

According to a research paper – European Hydrogen Backbone published in July 2020, the green hydrogen production capacity may reach 40 GW by 2030, as is the ambition stated in the European Hydrogen Strategy. This capacity could produce around 100 TWh of renewable hydrogen within Europe. Such scale-up will require largescale first-of-a-kind projects, e.g. around the North Sea and in Spain. In addition, 80 TWh blue hydrogen may be created by 2030, including retrofitted grey hydrogen production plants as well as newly built blue hydrogen facilities. Whereas blue hydrogen production will likely be located near hydrogen consumers, green hydrogen will be destined to consumers and offtakers located elsewhere, requiring dedicated transport routes already from the late 2020s onwards, which can be provided by the emerging backbone.

By 2030, a dedicated European Hydrogen Backbone can develop with a total length of approximately 6,800 km, consisting mainly of retrofitted existing natural gas pipelines. This backbone includes the proposed Dutch and German national hydrogen backbones, with additional branches extending into Belgium and France. Furthermore, unconnected regional networks are likely to emerge in Italy, Spain, Denmark, Sweden, France, and Germany.

Christopher Flavin, president of the Washington, D.C.-based Worldwatch Institute, believes that the future belongs to decentralized, renewable energy. Although he acknowledges that fossil fuels will continue to provide energy, and that a transmission and distribution infrastructure will still be necessary to get hydrogen to retail customers, he and many other experts see a renewable future. Flavin points out that the market for oil is growing at less than 1.5 percent per year, while the wind and photovoltaic (PV) markets are now doubling in size every three years.

## 1.6 Research Purpose and Goals

Taking cue from expert opinions world-wide, the author proposes to suggest a model on transforming the present fossil-fuel based economy to a green energy economy where green hydrogen will be the driving factor. Transformations in the emerging countries in the last few years have been studied through several research articles and the gap between the present dependence on fossil fuels and a green hydrogen dependence has been analyzed, to make a model, which will help reduce the harmful GHG emissions and help our future generations to lead a healthier life.

Keeping in view the primary objective of predicting a model on the transformation to a Green Hydrogen economy, the researcher will make a statistical model based on cost and expenditure, investments required, tech innovations, stakeholder’s participation and finally the time-frame required to reach all the above.

CHAPTER II:

# REVIEW OF LITERATURE

## 2.1 Introduction

With the sole purpose of reviewing relevant studies on Green Hydrogen economy, an exhaustive list of research papers were studied in depth by the researcher and the salient features in each were noted. The studies revealed that Green Hydrogen would be an important energy tool to reckon with in the next decade and would also be an important facilitator to reach the goal of Net Zero in the coming years. The goal of the researcher was to find out how the emerging economies were faring in their endeavor to enable a smooth transition to a "Green Hydrogen Economy". The purpose was also to find out the cost effectiveness of the present units of green hydrogen production and subsequently their transportation to sites where it will be utilized for manufacturing units as an alternative to fossil fuels. With this view in mind the following literature review was undertaken, and the results are produced in subsequent paras.

## 2.2 The Literature Review

### Global Trends in Renewable Energy Investment 2020

Governments and companies around the world have committed to adding some 826 gigawatts of new non-hydro renewable power capacity in the decade to 2030, at a likely cost of around USD 1 trillion. Those commitments fall far short of what would be needed to limit world temperature increases to less than 2 degrees Celsius. They also look modest compared to the USD 2.7 trillion invested during the 2010-2019 decade, as recorded by this Global Trends report. The Covid-19 crisis has slowed down deal-making in renewables in recent months, along with that in other sectors, and this will affect investment levels in 2020. However, governments now have the chance to tailor their economic recovery programs to accelerate the phase-out of polluting processes and the adoption of cost-competitive sustainable technologies. The stakes are high. If this chance is missed, it may be even more difficult to find the funding to decarbonize the energy system in a post-Covid-19 global economy characterized by elevated government debt and squeezed private sector finances.

Renewable energy 2030 targets already written into official policy by 87 governments around the world would mean the construction of an estimated 721 gigawatts of new capacity in wind, solar and other non-hydro renewable power technologies over the next decade, according to analysis by Bloomberg NEF. Meanwhile, those private sector companies that have joined the RE100 group, pledging to source 100% of their power from renewables, will need to buy an estimated 210 terawatt-hours of green electricity by 2030, on top of what they consume now, in order to be on track. This could prompt the construction of an estimated 105 gigawatts of new wind and solar plants.

Capacity investment in developing markets excluding mainland China and India gained 17% last year, reaching a record USD 59.5 billion. One of the highlights was Taiwan, where financial close for three large offshore wind projects drove a 390% jump in outlays to a record USD 8.8 billion. Renewables capacity investment increased handsomely in Brazil and, in particular, Chile. But several formerly active developing country markets saw outlays decline in 2019 – notably South Africa, Vietnam and Morocco.

Chile enjoyed a 302% jump in renewables capacity investment to USD 4.9 billion, its highest ever. Wind deals galloped to USD 2.7 billion, from almost nothing the previous year, while solar increased 85% to USD 2.2 billion. Much of the reason for Chile's increase came down to the timing of particular large financings, relating to projects that won capacity in previous years' auctions.

The Mexican total regained 17% to USD 4.3 billion, albeit still below the peak tally of USD 6.1 billion from 2016. Wind fell 15% to USD 887 million, but solar increased 31% to USD 3.4 billion. However, there was uncertainty over energy policy under the presidency of Andres Manuel Lopez Obrador, and there were no fresh auctions during 2019.

Vietnam saw a meteoric rise in solar investment in 2018 on the back of a generous feed-in tariff, but this faded markedly after June 2019, when the level of support was cut by the government. Overall renewable energy investment slipped 64% to USD 2.6 billion in 2019. The boom resulted in 5.4GW of solar being built in 2019, much of it financed in the previous year.

Kazakhstan chalked up a record tally of USD 832 million, up 58%, thanks to the financing of a string of medium-sized wind and solar projects developed by international players such as China Power International and Total Eren. The fossil fuel-rich Central Asian country introduced auctions for renewables in 2018, and its energy minister voiced an aspiration in early 2019 to more than-double green energy capacity in that year.

Research and development spending in renewable energy edged up 1% to USD 13.4 billion in 2019. Half of that went to solar and a fifth to wind, and corporate R&D significantly outstripped government spending for the third year running. The Wilder Hill New Energy Global Innovation Index, or NEX, which tracks the performance of about 100 clean energy companies, rose by just under 60 points to end the year at 221.76. The NEX's gain of 37% outstripped the S&P 500 Index by eight percentage points and the MSCI World Index by 11 percentage points.

**A Green Hydrogen Economy**

The hydrogen economy needs trained people, new ventures and public–private partnerships now. The paper points out how the concerns of today, including higher costs and technologies under development, can be turned into opportunities for both the public and private sectors. It was not too long ago that the size of a mobile phone was that of a briefcase, and then almost 10 years ago, the size of a shoe box. Today, they are not only the size of a man's wallet but also often given away free to consumers who subscribe or contract for wireless services. While hydrogen may not follow this technological commercialization exactly, it certainly will be on a parallel path. International events and local or regional security dictate that the time for a hydrogen must be close at hand.

Clean environment and renewable energy lead to a healthier atmosphere. Global climate is a concern of all citizens. Our children are depending on us to do something today. Not do anything and leave the problems to the research laboratory or future generations. Aggressive improvement in energy efficiency, along with well thought out and executed transitional strategies, are essential to a clean environment. However, to enable sustainable growth, the society needs renewable energy production and the constant development and commercialization of advanced technologies. New markets must be sought and created. Perhaps most significantly new infrastructures that merge energy, environment, water, waste and transportation must be built today in order to support a green hydrogen economy. The time is now.

**Green hydrogen in Europe**

The increasing ambition of climate targets creates a major role for hydrogen especially in achieving carbon-neutrality in sectors presently difficult to decarbonise. This work examines to what extent the currently carbon-intensive hydrogen production in Europe could be replaced by water electrolysis using electricity from renewable energy resources (RES) such as solar photovoltaic, onshore/offshore wind and hydropower (green hydrogen). The study assesses the technical potential of RES at regional and national levels considering environmental constraints, land use limitations and various techno-economic parameters. It estimates localised clean hydrogen production and examines the capacity to replace carbon-intensive hydrogen hubs with ones that use RES-based water electrolysis.

The total annual production of hydrogen in Europe is in the range of 9.756 Mt (merchant hydrogen and purposely produced hydrogen, and not hydrogen produced as a by-product)

A major finding in our study is that most of the examined European regions have sufficiently high technical potentials to be self-reliant using renewable energy. The regional focus of our work serves two additional purposes. First, it shows up to which extent each European NUTS2 region can take advantage of the decreasing costs of modern renewables in order to become energy self-sufficient. Furthermore, clean hydrogen offers new opportunities for re-designing Europe's energy partnerships with both neighbouring countries and regions and its international, regional and bilateral partners, advancing supply diversification and helping design stable and secure supply chains. As for example several major hydrogen-producing regions and especially densely populated regions (large cities, metropolitan areas) would not have sufficient green electricity to cover both current electricity consumption as well electrolytic production of hydrogen. The current work assesses the replacement of grey hydrogen with green hydrogen production through electrolysis power by renewable energy resources for the

EU27 and UK at regional level considering existing electricity consumption and hydrogen demand. Switching the current annual EU hydrogen production of 9.75 Mt to electrolysis would require 290 TWh of electricity (about 10% of current production). The available technical potential for producing green electricity from wind, solar and hydro is easily sufficient to cover all current electricity consumption as well as this additional demand for green hydrogen, showing that a partial utilisation of prime locations could suffice. It was possible to geo-locate approximately 75% of current hydrogen production to 109 out of the 309 regions in the EU and UK.

**Green hydrogen economy and opportunities for India**

With increasing numbers of vehicles on roads, India is facing the issue of large vehicular emissions. The burning of crude oil is the major issue behind these emissions. India doesn't have enough resources to fulfill all the energy demands of vehicles and hence, imports crude oil from oil rich countries. To tackle the issues associated with oil imports and vehicular emissions, there is a need to search for carbon-free alternate fuel that is available locally in sufficient quantity to meet India's energy demands. The green economy is a new concept evolving and gaining attention worldwide, the concept focuses on sustainable and environmentally friendly solutions. Hydrogen is such a carbon-free fuel that can help to achieve the targets of the green economy and the best means to store energy for a long time. Hydrogen is a high energy content fuel and has about zero greenhouse gas emissions when used in fuel cells. Hydrogen is not directly available in free form, but it can be produced using electrolyzers and various other techniques. India's continuously growing renewable power generation capacity gives the advantage to produce hydrogen from green sources like solar, and wind at the time of lower demand. The present review work focuses on the opportunities for India in green hydrogen production as the adaption of green hydrogen offers many benefits to India including energy security and decarbonizing the transport sector.

The main issue with hydrogen is its storage and transportation as hydrogen is a highly combustible gas. The very low volumetric density makes it difficult to store hydrogen even in small quantities. Liquid and compressed storage are widely used to store hydrogen on a large scale. The hydrogen consumes a large volume even after compressing it at very high pressure. Commercially available fuel cell vehicles opt for 700 bar storage pressure as hydrogen occupies a large space at low pressure. Similarly, high-pressure tanks for decentralized storage of hydrogen especially for transport applications are necessary. However, tanks capable of holding such high pressure are generally made up of carbon fiber which is a very expensive material. As the pressure requirement increases, the quantity of carbon fiber required for the tank rises along with the up-gradation of this compression system specification which can increase the initial cost of storage. Hence many researchers are now focusing on the hydrogen production methods, transportation of hydrogen, and its storage. Liquefaction of hydrogen requires a significant energy input as the boiling point of hydrogen is very low (-253 deg C) but liquid hydrogen provides comparatively a high storage density. Liquefaction consumes about 30% of hydrogen energy. The high volumetric density is the main advantage of liquid hydrogen storage. Another means of hydrogen storage is adsorption which exhibits van der Waals bonding between hydrogen molecules and materials that store hydrogen in the solid phase. Metal hydrides and chemical hydrides exhibit these reactions and operate at low pressure. All three storage options have their respective limitations and hence currently there is no perfect solution for hydrogen storage.

Based on India's current progress in the renewable energy sector, it is clear that green hydrogen will make a greater impact on India's overall energy sector. Green hydrogen will help to provide a sustainable solution for the Indian transport sector. The Energy and Research Institute (TERI) of India has predicted that the demand for hydrogen will increase from 6 Mt to 28 Mt by 2050 and the cost of hydrogen from renewables will fall by 50% by 2030. TERI claimed that about 80% of hydrogen in India will be produced from renewables by 2050. India has fewer reserves of natural gas and green hydrogen production from renewables can make a difference in this scenario. Under the 'Make in India' program, India has the opportunity to start the production of electrolyzers and fuel cells which will allow capturing a large share in this market worldwide. As compared to other parts of the world, India has a low cost of electricity from the solar photovoltaic systems, this generated power in the future will be helpful to scale up green hydrogen production.

Following are some benefits of using green hydrogen as a fuel in India (Source: Department of Science and Technology, New Delhi)

a. Reduced Petroleum Imports and Energy Security.

b. Decarbonization of Transport sector.

c. Integration of Renewables with Hydrogen production,

d. Addresses Climate Change Issues.

The world is slowly moving towards the adoption of a Hydrogen economy and India is also taking important initiatives. Indian organizations which include both government and public are investing in the research of hydrogen technologies. Many Ongoing research and demonstration projects are very important to develop hydrogen and fuel cell technology economically. The progress in this development will play a key role in the commercialization of the technology. Well-developed fuel cell technology and locally produced green hydrogen will be key players to decarbonize the Indian transport sector by replacing the current petroleum-based vehicle engines.

**A Roadmap to 100% Clean Electricity by 2035**

The United States of America must act urgently to reduce its carbon pollution to address the climate crisis. But this is not just a climate imperative—it is an opportunity to recharge the U.S. economy and create millions of good-paying jobs in the process. It is also an opportunity to address ongoing injustices, through transitioning away from polluting fossil fuel infrastructure overwhelmingly placed in communities of color. Achieving 100% clean, carbon-free electricity is a crucial first-order priority. Transforming electricity generation is a linchpin to rapidly decarbonizing the US economy. Not only will it eliminate carbon and other air pollution from electric power—the second-largest sector for domestic emissions—it will also enable the clean electrification of transportation, buildings, and parts of heavy industry. In this way, achieving carbon-free electricity throughout the economy can help to catalyze upwards of a 70-80% reduction in U.S. carbon pollution. The Evergreen Action Plan 1 has called for the president and Congress to pass a Clean Electricity Standard (CES), alongside complementary investments and justice-centered policies, to achieve 100% clean, carbon-free electricity by 2035. This policy is a foundational pillar in a national 2 mobilization to defeat the climate crisis and build a more just and thriving American economy.

Target of 100% by 2035 starts with 80% by 2030 On the road to 100% clean energy by 2035, federal lawmakers should be targeting at least 80% clean electricity generation by 2030. The Evergreen Action Plan calls for the next president and Congress to enact a CES that requires “utilities to achieve 100% carbon-neutral electricity by 2030, and all-clean, renewable and zero-emission energy in power generation by 2035.” This initial ten-year benchmark, based on 31 successfully implemented state policy in both Colorado and Washington, would require utilities to achieve at least 80% carbon-free generation by 2030. A federal 32 CES should prioritize 80% carbon-free generation by 2030 as the near-term target that will ensure sustained carbon pollution reductions in the power sector over the coming decade.

Setting a national Clean Electricity Standard (CES) will unlock enormous investments that will rapidly deploy new technologies and investment to sustain new businesses, job creation, and economic recovery. This approach is technologically feasible, cost-effective, and will result in significant direct and indirect benefits for the American economy. Congress should create a new national Clean Energy Accelerator or Green Infrastructure Bank or (also known by many other names), and capitalize it with USD 90 billion, to further accelerate deployment of clean energy and assist in the retirement of fossil fuel assets. Such a federal financing authority would deploy low-cost loans 116 and loan guarantees that earn a return, allowing for cost-effective support for clean energy transformation on an ongoing basis. Through such a green finance institution, the federal government stands to catalyze enormous investment in clean energy construction-- by one estimate, a green bank can attract private investment more than 10 times the size of its initial capitalization.

The United States could position itself to be the world leader on clean energy research and development, bringing much-needed technologies to (and from) the global market and signaling an American commitment to a clean energy future.

## 2.3 Case Studies on Green Hydrogen

### Case for a Global Green Hydrogen Alliance

By 23 April 2021, 44 countries and the European Union had declared net-zero commitments, promising to reduce their greenhouse gas (GHG) emissions to zero or offset whatever residual is difficult to completely eliminate. Whereas many of these countries have set 2050 as the target year, China is looking at 2060 and others are considering later years. Whereas the Intergovernmental Panel on Climate Change demands net-zero emissions for the world as a whole by 2050, the same principle need not apply to all countries. In fact, many of the developed countries that have set net-zero targets will enjoy long transition periods between when peaking emissions and bending the curve downwards to reach net-zero emissions. The transition period is likely to be far shorter for developing countries giving them fewer additional years of carbon space within which to reach higher standards of living. There also remain many questions about the credibility of the targets, given that they are not always backed up by adequate and concrete policies along a set timeline that would trigger near-term action and signal real intent. More recently, some countries have come forward to declare aggressive emission reduction goals for 2030 or 2035. For instance, the United States promised to reduce emissions by 50-52 per cent by 2030 against 2005 levels. The United Kingdom also raised ambition to reduce emissions 78 per cent by 2035 compared to 1990 levels. The EU pledged 55 per cent reduction (against 1990 levels) by 2030. These are, no doubt, encouraging signs of a clearer intention to reduce emissions to levels that give a chance for global average temperatures to stabilise. However, by some measures, high-income countries should be aiming for net-zero emissions latest by 2035, rather than wait for 2050 or later. Yet, the pressure on middle-income and low-income countries to reduce emissions disproportionately faster continues unabated.

Many countries have announced national and regional programmes for (green/clean) hydrogen. However, the technology and its applications in various industrial sectors are still significantly short of commercialisation at scale. Deployment so far is primarily via pilot projects. And, the centres for potential hydrogen demand, generally in emerging economies and particularly in Asia, remain mostly out of the loop of these developments. If industrial decarbonisation is to pick up speed, then research, demonstration and deployment of green hydrogen would also have to accelerate, at the global level, and connected to centres for potential hydrogen demand. This paper proposes a new platform, a Global Green Hydrogen Alliance, as an action-focused multi-country, multi-institutional network to assess, develop and design affordable green hydrogen technologies that can be deployed at scale. The premise of creating a new platform rests on the gaps in current efforts to develop and scale hydrogen technologies, coupled with the urgent need to find core solutions to make the practical transition to a clean energy future, in line with the crucial Paris Agreement goals.

The cost of electrolysers could reduce by 40 per cent by 2030 with 100 GW of capacity deployment; and in a close to zero emissions system, the cost of electrolysers is expected to reduce by about 70 per cent by 2050 with a deployment of 1700 GW. These estimates are in line with the estimates provided by the Hydrogen Council which aims at 60 per cent reduction in cost by 2030, India has recently announced the National Hydrogen Mission which aims for generation of hydrogen from green power resources Current Status , Refueling stations: 2 , FC Bus: 10 , National Hydrogen Mission . The Union Budget for 2021-22 has announced a National Hydrogen Mission for generating hydrogen from green power resources. The proposed mission would aim to lay down Government of India’s vision, intent and direction for hydrogen energy and suggest strategy and approaches for realisation of the vision. The mission aims to develop India into a global hub for manufacturing of hydrogen and fuel cells technologies across the value chain.

Major activities under the Mission include: creating volumes and infrastructure; demonstrations in niche applications (including for transport, industry); goaloriented research & development; facilitative policy support; and putting in place a robust framework for standards and regulations for hydrogen technologies.

The India H2 Alliance, led by Chart Industries and Reliance Industries, has come against the backdrop of the proposed National Hydrogen Mission, which may mandate fertiliser, steel and petrochemicals industries to shift to green hydrogen.

**Perspective of the role of hydrogen in the 21st century energy transition**

Hydrogen is gaining momentum in the current global energy transition framework. In fact a great and widespread enthusiasm is growing up towards it, as indicated by the current worldwide economic and political strategies, which endorse the carbon neutrality by 2030 and a fast transition to clean energy. Green hydrogen has the potential to create a virtuous cycle for the future renewables-based electricity grids, as it can provide the much-needed flexibility to power systems, acting as a buffer to non-dispatchable renewable generation. Indeed, the excess energy, provided by conventional and renewable power plants, can be stored as hydrogen and then employed to produce electricity (fuel cells or power systems), heat (combustion) or both (co-generation), abating drastically the greenhouse gas production. In this scenario, it is important to understand what benefits could derive from the use of hydrogen. For this reason, the present work not only aims at reviewing the recent updates on hydrogen economy (in terms of the main advantages and drawbacks) but also focuses on determining the impact that this hydrogen may have in various sectors (transport, industry and power generation). Different assessments have been carried out showing how hydrogen can effectively contribute to the carbon neutrality goal. This work points out that hydrogen can be really sustainable if produced via electrolysis powered by renewable energies. Furthermore, for the mobility, the use of fuel cells currently turns out to be less efficient than the adoption of Li-ion batteries, but at the same time far less polluting ($CO_2$, eq) and labor intensive. Finally, a near-term solution to contrast the power generation carbon footprint, namely the blending of fossil fuels with hydrogen, has been investigated. Thus, a real Combined Cycle Gas Turbine power plant has been selected as a case study, in order to assess the impact of the hydrogen employment in terms of power output and emissions with respect to the current status of the plant fueled with 100% natural gas. As a result, using a mixture with 70% $CH_4$ and 30% $H_2$ a remarkable reduction of $CO_2$ can be achieved (0.28 Mt $CO_2$/year).

The future energy scenario will need more and more energy produced by renewable sources and hydrogen, above all the green hydrogen, will play an important role in this transition. Given the current great and widespread enthusiasm growing up towards hydrogen, the present work aims to provide recent updates on hydrogen, by focusing on the effects that it can entail in different sectors in terms of renewable source exploitation and reduction of $CO_2$ emissions. Each road-map aiming at deploying hydrogen is constituted by three main milestones (production, storage and distribution, final use). Regarding the production, currently most of the hydrogen is produced from conventional fossil fuels (the so-called gray hydrogen) by means of SMR-CSS plants. Nowadays, these plants are effective only for large applications. This means that much more green hydrogen should be produced as production technologies become more and more mature with more competitive costs. At the same time, storage and distribution will be the key enabling technologies for this zero-emission scenario. Indeed, in a future where much more renewable sources will be exploited, more clean energy input will be available for a green hydrogen, which requires to be stored and transported on demand.

**Potential and economic viability of green hydrogen production by water electrolysis using wind energy resources in South Africa**

Due to the comparable use of hydrogen to fossil fuel in the transportation, industrial and electricity sector, hydrogen could be a potential solution to the current energy crises especially when produced from a clean and sustainable source. One of the most appropriate methods of green hydrogen production is the use of wind energy via water electrolysis. This paper therefore investigates the capability and viability of hydrogen production from the wind energy resources of South Africa using the actual wind speed obtained at 60 m anemometer height. Sensitivity analyses are also conducted to gain insight into the possible influences of wind turbine operating parameters on the cost of hydrogen production. Wind regime of fifteen different sites across five major provinces are analysed for possible wind-hydrogen production using eleven different off-the-shelf wind turbines ranging from small to large categories. Some of the key results revealed that the mean wind speed (Vm) varies from 5.07 m/s in Eston to 8.10 m/s in Napier. Wind turbine WT (Servion SE MM100) with rated wind power of 2 MW, cut-in wind speed of 2 m/s, rated wind speed of 11 m/s, cut-out wind speed of 22 m/s and turbine hub-height of 100 m has the highest capacity factor (Cf) across all the sites with the values that range from 24.04% in Eston to 54.55% in Napier. The sensitivity analysis conducted revealed that rated wind speed has significant effect on the cost of hydrogen production compared to other wind turbine parameters. Viability of hydrogen production from wind resources of South Africa is studied. Wind regime of 15 different sites across 5 major provinces are analysed. Influences of wind turbine operating parameters on hydrogen cost is also considered. Hydrogen cost is lowest at site S5 from USD 39.55/kg with WT1 and USD 1.4/kg using with WT Rated wind speed (vr) has most significant effect on the cost of hydrogen production.

**Review of hydrogen economy in Malaysia and its way forward**

Heavy fossil fuels consumption has raised concerns over the energy security and climate change while hydrogen is regarded as the fuel of future to decarbonize global energy use. Hydrogen is commonly used as feedstocks in chemical industries and has a wide range of energy applications such as vehicle fuel, boiler fuel, and energy storage. However, the development of hydrogen energy in Malaysia is sluggish despite the predefined targets in hydrogen roadmap. This paper aims to study the future directions of hydrogen economy in Malaysia considering a variety of hydrogen applications. The potential approaches for hydrogen production, storage, distribution and application in Malaysia have been reviewed and the challenges of hydrogen economy are discussed. A conceptual framework for the accomplishment of hydrogen economy has been proposed where renewable hydrogen could penetrate Malaysia market in three phases. In the first phase, the market should aim to utilize the hydrogen as feedstock for chemical industries. Once the hydrogen production side is matured in the second phase, hydrogen should be used as fuel in internal combustion engines or burners. In the final phase hydrogen should be used as fuel for automobiles (using fuel cell), fuel-cell combined heat and power (CHP) and as energy storage. Biomass and solar pathways for hydrogen production could be feasible in Malaysia. Hydrogen can be used as transportation fuel, heating fuel and energy storage. Hydrogen economy in Malaysia faces technical, economic and social challenges.

**Opportunities for Production and Utilization of Green Hydrogen in the Philippines**

The Philippines is exploring different alternative sources of energy to become energy-independent while significantly reducing the country's greenhouse gas emissions. Green hydrogen from renewable energy is one of the most sustainable alternatives with its application as an energy carrier and as a source of clean and sustainable energy as well as raw material for various industrial processes. As a preliminary study in the country, this paper aims to explore different production and utilization routes for a green hydrogen economy in the Philippines. Production from electrolysis includes various available renewable sources consisting of geothermal, hydropower, wind, solar, and biomass as well as ocean technology and nuclear energy when they become available in the future. Different utilization routes include the application of green hydrogen in the transportation, power generation, industry, and utility sectors. The results of this study can be incorporated in the development of the pathways for hydrogen economy in the Philippines and can be applied in other emerging economies. Green hydrogen as an energy carrier and fuel plays a crucial role in total decarbonization towards achieving the climate targets. With the country's abundance of sustainable energy sources, the Philippines sees a huge potential for green hydrogen production. The current study identified various production routes including the electrolysis from geothermal, hydropower, wind, solar, and biomass as well as ocean and nuclear energies once they become available in the country. Complementary to the deployment of different renewable energy sources, green hydrogen can be utilized for the decarbonization of various sectors such as transportation, power generation, industry, and utility. With the Philippine government's goal of attaining continuous economic growth by 2040 through the adoption of innovative technologies while ensuring ecological integrity, a healthy, and clean environment, the utilization of green or renewable hydrogen as added renewable energy sources could not be timelier and more significant. Moreover, this will be the Government's initiative in attaining Sustainable Development Goal for affordable and clean energy. However, its realization also rests on sustainable governance –leadership anchored into looking after the welfare of the present generation without compromising the well-being of the future generations resulting in the crafting of long-term public policies. The adoption of this new technology in the Philippines entails the formulation of policies, programs, and initiatives, in addition to the existing renewable energy law and the Philippine Energy Plan 2017-2040, that will facilitate the utilization of these renewable energy sources. To enable the realization of a green hydrogen economy in the country, the government must first intensify the development of infrastructures for renewable energy sources for green hydrogen production; strictly enforce the transport modernization program with the use of more sustainable fuel for transportation; encourage different industry for a circular economy with sustainable production; and accelerate the consumption of more sustainable fuels for household utilities and energy generation particularly in remote communities in the country. Despite the research's limited analysis, this preliminary study can be used as a basis for further development to investigate various aspects of the green hydrogen roadmap for the Philippines as well as for other developing countries.

**Green hydrogen in a circular carbon economy: opportunities and limit**

Green hydrogen in particular, defined as **hydrogen produced from water electrolysis with zero-carbon electricity**, could have significant potential in helping countries transition their economies to meet climate goals. Today, green hydrogen production faces enormous challenges, including its cost and economics, infrastructure limitations, and potential increases in CO2 emissions (e.g., if produced with uncontrolled fossil power generation, which would be hydrogen but would not be green).

Key findings include: Green hydrogen could play a major role in a decarbonized economy. Green hydrogen and fuels derived from it (e.g., ammonia, methanol, aviation fuels) can replace higher-carbon fuels in some areas of the transportation sector, industrial sector, and power sector. They can provide low-carbon heat, serve as low-carbon feedstock and reducing gas for chemical processes, and act as an anchor for recycling CO2.

The primary challenge to green hydrogen adoption and use is its cost. The cost of green hydrogen is high today, between USD 6–12/kilogram (kg) on average in most markets and may remain high without subsidies and other policy supports. Zero-carbon electricity is the primary cost element of production (50–70 percent) even in geographies with significant renewable resources, with electrolyzers and the balance of system as secondary costs.

Green hydrogen commercialization is also limited by existing infrastructure. Growing demand of green hydrogen will require enormous investment and construction of electricity transmission, distribution and storage networks, and much larger volumes of zero-carbon power generation, as well as electrolyzer production systems, some hydrogen pipelines, and hydrogen fueling systems. An 88 million tons per annum (Mtpa) green hydrogen production by 2030, corresponding to the Stated Policies Scenario from the International Energy Agency (IEA) for that year, could cost USD 2.4 trillion and require 1,238 gigawatts (GW) of additional zero-carbon power generation capacity.

The authors recommend the following set of policy actions:

Nations and regions that wish to pursue green hydrogen production and use should prioritize detailed analysis and planning today. Location and scale of infrastructure bottlenecks, limits to electrolyzer and fuel cell production, potential trade-offs in cost and speed with competition, resource availability, public risks, and financial gaps in specific markets and applications must be studied and considered in planning. To reduce emissions rapidly through green hydrogen deployment, nations and regions should adopt market-aligning policies and production standards. The substantial price gap between green hydrogen and "gray" hydrogen (produced with fossil fuels without carbon capture) calls for active policy intervention to bring production online to serve existing and future markets. This could include measures to reduce or subsidize the cost of zero-carbon electricity or measures to incentivize the value and use of low-carbon hydrogen. Local, regional, and national governments interested in green hydrogen development should prioritize the construction of necessary infrastructure. Major new infrastructure and infrastructure transformation (e.g., gas grid transformation for transporting and storing green hydrogen) is required for electricity transmission, hydrogen production, hydrogen storage, hydrogen transmission, fueling for transportation (both hydrogen and ammonia), and international trade ports.

**Challenges towards hydrogen economy in China**

The increasingly serious energy crisis and environmental pollution caused by the excessive use of fossil fuels have been prompting China to aggressively seek a clean and self-sufficient energy source in the future. In the past decades, hydrogen has emerged as a promising alternative due to its advantages of cleanliness, abundance, high energy density, and high conversion efficiency.

However, several challenges have to be overcome for China's successful transition to hydrogen economy. In this paper, the hydrogen supply chain is firstly described to help the readers to clearly understand the hydrogen economy. Subsequently, the feasibility of hydrogen economy is discussed by reviewing viewpoints from the literature. Finally, the challenges of China's transition to hydrogen economy are detailed summarized and discussed, and the strategies for China to develop hydrogen economy were compared with that of Japan and Australia.

Hydrogen and electricity should clearly have the same strategic position in China. Geographic differences in resources and demands should be addressed. It is necessary to diversify the application of hydrogen. CCS technology is significance to the medium-term development of China's hydrogen economy.

**Mission Hydrogen Accelerating the Transition to a Low Carbon Economy**

"Mission Hydrogen" is an ongoing collaboration between the Global Energy Technology Innovation (GETI) Initiative – a project of the Belfer Center's Environment and Natural Resources Program and the Science, Technology, and Public Policy Program – and the Italian Institute for International Political Studies (ISPI) on the future of hydrogen in the context of the 2021 G20 in Italy.

Clean hydrogen could play a significant role in an accelerated transition to a low carbon economy, particularly for hard-to abate sectors, and offers a path toward meeting national and international climate and pollution goals while avoiding reliance on imported fuels. The two key challenges to clean hydrogen adoption and use at scale are currently its cost and limited infrastructure availability. Public concerns around safety might also present additional challenges to deployment. From a market perspective, clean hydrogen, like natural gas, will initially flourish in regional markets with the corresponding potential for geopolitical conflicts.

Green or renewable hydrogen refers to hydrogen produced from renewable energy sources like wind and solar through a process known as water electrolysis, where an electrolyzer splits water molecules into oxygen and hydrogen. There are no CO2 emissions generated during the production process. Today, green hydrogen costs are significantly more than those of grey hydrogen, with estimates ranging from EUR 2.3 per kg to EUR 4.1 per kg. It accounts for less than 0.1% of the world's hydrogen production.

Before renewable hydrogen can truly become a game-changer in the transportation sector, significant barriers, mainly related to storage, infrastructure, and costs, will need to be addressed. From an innovation perspective, it will be crucial to reduce costs and improve performance. Technological challenges around weight and hydrogen storage need solutions, particularly in the maritime and aviation sectors.

Among developing countries, by far the largest share of investments in renewable energy has been in the three large emerging economies of Brazil, China and India, who together account for almost USD 60 billion, or 90%. Other developing countries, while representing only 10% of the total, are also experiencing accelerated growth, with investments in Latin America (excluding Brazil) almost tripling, Asia increasing by almost a third and Africa fivefold in 2010. However, these investments tend to be concentrated in a limited number of countries. For renewable energy investments to expand on a large scale in other developing countries, major efforts are needed to develop infrastructure including transmission and distribution systems, improving the functioning of financial markets and other institutions, and providing a supportive incentive framework. In addition, to installing significant renewable energy capacity, fast-growing emerging markets have also built up large equipment manufacturing industries in the sector, both for export to the global market and for local use. China has, for example, become the world's largest producer of solar PV panels and solar water heaters. The government has supported investments in manufacturing capacity for renewable energies, for example, by establishing preferential electricity tariffs for the solar industry.

The substantial potential of renewable energy sources could make a major contribution for enhancing the green economy in developing countries. As the economic potential of developing nations is increasing, the platform, mechanism and infrastructure could be shared in order to stimulate the use of renewable energy technologies in both the public and the private sectors. Furthermore, it is essential that priority is given to public sector infrastructure investments which are critical to the transition to the green economy, mainly for electricity as it is required by all infrastructure companies. Several countries may prefer to keep the control of these sectors under the government rather than as public–private partnerships or as a fully private property. International allocation of funds should fully respect national decisions in this area. Infrastructure investments are, of course, critical for directing private sector investments in the desirable direction (‘crowding-in’ private investments and ‘locking’ them in the direction of green investments). They may also demand a specific time profile, requiring in particular major upfront investments. If there is a decision to undertake these investments by the private sector, due account should be made of the allocation of risks. In Uzbekistan, the infrastructure and legislation of renewable energy market is developing, and the risk and return should be considered for maintaining long-run sustainable development in renewable energy in order to ensure an effective transition to a green economy.

**European Hydrogen Backbone, 2020**

Large-scale hydrogen consumption will require a well-developed hydrogen transport infrastructure. This paper presents the European Hydrogen Backbone (EHB), a vision for a truly European undertaking, connecting hydrogen supply and demand from north to south and west to east. Analysing this for ten European countries (Germany, France, Italy, Spain, the Netherlands, Belgium, Czech

Republic, Denmark, Sweden and Switzerland), we see a network gradually emerging from the mid-2020s onwards. This leads to an initial 6,800 km pipeline network by 2030, connecting hydrogen valleys. The planning for this first phase should start in the early 2020s. In a second and third phase, the infrastructure further expands by 2035 and stretches into all directions by 2040 with a length almost 23,000 km. The hydrogen backbone as presented in this paper will transport hydrogen produced from (offshore) wind and solar-PV within Europe and also allows for hydrogen imports from outside Europe.

By 2030, a dedicated European Hydrogen Backbone can develop with a total length of approximately 6,800 km, consisting mainly of retrofitted existing natural gas pipelines. This backbone includes the proposed Dutch and German national hydrogen backbones, with additional branches extending into Belgium and France. Furthermore, unconnected regional networks are likely to emerge in Italy, Spain, Denmark, Sweden, France, and Germany.

**South Korean efforts to transition to a hydrogen economy**

As the world increasingly looks to renewable energy sources to deal with climate change, South Korea is aiming to become a leader in the development of hydrogen as an alternative energy source. In developing an ecosystem for a hydrogen economy, South Korea is focused on increasing the production and use of hydrogen vehicles, establishing an ecosystem for the production and distribution of hydrogen and related technologies, and expanding the production of fuel cells. The government's vision has the backing of key industrial firms, most importantly the Hyundai Motors Group which plans on investing 7.6 trillion won (USD 6.7 billion) under its "FCEV Vision 2030" and is part of the HyNet consortium to build 100 new hydrogen refueling stations in South Korea by 2022. If South Korea's vision is successful, it expects hydrogen to account for 5% of its projected power consumption in 2040, to see its economy grow by 43 trillion won, 420,000 new jobs created, and significant reductions in both fine dust and greenhouse gas emission.

## Getting to Net Zero: An Approach for India at CoP-26 (CSEP Working Paper 13)

The Paris Agreement, which emerged from the CoP-21 held in Paris in 2015, was the next major step in building a global consensus on climate change. It was viewed as a landmark agreement for four reasons.

a) It was the first time the international community set a quantitative target of limiting average global warming to "less than 2°C and ideally 1.5°C above pre-industrial levels". This reflected a realisation that global warming beyond these levels would be disastrous.

b) It was also the first time that all the participants, including the developing countries, agreed to take some mitigation steps in the form of Intended

Nationally Determined Contributions (INDCs). India announced the following INDCs (i) a reduction of 33 to 35% in the emissions intensity of GDP between 2005 and 2030 (ii) raising the share of non-fossil fuels-based electricity generation capacity to 40% by 2030 and (iii) increasing land under forests to create additional carbon sink of 2.5 to 3 Gt-CO2 equivalent by 2030. We did not offer any commitment to reduce emissions, but we clearly accepted some responsibility in controlling the growth rate of emissions.

c) The developed countries formally accepted the target of scaling up financial assistance to developing countries, reaching USD 100 billion per year by 2020 to support the transition. This responded to some extent to the notion of climate justice.

d) Finally, all countries undertook to regularly submit national data on emissions. This was an important precondition for systematic monitoring of progress in future.

The INDCs adopted in the Paris Agreement were purely voluntary and were not calibrated to ensure achievement of the global warming target. In fact, it was known that they were insufficient even to limit the warming to below 2 deg C, but it was consciously decided to leave it to subsequent meetings to "ratchet up" obligations. That time has now come. The issue we have to face is whether we should continue with our policy of not accepting any emission reduction trajectory and limit our commitments only to specific mitigation actions as part of our revised INDCs. We will certainly be under pressure to make a commitment because India is now the fourth-largest emitter after China, the US and the EU and as it is known that we would be among the most severely affected countries, we will be expected to do more.

Diplomatic pressure cannot be a reason for adopting a course of action that is not in our national interest, but in this case, there are good reasons for changing our stand. Our traditional reluctance to offer an emissions reduction trajectory was based on the perception that the developmental objective of raising our per capita GDP would require an increase in energy use, which in turn would entail higher emissions. This argument is no longer valid because changes in technology now make it possible to increase energy use by relying on green sources which do not generate emissions. We can aim to meet all our additional energy needs from renewable sources and in due course replace existing fossil fuel use with renewable energy.

**A Policy Review of Green Hydrogen Economy in Southern Africa**

Green hydrogen energy policies should be formulated in a blended manner that incorporates the research institutions, public sector, and private sector and more focused on achieving certain specific goals such as decarbonisation, alongside other economic benefits such as a scaled-up energy sector with wind, solar, and tidal infrastructure, and technology; an improved health and environment that has reduced $CO_2$ emissions and particulate matter; improved water sector, especially for the countries with a seashore concerning desalination technologies; an improved transport system with hydrogen vehicles and pump stations, and an improved logistics and infrastructure that introduces a new infrastructure for (1) packaging the hydrogen as a compressed gas, liquid, hydride, etc.(2) distribution pipelines, pipes, roads, shipping and railroads; (3) dispensing-transfer from retailers to consumers; and (4) storage-pressurized containers. Research is needed to provide accurate base data on which policies can be formulated.

Finally, to accomplish green hydrogen policy formulation in Southern Africa, governments would need to take up the following measures:

a) Establish the role of hydrogen within long-term energy strategies that are embedded in national, regional, and local governments to guide future expectations. In this way, firms would clearly have their long-term goals outlined. Some key industrial sectors that can be targeted include refineries, chemical, iron and steel, transport, buildings, and energy generation and energy storage.

b) Share in the investment risks by incentivizing new entrants or firms that express interest in hydrogen energy production, supply, distribution, and infrastructural development projects, through hydrogen energy mentorship, incentivized loans, provide guarantees and tax rebates on tools, and even provide rewards.

c) Develop deliberate policies that enhance public financial institutional support for research and development (R&D) to reduce hydrogen production costs and enhance capacity building as production plays a critical role in any business.

d) Eliminate unnecessary regulatory barriers and harmonize standards. This will help hydrogen energy project developers develop investor confidence and eliminate licensing barriers that are experienced due to unclear licensing requirements and regulations, and such inconsistencies are capable of retarding progress in the transition to hydrogen energy-based economies.

e) Engage internationally and track progress to enhance their international and bilateral cooperation with firms and companies that are global leaders in hydrogen deployment to keep up with international standards, embrace knowledge sharing, lessons learnt, and adopt best practices in the hydrogen energy industry.

Most importantly, the hydrogen economy demonstrates a capability to help nations in Southern Africa (and SADC) to become major exporters of green hydrogen as an interim or short-term benefit as well as in decarbonizing the carbon-intensive emission sectors and reducing greenhouse gas (GHG) emissions and climate change in the long-run, alongside providing a future fuel for the transport sector and industries. Southern Africa stands to benefit from the deployment of hydrogen energy and become a major supplier of hydrogen.

### 2.4 Learnings from the Literature Review and the way forward

i. The researchers do not confirm on the specific areas where the thrust is required to transform the fossil fuel-based economy to a green hydrogen economy. Some case studies in Europe, Africa, China and the Latin American countries have been projected, however whether that model will be applicable elsewhere is uncertain due to relevant socio-economic pattern in the other countries.

ii. It is also not clear from the research papers as to how the electricity required for the production of green hydrogen will be produced economically so that the production costs are reduced. The aim of majority of the countries of the world is to transform to a green economy but most of them have not set their benchmarks or chalked out a specific plan to meet the goal.

iii. The present research paper will endeavor to predict a model for the necessary modifications required in infrastructure, stake-holder participation, investments, tech innovations and finally the cost involved in all the above to enable a transformation to a Green Hydrogen Economy in the Emerging countries.

CHAPTER III:

# METHODOLOGY

## 3.1 Introduction

- Most researchers predict that Green Hydrogen will be a major player in the energy scenario of the world in the next 20-years.
- Cost of producing Green Hydrogen will decrease with increase of infrastructure and funding from the corporate sector.
- Private and public sector collaboration will increase with increasing awareness amongst the emerging economies to reach the target of carbon zero in line with the Paris agreement and COP-26 deliberations.
- Major economies of the world will invest more on green electricity , solar energy , wind energy and install more electrolyzers for the production of green hydrogen.
- Green hydrogen hubs similar to oil distribution hubs will come up in different parts of the world and new players in the green energy sector will come up.
- Countries where green hydrogen production constraints are there due to land availability and skilled manpower shortage will be importers of hydrogen in the next 15-20 years.
- Emerging economies of the world will invest more on green hydrogen production and logistics due to their commitment to net zero emissions.

- To reduce emissions to a level that would keep the concentration of GHGs at 450 ppm in 2050, the IEA projects that renewable energy would need to account for 27% of the required CO2 reductions. A major part of the CO2 reductions resulting from the promotion of renewable energy technologies would take place in developing countries.

### 3.2 Limitations in the Literature Review

- The researchers do not confirm on the specific areas where the thrust is required to transform the fossil fuel-based economy to a green hydrogen economy. Some case studies in Europe, Africa, China and the Latin American countries have been projected, however whether that model will be applicable elsewhere is uncertain due to relevant socio-economic pattern in the other countries.
- It is also not clear from the research papers as to how the electricity required for the production of green hydrogen will be produced economically so that the production costs are reduced. The aim of majority of the countries of the world is to transform to a green economy but most of them have not set their benchmarks or chalked out a specific plan to meet the goal.
- The present research paper will endeavor to predict a model for the necessary modifications required in infrastructure, stake-holder participation, investments, tech innovations and finally the cost involved in all the above to

enable a transformation to a Green Hydrogen Economy in the Emerging countries.

### 3.3 Methodology of the Research Model

- The primary methodologies in this research model was based on the following:
    - Study of a large number of research papers and case studies on the progress of Green Hydrogen Economy in the emerging nations.
    - Analyze critically the literature review papers on the subject and draw conclusions on what more needs to be done to achieve a Green Hydrogen Economy of about 25% of the world economy by 2035.
    - Based on the feedback on the questionnaire , construct a statistical model to predict the requirements based on the following five parameters:
        - **Cost of Production**
        - **Expenditure/Investments**
        - **Innovation on Technology Expansion**
        - **Time**
        - **Stakeholder Participation (Public and Private)**

- Search for avenues to offer a model of making the green –hydrogen transformation in the emerging countries of Asia, Europe and Africa, economically viable, less costly, environment friendly and lead to a contributor to a more sustainable economy where the goals of many countries towards reducing the carbon-footprints in the next 15-20 years will be fulfilled.
- A brief project schedule that was followed by the researcher is given in Table – 1.

**TABLE-1:** ***Research Methodology-Project schedule***

| **Serial no** | **Project Type** | **Project schedule** | **Brief methodology** |
|---|---|---|---|
| 1 | Literature review | Jan 2022 to April 2022 | Study the relevant research papers, journals, books and research projects and make an analysis of what has been done on the subject of Green Hydrogen Economy and what needs to be done to meet the present goals of our research model. |

| | | | |
|---|---|---|---|
| 2 | Case studies | Feb 2022 to April 2022 | Study the relevant case studies from research papers on the subject and draw inferences on the applicability of the same in our present research model. The way forward to justify our research model. |
| 3 | Feedback on questionnaire | Feb 2022 to June 2022 | A questionnaire comprising of 30-questions was prepared in Google forms and circulated to all our contacts. Till date about 75 responses have been received. And we will evaluate the same on 5-6 criteria and prepare a statistical model. |
| 4 | Research model | July 2022 to Sept 2022 | Evaluate the results from the responses on the questionnaire, literature review, case studies and the statistical model to write the final thesis of our research model on Transition to a Green Hydrogen Economy in emerging countries. |

### 3.4 Summary

The methodology adopted in the present research model was two-fold. The first part involved study and analysis of a large number of research papers and books related to Green Hydrogen Economy. Several case studies in different countries were critically studied and inferences drawn on the progress of emerging countries in the transformation to green hydrogen usage from the present dependance on fossil-fuels. Data collected from the research papers were put in a tabular form to be analysed and our present model to be formulated.

The second part involved responses from all over the world from a huge cross-section of people in the Oil Industry, Government functionaries, education institutions, bureaucrats , people from other Industries like IT, Chemical and Rubber and self-employed people. More than 75 responses were received and the results would be analysed based on five parameters of a) cost of production, b) expenditure/investments, c) tech expansion/innovation, d) time taken for the transformation process and lastly e) stake holder (public/private) participation.

A mathematical model based on the above parameters would be formulated and the results verified with the literature review findings to predict a model for the effective transformation to a Green Hydrogen economy.

The model will predict the procedures and measures to be undertaken to help in the above transformation to a 25% green hydrogen economy by 2035. With this the emerging nations would also reach their net-zero goals and ensure a cleaner environment to their citizens in line with commitment of many countries in the Paris agreement and subsequent interactions on the global platform.

CHAPTER IV:

# RESULTS

## 4.1 Introduction

This research paper searches for avenues and will offer a model of making the green –hydrogen transformation in the emerging countries of Asia, Europe and Africa, economically viable, less costly, environment friendly and lead to a contributor to a more sustainable economy where the goals of many countries towards reducing the carbon-footprints in the next 15-20 years is fulfilled.

This research paper will also explore and provide a model for the necessary steps to be taken so that green hydrogen contributes to 25% of the total world economy by 2035.

**TABLE-II:** ***Datasheet on Green Hydrogen in Emerging Nations:***

***(Expenditure in 2019 & growth over 2018 has been taken from UNEP Centre-Bloomberg NEF)***

| Serial No | Country | Cost of production (in $/kg) | Expenditure/ Investments (in billion $)in 2019 | Growth % on 2018 | Stakeholder participation (Govt/private) |
|---|---|---|---|---|---|
| 1 | India | 6-10 | 9.3 | -14 | Both |
| 2 | Taiwan | 6-9 | 8.8 | 390 | Both |

| | | | | | |
|---|---|---|---|---|---|
| 3 | Vietnam | 6-10 | 2.6 | -64 | Both |
| 4 | Brazil | 6-12 | 6.8 | 74 | Both |
| 5 | UAE | 6-10 | 4.5 | 1223 | Both |
| 6 | Mexico | 6-9 | 4.3 | 17 | Both |
| 7 | Korea (Republic) | 6-11 | 2.4 | 31 | Both |
| 8 | Sweden | 6-9 | 3.7 | -19 | Both |
| 9 | South Africa | 6-10 | 1.0 | -76 | Both |
| 10 | Netherlands | 6-9 | 5.5 | 25 | Both |
| 11 | Poland | 6-10 | 1.8 | 349 | Both |
| 12 | Italy | 6-8 | 1.3 | -35 | Both |
| 13 | Finland | 6-8 | 1.5 | 41 | Both |
| 14 | Australia | 6-11 | 5.6 | -40 | Both |
| 15 | Spain | 6-9 | 8.4 | 25 | Both |

**TABLE-III:** ***Trends in renewable energy investments (in billion USD)***

| Serial No. | Country | 2017 | 2018 | 2019 | 2018-19 % Growth |
|---|---|---|---|---|---|
| 1 | USA | 48.6 | 47.1 | 59.0 | 25 |
| 2 | Brazil | 6.2 | 3.8 | 6.8 | 78 |
| 3 | Europe | 49.1 | 60.8 | 58.4 | -4 |

| | | | | | |
|---|---|---|---|---|---|
| 4 | Middle East & Africa | 10.7 | 16.5 | 15.4 | -7 |
| 5 | China | 148.4 | 95.9 | 90.1 | -8 |
| 6 | India | 13.7 | 11.6 | 11.2 | -4 |
| 7 | ASOC (excl. China & India) | 41.6 | 49.6 | 48.2 | -3 |

From the data above the average growth percentage of renewable energy investments is around 11% for the year 2018-19. Green Hydrogen investments vary from country to country and year to year. Taking an overall conservative view, the present trend in renewable energy investments is about 10% growth year to year. In the next 10 years with the average trend of 10% per year, we can forecast an investment of 100 % over the investment in 2019, i.e., of around billion USD 135, which comes to around billion USD 9 for each of the 15-countries shown in Table-1.

For six countries like India, Brazil, Taiwan, Netherlands, Australia & Spain, whose investments in 2019 are more than USD 5 billion, the forecasted investments in 2029 will be about USD 10-18 billion. This will further increase to USD 16 – 29 billion in 2035 with the same trend.

Similarly, in developed countries if we consider the same trend of 10% growth in investments per year, the investments in 2035 for renewable energy would be in billion USD for: USA - 153, Europe - 152 & China - 234. So total investments in

2035 for the 3-developed countries as above would be USD 539 billion. Whereas the 15 developing nations would require an investment of USD 345 billion.

The above investments in renewables and green hydrogen in the countries considered above would depend upon the socio-political scenario as well as the economic strength of the individual countries.

**TABLE-IV:** ***Overall renewable Energy Investment in Africa and globally, 2000-2020***

***(Source: BNEF(2021c), From : Renewable Energy Market Analysis, Africa and its regions)***

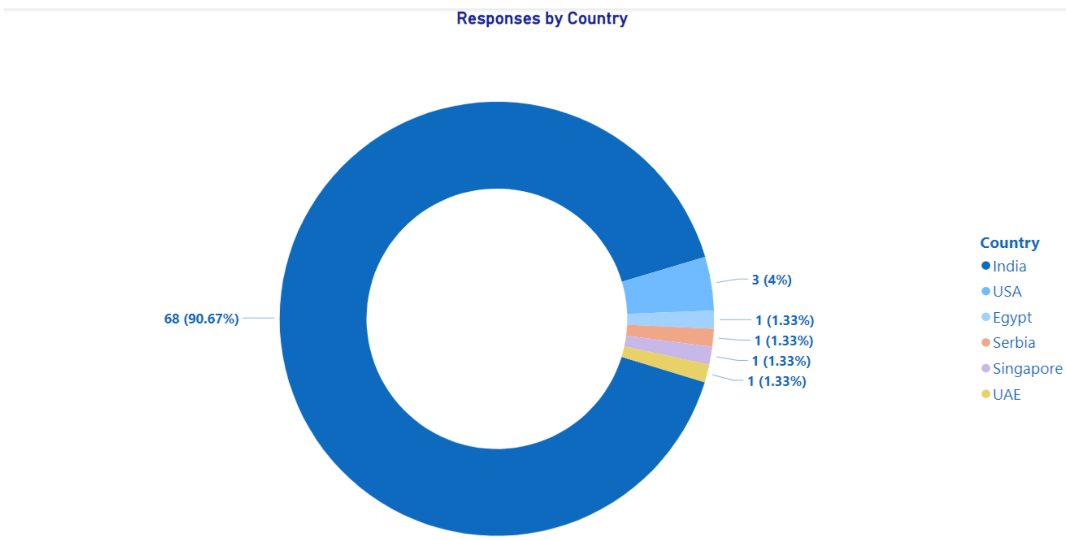
| Serial No | Countries in African Continent | Investment in USD billions, 2000-2009 | Investment in USD billions, 2010-2020 | Investment in USD billions, Cumulative 2000-2020 | Percentage (%) investment in Africa(2000-20) |
|---|---|---|---|---|---|
| 1 | North | 1.9 | 17.5 | 19.2 | 32 |
| 2 | West | 0.5 | 3.9 | 4.2 | 7 |
| 3 | East | 2.0 | 9.7 | 12 | 20 |
| 4 | Central | 0 | 1.3 | 1.2 | 2 |
| 5 | South | 0.3 | 22.4 | 22.8 | 38 |
| 6 | Total Africa | 4.8 | 55 | 60 | 2% of global |

| | | | | | |
|---|---|---|---|---|---|
| 7 | Global | 587 | 2254 | 2841 | |

### 4.2 Analysis based on the survey

A detailed analysis was carried out by the researcher , based on the survey carried out on the subject and responses from 75 persons from all over the globe. The results are produced below:

**FIGURE 1:** ***Responses break-up country wise***




*Questionnaire Details:*

1 - Totally Disagree

2 - Somewhat Disagree

3 - Neutral

4 - Somewhat Agree

5 - Totally Agree

**Investment Horizon Variable Explanation:**

- Do you believe Green Hydrogen will be a major energy source in the next 10-15 years? (Q1 in Questioannaire)

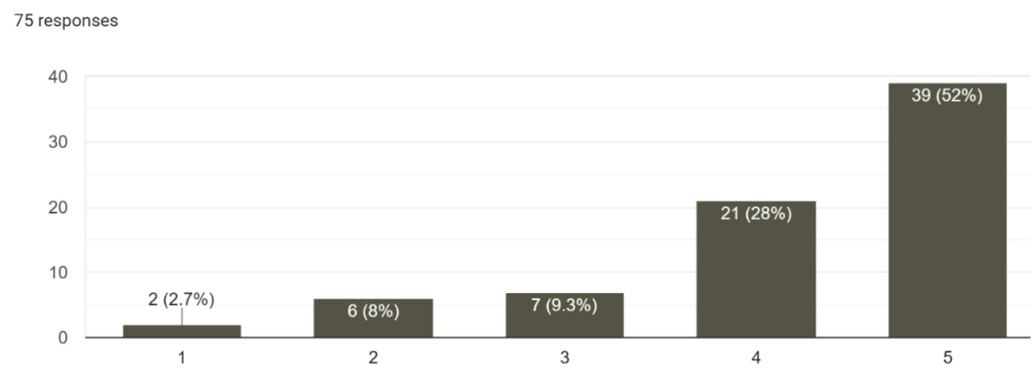
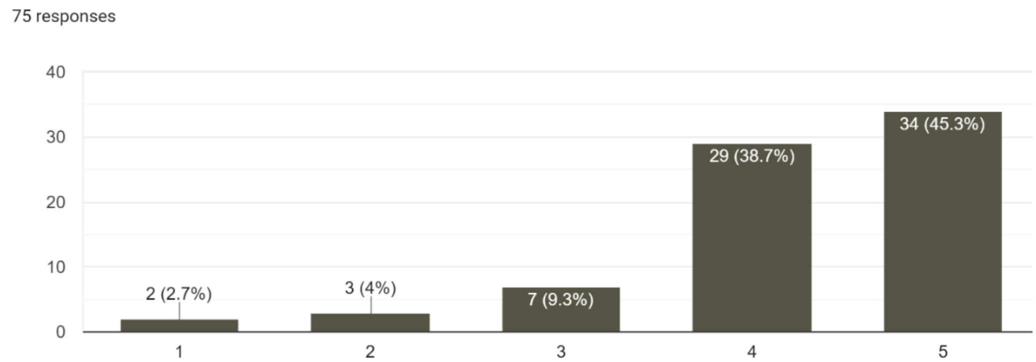



**FIGURE 2**

- The Emerging economies like India , Philipines , Brazil and South Africa have planned to spend a lot of money in Green Energy projects. Do you believe that these measures will help to bring down carbon emissions in our planet? (Q2 in Questionnaire)

**FIGURE 3**




- Developing countries spent USD 152.2 billion on renewables investment compared to USD 130 billion by developed countries in 2019 , according to a study on Global Trends in Renewable Energy by Bloomberg NEF. Do you think if this trend continues, developing economies will be able to meet their targets towards a Green Economy? (Q22 in Questionnaire)

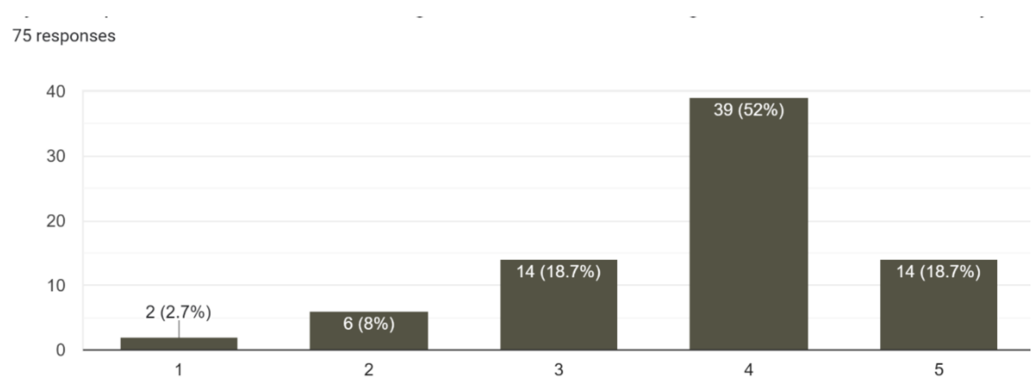
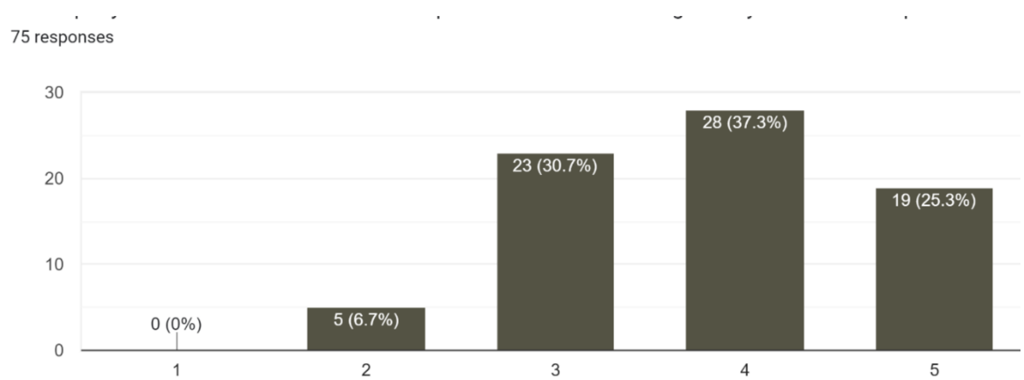



**FIGURE 4**

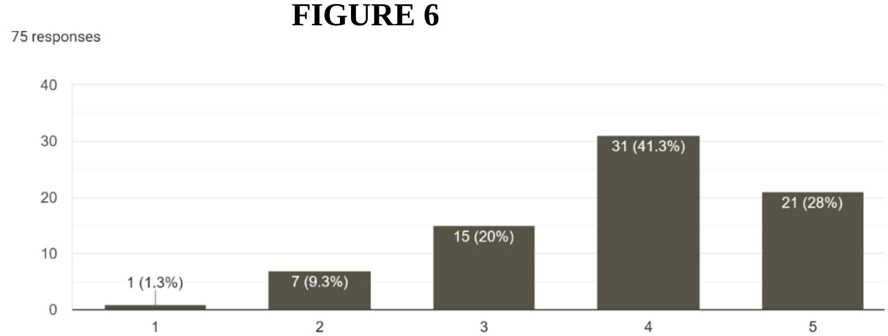
- IPCC/McCollum et al. (2018) had estimated that requirement for India alone is at least USD 150 billion per year or about 2% of GDP over the period 2020-50 to meet the net zero target. Do you think this is possible? (Q25 in Questionnaire)

**FIGURE 5**



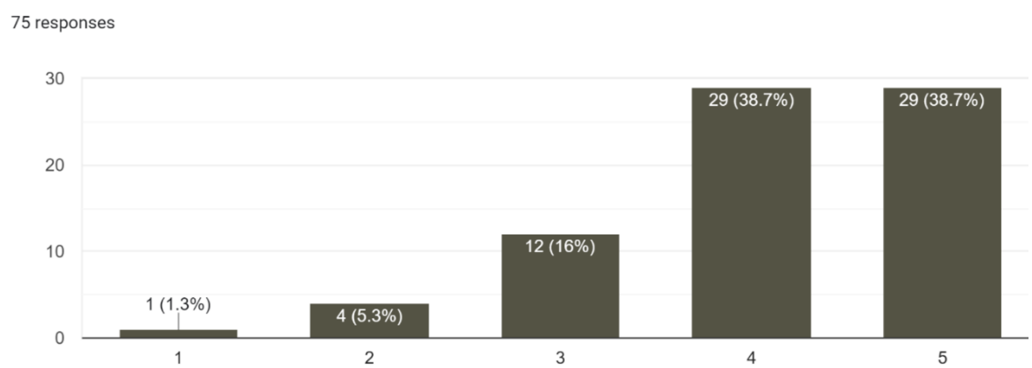

- The IEA report (2021) in its most ambitious scenario has predicted that the share of renewables (excluding large hydro) in the electricity generation would rise to 69% in 2040 mainly driven by solar and wind (60%). In your opinion is this viable? (Q26 in Questionnaire)

**FIGURE 6**



- The Govt. of India aims to halve the cost of green hydrogen in the country from currently around USD 5/kg to USD 2.2/kg by 2029. With ambitious plans of the private sector also in India, do you feel this target is possible? (Q27 in Questionnaire)

**FIGURE 7**




**Stakeholder Participation Variable Explanation:**

- Green hydrogen production on a large scale would require green fuel like electricity, nuclear power, solar power etc. Do you think public – private collaboration would be a positive approach towards enhancing production of green energy? (Q7 in Questionnaire)

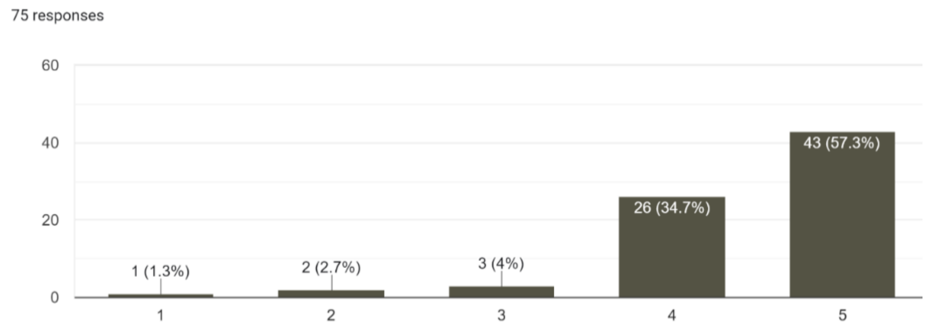



**FIGURE 8**

- Do you think the emerging economies should help private sector participation in increasing energy production through solar and wind plants? (Q14 in Questionnaire)

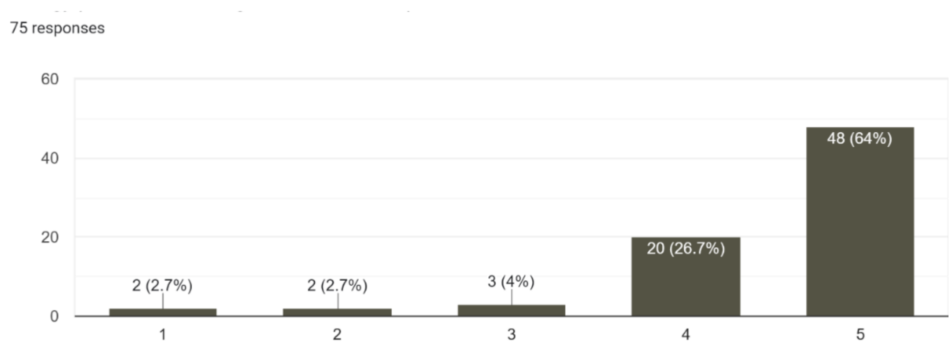


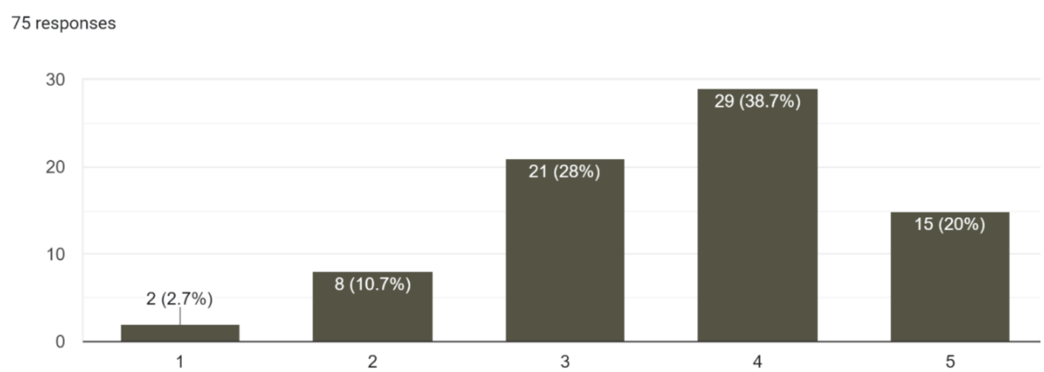

**FIGURE 9**

On the basis of Q7 and Q14 we can explain that more the public-private participation, more would be the enhancement of green energy production.

**Time Frame Variable Explanation:**

- Hydro-electric power commissioned capacity is 903 Mega Watt and balance to be commissioned is 1291 Mega Watt. Do you think this increase is adequate for India to achieve self-sufficiency in Hydro-power required for green hydrogen production by 2035? (Q18 in Questionnaire)

**FIGURE 10**




- Is a ‘Green Hydrogen Economy’ possible according to you by 2035? (Q3 in Questionnaire)

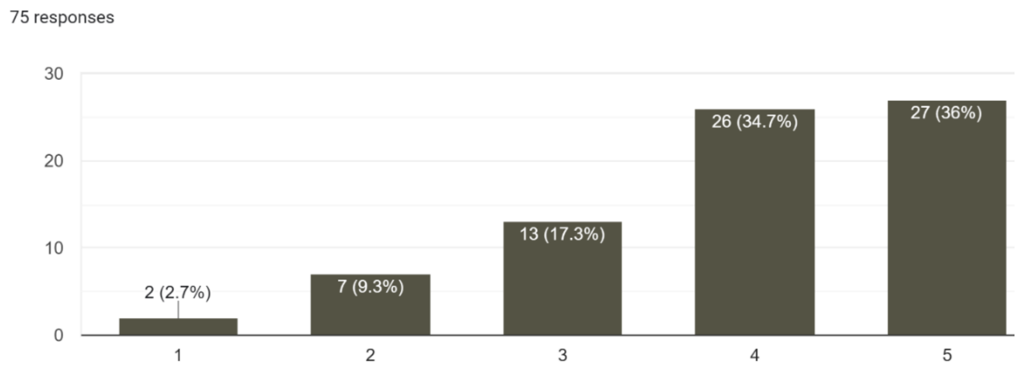



**FIGURE 11**

- Total renewable energy allotted capacity in India is approximately 36916 Mega Watt and commissioned capacity till Nov-2021 is 15374 Mega Watt. To make major strides towards a Green Hydrogen economy, should India increase the pace in which investments on green fuels are going on, say about 25% per year till 2030? (Q19 in Questionnaire)

**FIGURE 12**

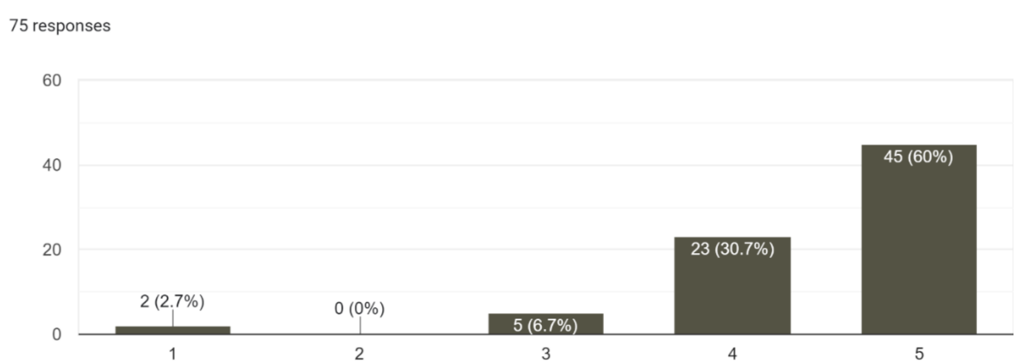
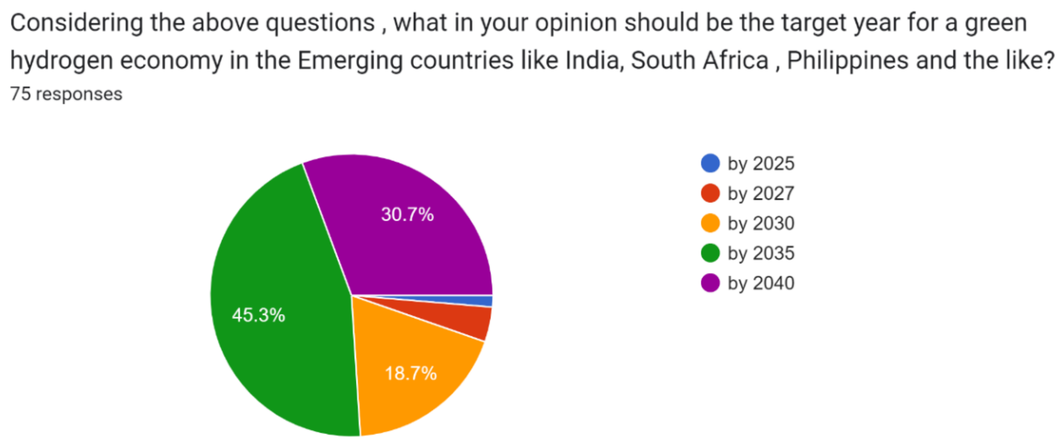


**FIGURE 13**

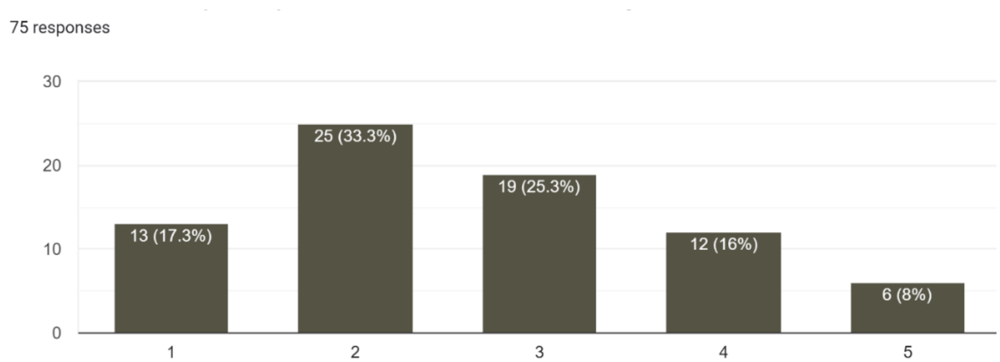



From the above pie-chart, we can observe that about 69% of the persons who have responded to the survey have expressed their opinion that a Green Hydrogen Economy in the emerging nations is possible by 2035, which is in line with the researcher's prediction also.

**Tech Expansion Variable Explanation:**

- Many countries have taken measures to control GHG (Green House Gases) emission to protect our Earth's ozone layer. Do you think these measures are enough? (Q14 in Questionnaire)

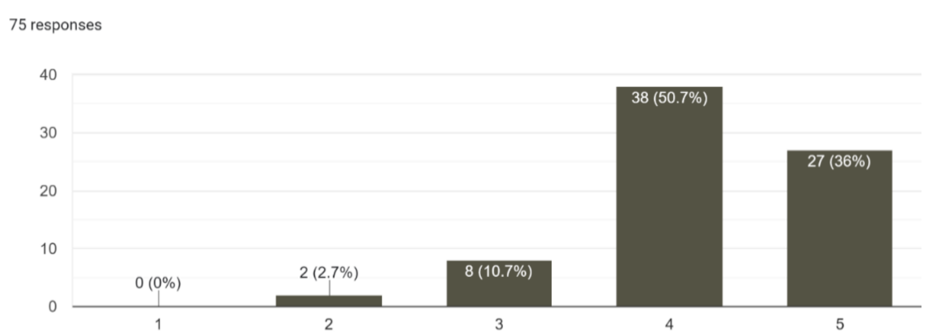
**FIGURE 14**




**Why Tech Expansion is needed?**

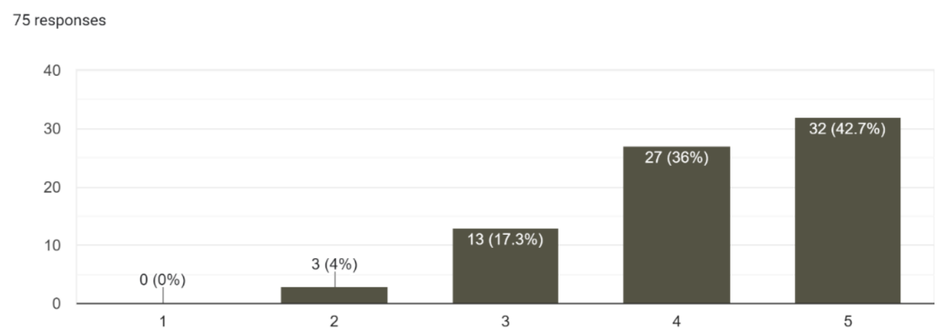
- Some experts have suggested creating of Green Hydrogen Hubs similar to Petroleum Hubs to monitor the distribution of green hydrogen smoothly. Do you think this is a positive approach towards a green economy? (Q6 in Questionnaire)

**FIGURE 15**



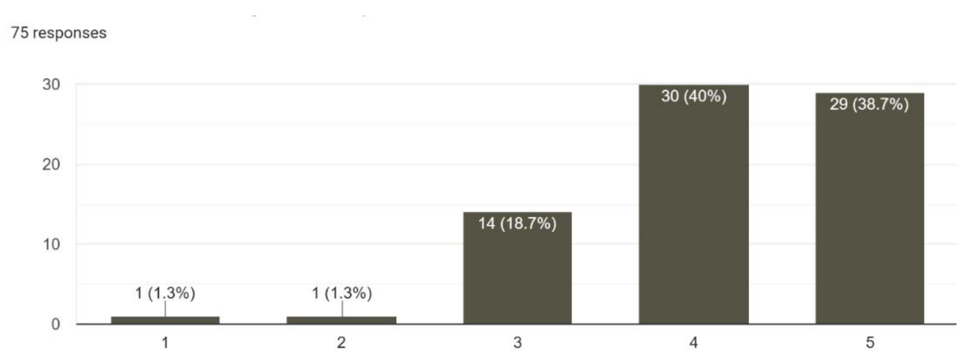
- Liquid hydrogen transportation requires cryogenic containers which are very costly to maintain. Do you think production of hydrogen at the factory sites are more advisable than bringing hydrogen from far-off plants? (Q8 in Questionnaire)

**FIGURE 16**



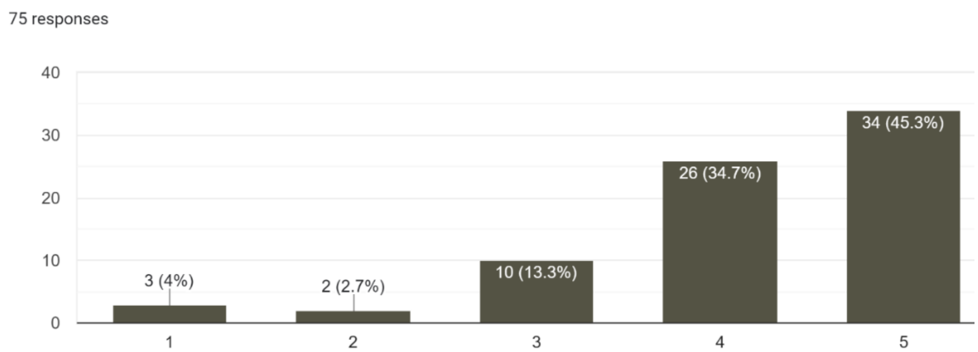

- Do you feel that green hydrogen production costs can be lowered by taking constructive steps to increase manufacturing of electrolysers? (Q13 in Questionnaire)

**FIGURE 17**



- Do you think it is a good proposal to set-up green hydrogen production units near the sea-shore and convert sea-water through electrolysers to green hydrogen? (Q15 in Questionnaire)

**FIGURE 18**




**General Explanation around these observations:**

- Similarly, Solar Energy data shows commissioned capacity of 7505 Mega Watt and balance allotted capacity of 1941 Mega Watt to be commissioned. Do you think solar energy potential in India is much more than this? (Q17 in Questionnaire)

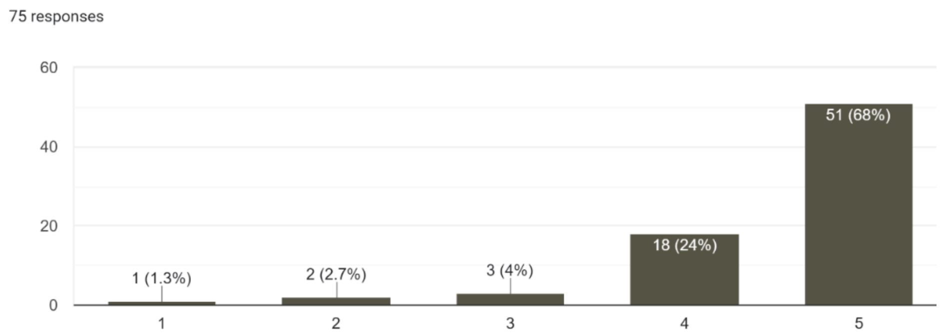
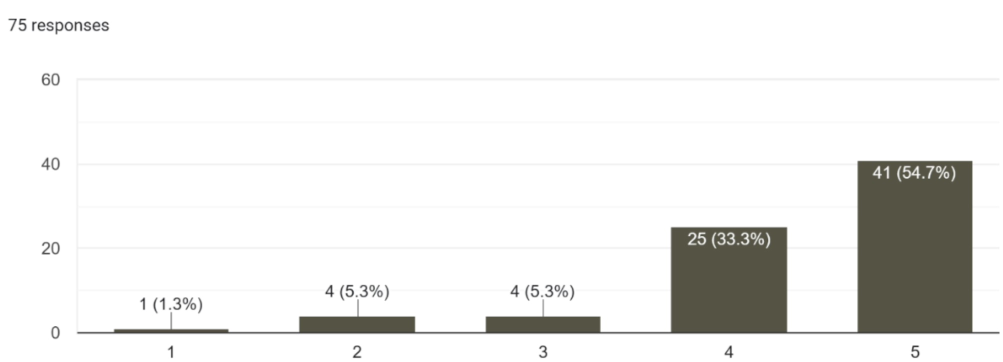



**FIGURE 19**

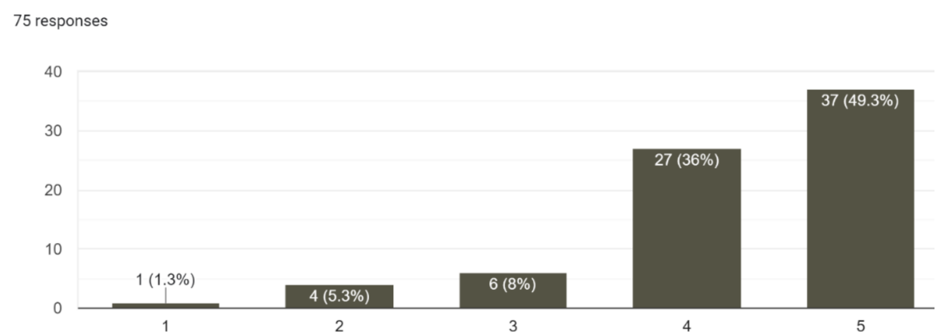
- From the Indian Government site, data up to Nov 2021 in Wind energy shows a commissioned capacity of 5095 Mega Watt and balance allotted capacity of 6670 Mega Watt to be commissioned. Do you think India has the potential to do better than this capacity utilisation. (Q16 in Questionnaire)

**FIGURE 20**



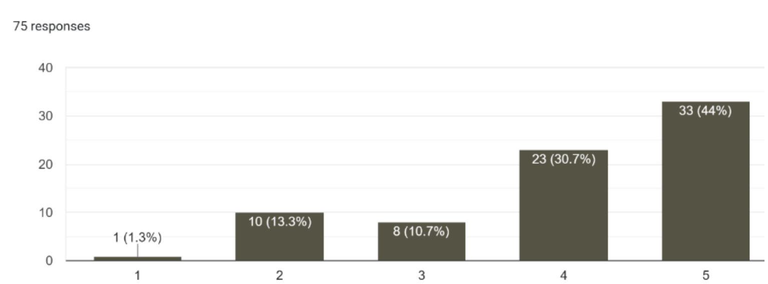
- Electric vehicles are fast replacing vehicles running on fossil fuels in India, China and European countries. According to your view is this a positive step towards a carbon-zero economy? (Q20 in Questionnaire)

**FIGURE 21**




- Green Hydrogen buses and trains are running commercially in Germany and some other European countries. Do you believe India and other emerging economies will convert to these modes of transportation soon? (Q21 in Questionnaire)

**FIGURE 22**



### 4.3 Remarks by the persons surveyed

Any other opinion on the subject (from Survey):

- Be careful about committing huge resources as the technology is not yet proven to be commercially viable. First scale up solar / wind / nuclear at 10X speed.
- Frugal consumption of energy is more sagacious
- The cess on Fossil fuel should be increased to encourage EVs use. More incentives to be given for Electrical Vehicles sales.
- Nuclear energy shall be harnessed for generation of electricity. Around 80% of electricity is generated in France from Nuclear power.
- Emerging economies like India should focus more on EVs in public transport rather than private transportation. EVs are not an alternative to traditional fossil fuels because, somewhere it is indirectly contributing towards carbon emission.
- Governments need to accelerate Green energy production by implementing strict and religious methods with Public/Private support.
- India should start producing vehicles running on hydrogen in a mass scale to significantly reduce carbon footprints on one hand and reduce the consumption of fossil fuel on the other. this will have tremendous impact on the psychology of the people and energy conservation shall get deeply rooted in the minds in no time.
- Awareness required at all levels to achieve this target .
- Connecting and collaboration of the India Hydrogen Project with other projects such as SLDE, GHG Calculator and Gatishakti will help develop a more comprehensive solution in the longer run.

- To move towards being a Green Hydrogen economy, a country, and also the world will need to invest significantly more on developing multiple parallel technologies in storage, distribution, automobiles, and most importantly aviation. Only if significant work is carried out in these fields, will it be feasible to use Green Hydrogen as a way to combat global warming.
- I feel this is a serious matter for countries like India. The PPP model is the best to move forward.
- Push for green initiatives should be geography/economy specific and no uniform thrust to push green initiatives across the globe will work. All developing economies should be funded by the developed economies for taking forward green drives.

### 4.4 Conclusions based on the survey

- From the 75 responses on the questionnaire sent to them, we have corroborated our findings from our research model and our conviction that a 'Green Hydrogen Economy' is possible by 2035 is confirmed. The cost reduction predicted by our model is also supported by the survey . For emerging nations of Asia, Africa & Europe to have a 25% contribution from green hydrogen of their total energy requirements by 2035 is also supported by the findings of the survey.
- The survey also supports the prediction of our model about the private – public contribution and that more of private participation is required in all the emerging nations, to contribute to enhanced production of electrolyzers

and for funding of a larger infrastructure to enable green hydrogen production, storage and transportation. From the responses it is clear that the participants have expressed their opinion in favour of a ‘Green Hydrogen Economy’ in the emerging nations by 2035 and also expressed their conviction of a net-zero economy in all the nations, to save our next generation from the ill-effects of carbon emissions. From the above findings the researcher can state with conviction that a ‘Green Hydrogen Economy” in the emerging nations of Asia, Africa and Europe is possible by 2035. It is also clear from the present model that cost of production of green hydrogen would reduce to USD 2-3 per kg by 2035 and that wind and solar energy would contribute to about 80% of the energy requirements by then. Private participation and funding alongwith government funding would be an important factor to contribute to enhanced production of green hydrogen by 2035. Technology expansion to create about double the electrolyzers at present, would also contribute to the volume of green hydrogen production required for the emerging nations to reach the goal of 25% of total energy requirements by 2035.

- The results of the research alongwith the survey have been reproduced in the next few pages through pictorial representation and bar charts.

### 4.5 Data Analysis

We have performed a Descriptive Statistics namely Arithmetic Mean, Median, Standard Deviation and Variance for the data collected on Green Hydrogen Cost of Production (in USD) and Investments in this arena (also in USD) and summarized the same. For the data related to Renewable Energy Investments in the country we have also performed a descriptive statistical analysis for the data available to us. Pictorial representation of the results are produced below.

**FIGURE 23: Expenditure in USD billion in 2019 (country-wise representation in the bar-chart)**

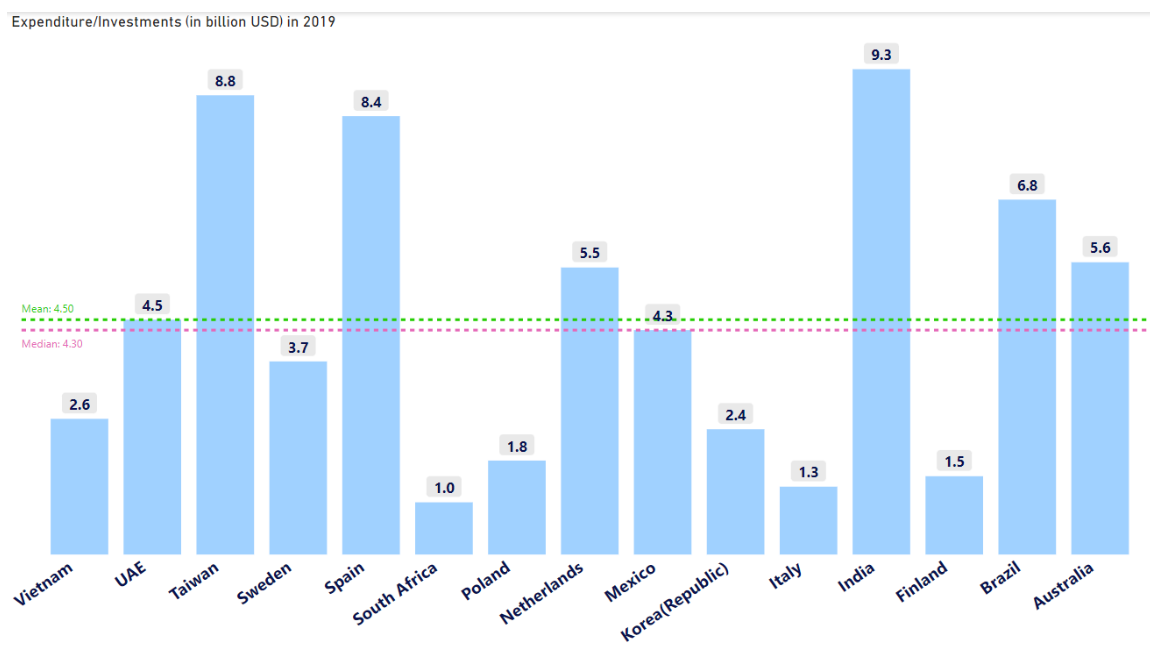


**FIGURE 24: Investments in USD from 2017-2019 (country/region-wise representation in stacked bar-chart)**

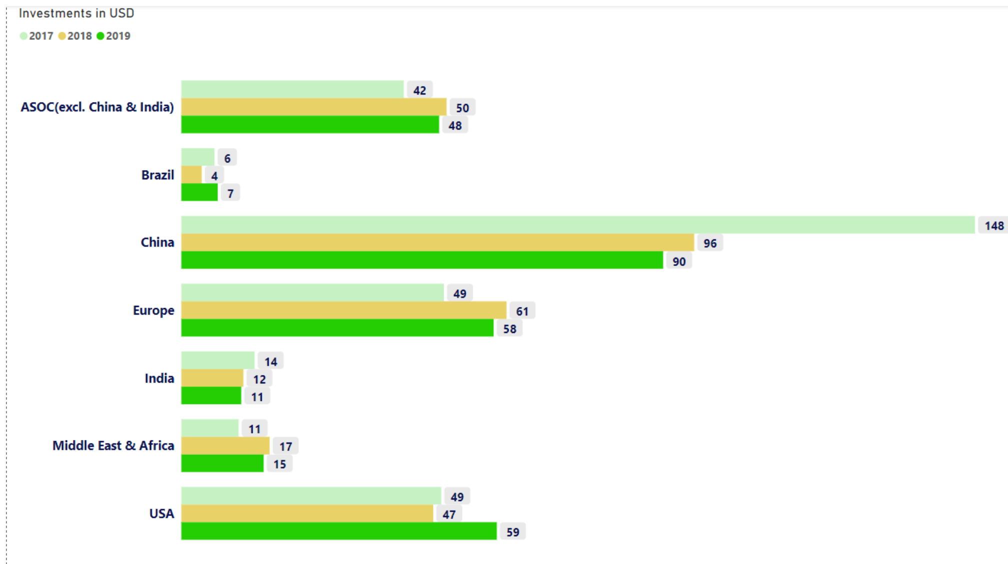



**FIGURE 25: Expenditure in USD billion in 2019 (country-wise representation in the world map – bigger bubble indicates higher expenditure)**

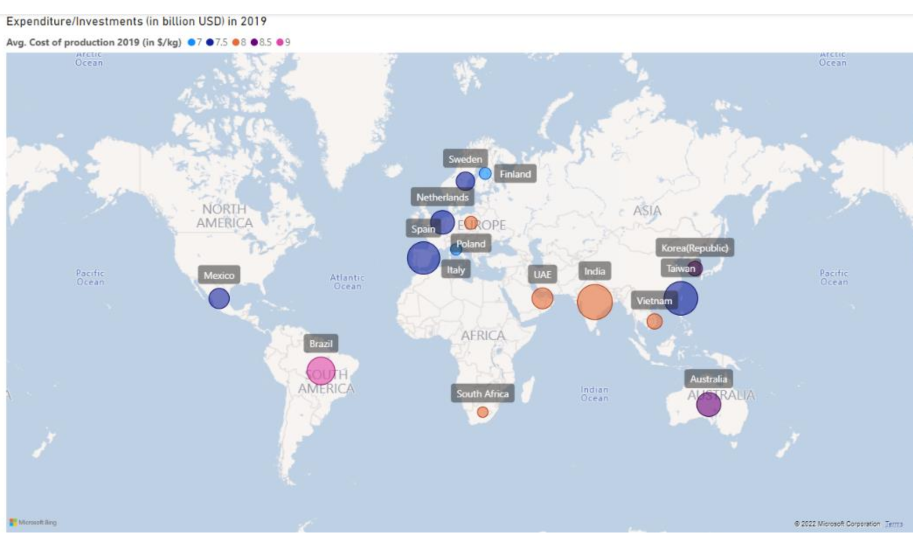
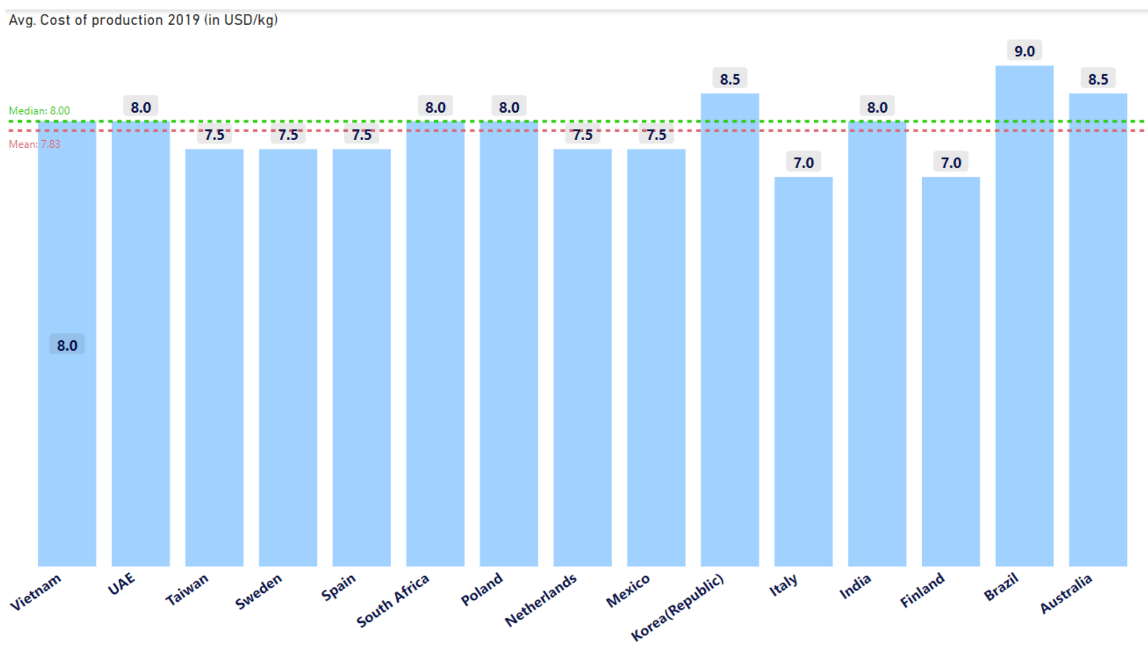


**FIGURE 26: Average Cost of Production in 2019 in USD/kg (country-wise representation in the bar chart)**




## 4.6 Conclusions on the survey and research

From the responses from 75 persons on the questionnaire sent to them, we have corroborated our findings from our research model and our conviction that a 'Green Hydrogen Economy' is possible by 2035 is confirmed. The cost reduction predicted by our model is also supported by the survey. For emerging nations of Asia, Africa & Europe to have a 25% contribution from green hydrogen of their total energy requirements by 2035 is also supported by the findings of the survey. The survey also supports the prediction of our model about the private – public contribution and that more of private participation is required in all the emerging nations, to contribute to enhanced production of electrolyzers and for funding of a larger infrastructure to enable green hydrogen production, storage and transportation. From the responses it is clear that the participants have expressed their opinion in favour of a 'Green Hydrogen Economy' in the emerging nations by 2035 and also expressed their conviction of a net-zero economy in all the nations, to save our next generation from the ill-effects of carbon emissions.

CHAPTER V:

# CONCLUSIONS AND DISCUSSIONS

## 5.1 Abstract


- This research paper searches for avenues and will offer a model of making the green–hydrogen transformation in the emerging countries of Asia, Europe and Africa, economically viable, less costly, environment friendly and lead to a contributor to a more sustainable economy where the goals of many countries towards reducing the carbon-footprints in the next 15-20 years is fulfilled.
- This research paper will also explore and provide a model for the necessary steps to be taken so that green hydrogen contributes to 25% of the total world economy by 2035.


## 5.2 Conclusions

Following conclusions have been drawn by the researcher based on Literature review on the trends visible in the emerging nations in Asia, Europe and Africa. Responses to the survey on Green Hydrogen Economy was also undertaken and 75 responses have been received from all over the Globe as is shown in Annexure-I. The questionnaire was sent to experts in all fields starting from Oil & Gas Industry, manufacturing & chemical Industry, Government officials, Bureaucrats, business men & women, World Bank officials and retired army & government officers. Their responses have been analysed on five parameters: ***cost, expenditure, tech expansion, time frame and stakeholder participation.*** Based on the rigorous research carried out on the subject, the researcher under the guidance of his mentor, has come to the following conclusions:

- Green Hydrogen will contribute to about 25% of the total World Economy by 2035, if the developing as well as the developed countries take on war-footing the measures suggested in our research project namely doubling the manufacture of electrolysers, reduce usage of fossil fuels in the industry, increase wind and solar energy manufacturing at a fast pace and encourage usage of green hydrogen.
- Cost of green hydrogen production will reduce to USD 2 per kg from the present cost of USD 5 per kg by 2035. This will off-course depend upon the socio-economic patterns in the green hydrogen manufacturing countries and the infrastructure projects undertaken by them.
- The developing countries would spend about USD 500-600 billion on green hydrogen and other renewable energies during 2030-2040, to meet the net zero carbon emission target .

- Through a vast increase in the production of electrolysers in all the developing countries, the cost of production will be reduced by more than half of what it is today. Of-course support from the developed countries would be a vital factor in ascertaining the smooth transition to a Green Hydrogen Economy.
- Extensive private participation is required in the developing countries to increase the renewable electricity production required for green hydrogen production and solar and wind-power will contribute about 80% of the total energy requirement.
- Finally a mathematical model has been formulated based on the responses received for the 30-nos questionnaire (shown in Annexure-II). This corroborates the theoretical findings of the researcher and confirms the research model proposed in the present thesis.

### 5.3 Proposed Model by the Researcher

For Green Hydrogen to contribute to 25% of the World Energy requirement by the year 2035, the researcher proposes the following steps to be undertaken by the emerging economies of Asia, Europe and Africa :

- Reduction of cost of green hydrogen production from the present rate of USD 5-6 per Kg to an achievable rate of USD 2-3 per kg. This will only be possible if the production units, mainly the number of electrolyzers are increased to almost double of what is there at present. Moreover the electrolyzers need to be installed in areas where there is abundance of water, say near the sea-shore. Solar and wind energy plants are also required to contribute about 80-90 % of the total electricity requirements to run the electrolyzers. Balance electricity requirement of about 10-20 % may be received from hydro-electric plants and nuclear plants. In India alone, about 9000 mega watt of wind energy capacity has to be added by 2035 and about 3000 mega watt solar energy and 2500 mega watt hydro-electricity needs to be added to meet the target proposed by the researcher. This will enable the developing countries to meet their net-zero targets by 2050.

- The transition to a Green Hydrogen Economy would require an investment of about USD 200 billion per year upto 2050 for India alone, which is a tall figure by itself. So private sector participation is a must to enable setting up of infrastructure projects for green hydrogen manufacturing, its storage and its transportation by cryogenic containers, which all cost a lot. Moreover each government has to take a call to systematically phase-out the usage of fossil-fuels in the Industry, transport sector and the consumer sector by 2030. Setting up of electrolysers for green hydrogen production on a large scale requires active participation of the public sector and private sector both with adequate funding and spreading mass awareness to switch-over to more eco-friendly vehicles to reduce carbon emissions in our planet.

- Green hydrogen transportation involves huge cost and many countries are taking up pipeline projects for faster delivery and reducing costs. Green hydrogen hubs need to be set up on a large scale to supply hydrogen at cheaper rates and at a faster pace. In Europe trans-continental gas pipelines have been set-up and by 2040 almost all countries would be connected with the pipeline (about 23000 kms) ,which will deliver hydrogen along-with CNG at a much cheaper rate than road or rail transportation. Other developing countries of Asia and Africa need to develop pipeline infrastructure for green hydrogen within the next 2-3 years for cheaper transportation and also utilize the present gas pipelines for the same. Investments of around USD 20-25 billion would be required for a country like India to build a trans-country pipeline connecting the major ports like Mundra, Mangalore, Ennore, Vizag and Paradeep.

India can import green hydrogen through large vessels, unload at the major ports, store the hydrogen in storage tanks or caverns and transport the hydrogen through pipelines to the Industrial customers and major hubs. From there road transportation can be done to end consumers through cryogenic trucks. In India GAIL already has a large infrastructure of gas pipelines and private players like Reliance and Adani are investing a lot in this sector. In other Asian countries and African countries, gas pipelines have to be set up for cheaper transportation and developed countries may lend support by funding and providing the necessary technical guidance and expertise on the subject matter.

- Solar and wind energy plants have to be set up at each potential site and usage of coal and other fossil-fuels have to be slowly phased-out by 2030. In Africa there is a huge potential of Solar energy and Wind energy at high levels, which has to be harnessed for generating clean electricity for the purpose of green hydrogen production. Developed countries like China, Japan, Germany, France, UK and USA are already investing in Solar and Wind energy projects in Africa, but the projects have to be scaled-up by more than

100% to meet net-zero target by 2050. At present about USD 60 billion of investment has been done on renewable energy in African countries in the past decade, but this is not enough. So foreign funding from developed countries to the tune of about USD 10-12 billion per year for the next 10-years have to be done to create an infrastructure capable of bringing in the transition required in African countries.

- The electricity requirement in the next 10-years would double to what it is at present and about 47% of the total energy would be from electricity in 2050. The four major sources of electricity production would be from Solar, Wind, Hydro and Nuclear power. To meet the net-zero target by 2050, these sources of power would have to be given prime importance to drastically reduce GHG emissions. In the tropical countries of Asia and Africa, solar power is in abundance and has to be harnessed in a professional manner to reduce cost of electricity production. Similarly in Africa and Europe, wind energy has to be harnessed potentially to meet the enhanced electricity demand for the transition to a green hydrogen economy. From a study by Bloomberg NEF, to control the temperature rise of our planet to < 2 deg Celsius, we require to have about 2836 Giga Watt of new non-hydro renewable energy by 2030. To enable this more of solar and wind energy plants have to be set-up since nuclear plants are very costly and raw materials are scarce.

- Finally the researcher proposes to provide mass public awareness for the usage of Green Hydrogen in the transport sector, household appliances, big Industries, real estate establishments and in the medical sector as well. More incentives may be given out by the developing nations to encourage maximum usage of green hydrogen in the transport sector and the household sector, which involves a large percentage of the population in any country. Through the help of NGOs, mass awareness campaigns can be held, so as to inculcate the feeling of inclusiveness amongst the citizens and apprise them of the benefits of a "Green Hydrogen Economy".

- From the responses from 75 persons on the questionnaire sent to them, we have corroborated our findings from our research model and our conviction that a 'Green Hydrogen Economy' is possible by 2035 is confirmed. The cost reduction predicted by our model is also supported by the survey. For emerging nations of Asia, Africa & Europe to have a 25% contribution from green hydrogen of their total energy requirements by 2035 is also supported by the findings of the survey. The survey also supports the prediction of our model about the private – public contribution and that more of private participation is required in all the emerging nations, to contribute to enhanced production of electrolyzers and for funding of a larger infrastructure to enable green hydrogen production, storage and transportation. From the responses it is clear that the participants have expressed their opinion in favour of a 'Green Hydrogen Economy' in the emerging nations by 2035 and also expressed their conviction of a net-zero economy in all the nations, to save our next generation from the ill-effects of carbon emissions.

- From the above findings the researcher can state with conviction that a 'Green Hydrogen Economy' in the emerging nations of Asia, Africa and Europe is possible by 2035. It is also clear from the present model that cost of production of green hydrogen would reduce to USD 2-3 per Kg by 2035 and that wind and solar energy would contribute to about 80% of the energy requirements by then. Private participation and funding alongwith government funding would be an important factor to contribute to enhanced production of green hydrogen by 2035. Technology expansion to create about double the electrolyzers at present, would also contribute to the volume of green hydrogen production required for the emerging nations to reach the goal of 25% of total energy requirements by 2035.

# CHAPTER VI:

# SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

## 6.1 Further Research on Green Hydrogen Economy

- Future research on the subject in emerging nations of the world may focus on the mass scale production of electrolyzers to enable an output of large volumes of green hydrogen, which can be used in the industrial sector, transport sector and household appliances. All countries should prioritise laying of pipelines for the transfer of green hydrogen at a cheaper cost than in cryogenic containers through road or rail. Big hydrogen hubs should be created for easy availability of the product world-wide. To sum-up, all countries should attach prime importance to the production, storage, transportation and usage of Green Hydrogen, if their net-zero goals till 2050 have to be accomplished.
- Developed countries like Germany, USA, Japan, Russia and China, should play a leading role in the transition to Green Hydrogen from the traditional fossil fuels by transferring their knowledge base, technology, infrastructure projects and their expertise to the emerging economies of the world, which would enable the whole world to move towards the net-zero target by 2050.
- Since this transformation would involve a lot of funding, the active participation of big corporate houses in the private sector along-with

government support is essential to move this transformation at a fast pace. With this bonding the vision of a ‘Green Hydrogen Economy’ around the world would be fulfilled by the middle of the present century and our next generation would experience a better, cleaner and a healthier world to live in.

APPENDIX A

**QUESTIONS IN THE SURVEY**

1. Do you believe Green Hydrogen will be a major energy source in the next 10-15 years?

2. The Emerging economies like India, Philippines, Brazil and South Africa have planned to spend 20-25 % of their total yearly budget in Green Energy projects. Do you believe that these measures will help to bring down carbon emissions in our planet?

3. Do you believe that the measures taken at present in the developed and developing countries to control the temperature rise of our Earth are sufficient?

4. Many countries have taken measures to control GHG (Green House Gases) emission to protect our Earth's ozone layer. Do you think these measures are enough?

5. Is a Green Hydrogen Economy possible according to you by 2035?

6. Some experts have suggested creating of Green Hydrogen Hubs similar to Petroleum Hubs to monitor the distribution of green hydrogen smoothly. Do you think this is a positive approach towards a green economy?

7. Green hydrogen production on a large scale would require green fuel like electricity, nuclear power, solar power etc. Do you think public private collaboration would be a positive approach towards enhancing production of green energy?

8. Liquid hydrogen transportation requires cryogenic containers which are very costly to maintain. Do you think production of hydrogen at the factory sites are more advisable than bringing hydrogen from far-off plants?

9. COP-26 leaders had deliberated on measures to keep the temperature of the Earth from increasing beyond a threshold limit of 2 degree Celsius. Do you think the present measures taken and the forecasted measures in the emerging economies would be sufficient in the next 10-years?

10. Countries like USA, Germany & China have taken long strides towards a Green Hydrogen Economy, do you think that these countries should share their know-how with the emerging countries towards a common goal?

11. The present pandemic situation has forced the developing countries to postpone their ambitious goals towards a green economy. Do you think the developed countries should help them to achieve their common goal?

12. Do you feel that green hydrogen production costs can be lowered by taking constructive steps to increase manufacturing of electrolyzers?

13. Do you think the emerging economies should help private sector participation in increasing energy production through solar and wind plants?

14. Do you think it is a good proposal to set-up green hydrogen production units near the sea-shore and convert sea-water through electrolyzers to green hydrogen?

15. From the Indian Government site, data up to Nov 2021 in Wind energy shows a commissioned capacity of 5095 Mega Watt and balance allotted capacity of 6670 Mega Watt to be commissioned. Do you think India has the potential to do better than this capacity utilization?

16. Similarly Solar Energy data shows commissioned capacity of 7505 Mega Watt and balance allotted capacity of 1941 Mega Watt to be commissioned. Do you think solar energy potential in India is much more than this?

17. Hydro-electric power commissioned capacity is 903 Mega Watt and balance to be commissioned is 1291 Mega Watt. Do you think an approximate increase of 20% per year is sufficient for India to achieve self-sufficiency in Hydro-power required for green hydrogen production by 2035?

18. Total renewable energy allotted capacity in India is approximately 36916 Mega Watt and commissioned capacity till Nov-2021 is 15374 Mega Watt. To make major strides towards a Green Hydrogen economy, should India increase the pace in which investments on green fuels are going on , say about 25% per year till 2030?

19. Electric vehicles are fast replacing vehicles running on fossil fuels in India, China and European countries. According to your view is this a positive step towards a carbon-zero economy?

20. Green Hydrogen buses and trains are running commercially in Germany and some other European countries. Do you believe, India and other emerging economies will also convert to these modes of transportation soon?

21. Developing countries spent USD 152.2 billion on renewables investment compared to USD 130 billion by developed countries in 2019, according to a study on Global

Trends in Renewable Energy by Bloomberg NEF. Do you think if this trend continues, developing economies will be able to meet their targets towards a Green Economy?

22. According to a green energy study by Bloomberg NEF, to keep the global temperature rise below 2 degree Celsius, about 2836 GW of new non-hydro renewable energy capacity would be required by 2030. In this solar and wind energy will contribute the most. Do you think solar energy projects should be taken up on war-footing in the tropical countries to meet this goal?

23. The TERI/Shell report (2021) projects the energy sector to reach net zero by 2050, with electricity meeting 47% of the final energy demand in 2050. Solar and wind are estimated to produce 88% of the total electricity. With solar and wind energy in abundance in India, do you think this is possible?

24. IPCC/McCollum et al.(2018) had estimated that requirement for India alone is at least USD 150 billion per year or about 2% of GDP over the period 2020-50 to meet the net zero target. Do you think this is possible?

25. The IEA report (2021) in itâ most ambitious scenario has predicted that the share of renewables (excluding large hydro) in the electricity generation would rise to 69% in 2040 mainly driven by solar and wind (60%). In your opinion is this viable?

26. IPCC / Mc Collum et al.(2018) had estimated that developing countries together will need USD 600 billion per year in the period 2020-2050 by way of additional investment in the energy sector alone to achieve the transition to green hydrogen economy, in which India alone would require USD 150 billion per year or about 2% of GDP over the period as a whole. Do you think this target is achievable?

27. The Govt. of India aims to halve the cost of green hydrogen in the country from currently around USD 5/kg to USD 2.2/kg by 2029. With ambitious plans of the private sector also in India , do you feel this target is possible?

28. Electric vehicles are likely to be the main low-carbon option between now and 2030. However, how sustainable EVs are, depends hugely on what is used to generate the electricity they consume- coal, gas, nuclear, hydro, wind or solar. In your opinion will the last three be the major electric energy producers till 2030?

29. Some countries like China are directly incentivizing electric vehicle sales to reach a target of 25% of total passenger vehicle sales by 2025. Do you think this is a

good approach for low-emission transport and other developing countries should emulate the same?

30. Considering the above questions, what in your opinion should be the target year for a green hydrogen economy in the Emerging countries like India, South Africa, Philippines and the like?

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