Green Hydrogen: A Clean Energy Solution for Germany's Transportation Sector

A.D. Asiegbu, M.T.E. Kahn, and A.M. Almaktoof

Abstract—**The need for sustainable and environmentally friendly energy sources is very important if future generations are to be spared of the misdoings of past generations. Climate change, environmental pollution, radiation pollution, and altering of the balanced ecology of the green planet earth is now a significant challenge, because if not mitigated, some island nations will disappear in the future, due to human activities energized by unsustainable fossil fuels. Based on these facts, Germany has taken concrete and important steps to stem the tide of this ill wind by embracing the Green Hydrogen system. This is more obvious in the transport system that produces more than 40% of Green House Gases in Europe. Because Germany is an industrialized European nation, the government has introduced Green Hydrogen for transportation in accordance with European Union energy policy. Therefore, this paper provides a clear, concise analysis and implementation of Green Hydrogen energy in the smart energy system. The paper presents Green Hydrogen analysis in transportation in four sections, namely, Geographical, Chemical, social, and economic aspects, respectively. The last section of this paper is the discussion of results from cost/feasibility analysis, which shows that although the expected or forecasted GH cost is US$7.11per kg from 2020 to 2050, the current growth in the green hydrogen infrastructure and technology, reduced the overall cost of GH in 2020 to $1.60/kg. An erudite conclusion and recommendations are made at the end of this research.**

Index Terms—**hydrogen, renewable energy, energy storage, fossil fuel, hybrid energy, energy mix, energy generation, green hydrogen, transportation sector.**

I. INTRODUCTION

THE need for reducing Green House Gases (GHGs), mitigating climate change, environmental pollution, and the rise in sea level, necessitates the need for alternative energy supply and a shift from conventional generation of energy from fossil fuel sources to hybrid renewable energy. Hydrogen produced from green ammonia, and renewable sources like electrolysis of water, using electrical energy from renewable sources like hydro, wind, solar, is called Green Hydrogen (GH) [15]. In a hybrid renewable energy generation mix, GH plays the critical role of energy storage and energy source. It also serves as an important chemical in the manufacturing of chemical substances and products like the industrial hydrogenation process, green ammonia, the main constituent of synthetic fertilizer. The GH serves as a replacement for current hydrogen feedstocks like blue and grey hydrogen in many industrial activities, such as industrial heating, chemical production, semiconductor manufacturing, iron and steel production, oil and gas refineries, and food production. It can also be used for long-duration grid energy storage and for long-duration seasonal energy storage, which will significantly improve the transport sector energy requirements. The transport sector in Germany is a significant energy consumer and GHGs emitter. To reduce these GHGs, hydrogen energy access and use in the transport sector is imperative. This objective is achieved by analysis of hydrogen as an energy source and storage in the transport sector, using Germany as a model. This model can serve as a standard for other countries to implement hydrogen as an important player in their energy and power generation mix. GH in transportation is analyzed in four sections, namely, Geographical, Chemical, social, and economic aspects, respectively. A conclusion is drawn from these aspects at the end of this paper.

II. GEOGRAPHICAL FEATURES OF GERMANY

The Federal Republic of Germany (FRG) has a well-structured, democratic, and federal form of government with its capital in the metropolitan city of Berlin as the national capital. The official language is German, the national currency is the (continental) Euro, the total geographical area is 349,223 square kilometers, and the major rivers are Danube, Rhine, Main, and Elbe. The population projected growth rate is 200,000 per year starting from 1985, and currently, the population is 80,457,737 [1]. Germany has various landscapes and many primary energy sources, like wind energy, hydropower, biomass, solar energy, and other renewable, environmentally friendly, and sustainable primary energy sources [2]. Because of the rise in demand or consumption of energy with respect to time from fossil fuel energy sources, which results in climate change, ozone layer depletion, environmental pollution, and the increase of Green House Gases (GHGs) like Carbon (IV) Oxide (CO_2), Sulphur (IV) Oxide (SO_2), Carbon (II) Oxide (CO), Nitrogen (IV) Oxide

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(N_2O), Hydrofluorocarbons, Perfluorocarbons, Sulphur hexafluoride (SF_6) [3], the government of Germany seeks to discourage generation of energy from fossil fuel sources like coal, crude oil, natural gas, and fuel wood, but supports renewable energy sources which are environmentally and economically sustainable, especially, the GH energy sources [4].

Transportation activities produce an average of 28% of CO_2 emissions in the European union (EU) [5]. Germany being the largest economy, the wealthiest and a post-industrial nation in continental Europe, respectively, produces more CO_2 than the average value in Europe. Thus, the need for change in primary energy sources that will positively change the geographic, social, economic, and salient features of the world, and the post industrialized German nation, is very crucial. To reduce the exploration and exploitation of land, atmosphere, and the earth's biosphere for fossil energy primary sources, the geography and geology of green planet earth need to be balanced and maintained by switching to renewable energy sources like hydro or hydrokinetics energy, solar energy, and wind energy.

These primary sustainable energy sources are seasonal and fluctuate, making reliable energy storage inevitable [29]. Generating long lasting and reliable energy storage, and energy mix, especially in the distributed generation can achieved using GH energy [30]. The ArcGIS® simulation software produced by Environmental Systems Research Institute (ESRI) is a Geographic Information System (GIS) used to analyze, organize, and map spatial data in the modelling of hydrogen supply chain network [31]. ArcGIS is a software platform for Geographic Information Systems (GIS) that allows for the creation, analysis, visualization, and management of spatial data. ArcGIS has various tools and applications for different purposes, such as mapping, geocoding, geoprocessing, geostatistics, 3D visualization, and more [32].

Geostatistical simulations are methods to generate multiple possible realizations of a spatial phenomenon based on a statistical model and sample data, and it is useful for assessing uncertainty, risk analysis, scenario planning, and decision making. ArcGIS CityEngine can create realistic or fictional cities based on GIS data or procedural rules. ArcGIS CityEngine can be used for urban planning, architecture, entertainment, simulation, and more [33].

The Model for Optimization of Regional Hydrogen Supply (MOREHyS) is used to design the hydrogen infrastructure to serve the energy storage and source role [6]. The MOREHyS is a very useful tool that assesses the introduction of hydrogen as a transportation or locomotive fuel by implementing energy-system analysis. This software is technology-based, mixed-integer, myopic linear optimization model that reduces the overall total cost of hydrogen supply with respect to time, after considering the regional demand, available resources, production plus delivery technologies, and the infrastructure build-up. Thus, MOREHyS is extensively utilized in the evaluation of different scenarios and strategies for hydrogen supply chain development, identification of the optimal locations, sizes, and operations of hydrogen production, in addition to refueling facilities.

III. CHEMICAL ASPECTS OF HYDROGEN

Hydrogen can be economically produced from electrolysis of (acidified) water (with few drops of Tetraoxosulphate (VI) acid (H_2SO_4)). The input electrical energy is converted to chemical energy stored in the liberated hydrogen gas (the lightest gas) through an upward delivery channel, with highest thermal combustion energy of all the fossil fuels per kilogram equal to 141.80 MJ/kg according to Table 1. This is the highest heating value per kilogram and more than twice the heating value of methane.

TABLE 1: HIGHER HEATING VALUE (HHV) AND LOWER HEATING VALUE (LHV) OF SOME COMMON FUELS AT 25 °C [7].

Fuel	**HHV (MJ/kg)**	**LHV (MJ/kg)**
Hydrogen	141.80	119.96
Methane	55.50	50.00
Ethane	51.90	47.62
Propane	50.35	46.35
Butane	49.50	45.75
Pentane	48.60	45.35
Paraffin Wax	46.00	41.50
Kerosine	46.20	43.00
Diesel	44.80	43.40
Coal (Anthracite)	32.50	
Coal (US-Lignite)	15.00	
Wood (MAF)	21.70	
Wood Fuel	21.20	17.00
Peat (Dry)	15.00	
Peat (Damp)	6.00	
Fuel	**MJ/kg**	**KJ/mol**
Methanol	22.70	726.00
Hydrazine	19.20	622.00
Hexamine	30.00	4200.00
Ethanol	29.70	1367.00
Carbon	32.80	393.50
Benzene	41.80	3268.00
Ammonia	22.50	382.60
Acetylene	49.90	1300.00
1-Propanol	33.60	2020.00

Oxygen, being the other liberated chemical element, which is particularly useful in the hospital, is evolved through the downward delivery channel (heavy gas). The stored energy in the hydrogen gas can be controlled and used as a fuel for Internal Combustion Engine (ICU) for locomotives, mechanical machines, aircraft engine, industrial manufacturing of various chemical products, and fuel cell for powering electrical machines and devices. In the fuel cell the hydrogen gas chemical energy is converted to electrical energy, producing water as the product of the electrochemical reaction between hydrogen and oxygen in the fuel cell. Fuel cells can operate and generate electricity indefinitely with an indefinite supply of GH fuel and oxygen, continuously releasing water as the chemical product. This process is environmentally friendly, and in line with United Nations (UN) Sustainable Development Goals (SDGs). Thus, this is a great attribute of the fuel cell as an energy source, unlike batteries that can only contain energy within its container, without the option of indefinite supply of energy.

In addition, fuel cells have many advantages over conventional combustion engines, like higher efficiency, reduced or zero emissions, reduced noise, quiet operation, DC power output with less complex power analysis, and greater reliability. The common types of fuel cells [8], [9], are:

- Alkaline Fuel Cells (AFCs): this fuel cell contains an aqueous solution of sodium hydroxide or potassium hydroxide (electrolyte) and works at temperatures ranging from 60 to 90 °C, with high power density and low cost, but sensitive to $CO_{2(g)}$ contamination.
- Phosphoric Acid Fuel Cells (PAFCs): this fuel cell contains orthophosphoric acid (electrolyte), working at temperatures up to 200 °C, with moderate power density and efficiency, but relatively tolerant to $CO_{(g)}$ and sulfur impurities.
- Molten Carbonate Fuel Cells (MCFCs): this fuel cell contains mixture of molten lithium, sodium, and potassium carbonates as the electrolyte working at temperatures ranging from 600 to 700 °C, with high efficiency, and ability to use various fuels. However, their power density and durability are low.
- Solid Oxide Fuel Cells (SOFCs): They use solid ceramic material as electrolyte and operate at temperatures higher than 800°C, with a very high efficiency, accepting a wide range of fuels. The downside is that they are much more expensive compared to the other types of fuel cells. They also have a long startup time.
- Proton Exchange Membrane Fuel Cells (PEMFCs): these fuel cells have solid polymer membrane (electrolyte), working at temperatures that are lower than 100 °C, with high start-up time and high-power density. The demerit of these fuel types is that they need pure hydrogen as the fuel and expensive platinum group of elements as catalysts.

The energy density of hydrogen is 120 MJ/kg or 33.6 kWh/kg [13]. Thus, hydrogen serves as an energy source and storage. A prototype fuel cell system delivers a nominal output power of 31.5 W at 12 V for 38 h (1.2kWh) with only one recharging cycle, and twice the energy density of conventional storage systems [14].

Transportation being a significant energy consumer is considered as a standard for implementation of the green hydrogen energy, and this is referred to as the GH for transportation, using Germany as a case study or template. Chemically, GH is the splitting of a water molecule to yield one molecule of hydrogen (two atoms of hydrogen) and one atom of oxygen, when a direct current electricity is passed through water. the GH produced can be stored as Liquid Hydrogen (LH) or Compressed Hydrogen (CH), transported (in pipelines or in tanks using trucks), and used as a primary energy source (for direct heating, electrical energy, industrial or commercial purpose) when the wind energy, solar energy, and other renewable sources are not available or in short supply [16]. Oxygen atom is very reactive, and solely responsible for combustion (an example of oxidation reaction) and must be paired to form diatomic (O_2) gas in nature, yielding heavy oxygen molecules that descend through the downward displacement delivery. Hydrogen atom is also reactive and the only atom that loses electron to form proton (an example of reduction reaction) that must be paired to form the lightest chemical element ($H_{2(g)}$), ascending through the upward displacement delivery. The two half (electron) reactions are collectively known as redox reaction, with water as the product. $O_{2(g)}$ is abundant in the atmosphere but $H_{2(g)}$ is not, making it the limiting chemical reagent that is very useful as a renewable green energy source and storage.

IV. SOCIAL ASPECTS OF GREEN HYDROGEN

The GH produced should be acceptable, socially, and economically appealing, strategically located, and must pass through some market and economic routes before getting to the energy consumer (Households, Industries, commercial users, Building energy users) in the society. GH is a game-changer in the transition to a low-carbon economy [34]. It is an emerging key player due to its versatility, sustainability and as a promising alternative to decarbonize the "hard to abate" sectors, such as heavy industry, transport, and energy, which account for more than 50% of the world's GHG emissions [35].

The social aspects and challenges of GH identified for the future are encapsulated in the following three social parameters [36]:

1. Risks, socio-environmental impacts, and public perception.
2. Public policies and regulation.
3. Social acceptance and willingness to use associated technologies.

The production, storage, and transport of green hydrogen are not without risks and impacts on the environment, society, and people [12]. A crucial aspect of the process of developing a GH value chain is the identification of potential sites for developments and their possible cumulative and indirect impacts, as the siting of facilities may directly trigger several additional risks and impacts addressed by other performance standards.

The cost of GH transportation using truck is reduced using four different strategies, and at high compressed pressure of 250 Bars and 350 bars in the year 2030 [17]. Thus, modern infrastructure must be in place, or the old infrastructure must be upgraded to accommodate the peculiar needs of GH storage, transportation, and end device direct use as a clean energy source. The hydrogen transportation network and infrastructure in Germany, projected/modelled for year 2030 is shown in Fig. 1. The parameters and different strategies that can improve hydrogen access include [11]:

- ❖ the hydrogen storage facilities,
- ❖ the hydrogen production plants in place,
- ❖ the number of connecting networks for hydrogen transportation,
- ❖ the flow rate of hydrogen gas or liquified hydrogen.

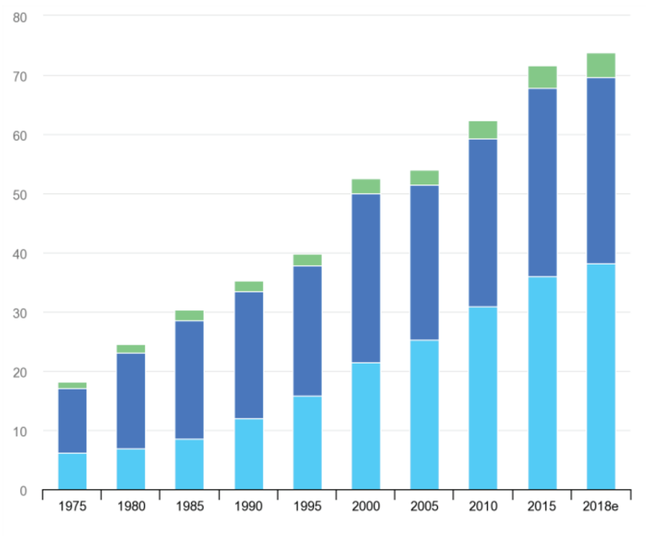
In Fig. 1, these four different strategies are implemented in achieving a well-coordinated, low cost, and optimal GH transportation infrastructure in 2030.

Fig. 1: The GH transportation infrastructure for 2030 [18].

V. ECONOMIC ASPECTS OF GREEN HYDROGEN ENERGY SOURCE

To encourage the use GH, the Germany government introduced a pilot program for the use of Fuel Cell Electric Vehicles (FCEV) and Hydrogen Supply Chain (HSC) [19]. Based on the current trend in energy demand and savings from using high energy equipment or energy system, the cost savings from avoiding health issues resulting from GHGs, and environmental pollutions, implementation of distributed energy system, advancement in technology, and future research breakthroughs, the cost of generating GH will decrease and GH/energy access will increase. GH is considered a more economical means of energy storage to address renewable energy intermittency in terms of capital expenditures than pumped-storage, hydroelectricity, or batteries [10]. However, the economics of GH are challenging today, primarily because the underlying costs and availability of renewable energy sources vary widely.

According to Bloomberg New Energy Finance, if these costs continue to fall, GH could be produced for \$0.70 – \$1.60 per kg in most parts of the world by 2050, a price competitive with natural gas, and in 2020, GH produced using solar powered electrolysis had a production cost of about \$3/kg2. The overall cost of GH in 2020 came out to about \$1.60/kg based on energy and electrolysis platforms [40]. GH could be a critical enabler of the global transition to sustainable energy and net zero emissions economies. There is unprecedented momentum around the world to fulfill hydrogen's longstanding potential as a clean energy solution, and various national governments (especially German government), and the industry (especially the transport industry and sector), have both acknowledged hydrogen as an important pillar of a net zero economy [41], The global need and demand for hydrogen from refining, ammonia, and other sources is shown in Fig. 2 [20].



Key: Refining, Ammonia, Other

Fig. 2: World Hydrogen needs and demand.

Opportunities for several utilization pathways include transportation, industry, utility, and energy storage. The roadmap for a GH energy by 2050, can be achieved in three phases as follows [37]:

1. GH as industrial feedstock
2. GH as fuel cell technology
3. GH commercialization.

GH is a clean and renewable energy source with the highest energy density among the fuels, with six times more energy than ammonia as depicted in Table 1 and Fig. 2. Green ammonia is the most common GH carrier because it has no carbon atom, but it has three hydrogen atoms, making green ammonia, a suitable fuel to produce GH. There are many pathways for GH production, based on the production technologies, and pathways which are based on the raw materials and energy sources, and their different scales. The main technological processes of producing GH from ammonia energy vector [38] are:

1. The electrochemical process
2. The photocatalytic process
3. The thermochemical process

Thus, the economic aspect of producing GH takes into consideration the cost associated with each of the three processes of GH production from ammonia and compares it with the cost associated with GH production from electrolysis. Also, the production plants, fueling stations, conversion efficiency, reactors, catalysts, and their related economics are other important factors of GH production for the transport sector in Germany. The commercial process of GH production from ammonia ($NH_{3(g)}$) is done using platinum group of metals like (expensive) Ruthenium (^{44}Ru) catalysts in the ammonia chemical conversion process, which can be substituted by other similar chemical elements like Nikel (Ni), Cobalt (Co), Lanthanum (^{57}La), and other perovskite catalysts, which have high commercial potential with equivalent activity for the extraction of GH from ammonia [39]. To fully embrace GH revolution, especially in the transport sector of the German economy, integration with green technologies like electrolysis, an economical method of GH production, as well as safety aspects, need to be analyzed and employed. The hydrogen supply chain depicted in Fig. 3, shows the renewable energy sources that are used to produce hydrogen.

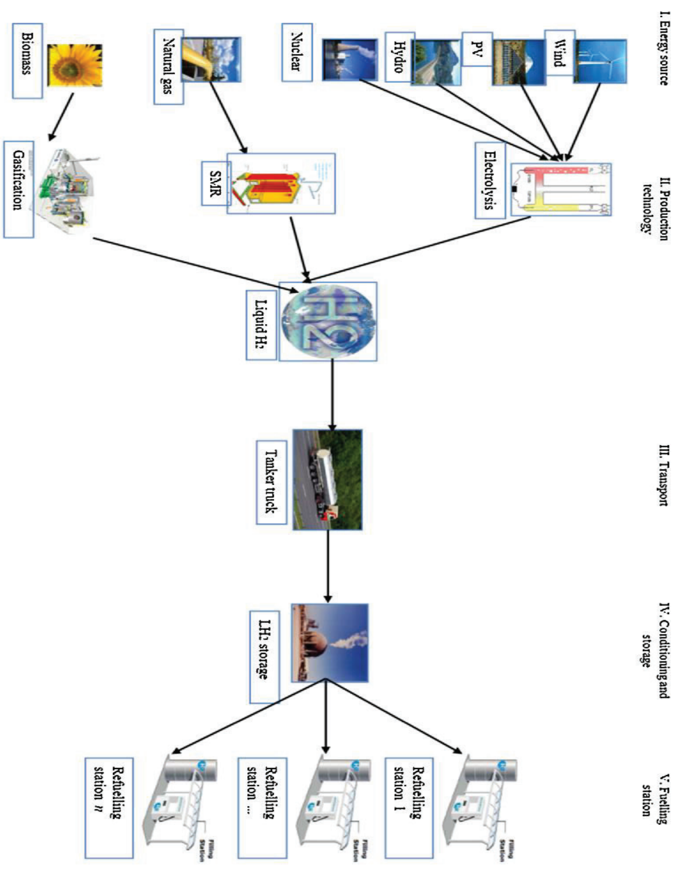


Fig. 3: Hydrogen Supply Chain (HSC) [21].

The hydrogen is liquified and transported through a tanker truck to conditioning and storage facilities. Finally, hydrogen is supplied to the fueling and refueling stations for easy access to the public and industrial users.

Geographic tools, like the geographic information system (GIS) can be used to model the supply chain managements systems like the HSC systems. Model for Optimization of Regional Hydrogen Supply is used to do geographic analysis (and economic feasibility) of the German HSC [6]. FCEVs will be sustainable, since it is an example of hydrogen to renewable energy technology, which is reliable (it can travel long distances without the need to recharge or refuel the car batteries), can be integrated into the distributed generation system, and can capture wind energy, hydro energy, nuclear energy, and solar energy directly from a natural energy rich environment.

The new cost of using hydrogen energy will change according to (1) [22]:

New Cost = reference Cost * (New Capacity / Reference Capacity)$^{\text{Power Low Factor}}$ -------------(1)

Where the power low factor is assumed to be 0.6 for GH, transported through pipelines. The capacity of GH in Germany is 960 Tons/day, capital cost of production is 1910 million $USD, and production unit cost is 6.40 $USD [23]. Using (1), the increase in demand of GH in Germany, resulting in the new expansion cost of the current capacity that will double the original capacity (from 960 Tons/day to 1920 Tons/day at a power factor of 0.6), is calculated as follows:

$$\text{New Cost} = 1910 * 10^6 * (1920 / 960)^{0.6} = 2895 * 10^6 \text{ \$USD}$$

At a power low factor of 1, it will cost $USD 3820 million (double of the cost), and a new unit cost of $USD 12.8.

This shows that if the demand is doubled, the cost tends to double, if the present infrastructure is not modernized in future. The pipeline transportation of GH becomes viable when the GH market share value of Fuel Cell Electric Vehicle (FCEV) is at least 10%, and if more than 30% of GH is to be transported, national centralized network should be implemented instead of regional networks [24]. GH produced needs to generate less than 9.5 kg $CO_{2(g)}$ per kg of $H_{2(g)}$ produced, to offer an advantage, with a reduction of tank-to-well emissions by 2020 to 95 g/km, equivalent to 113 g CO_2/km in a well-to-wheel scenario [25]. GH should cost < 5.3 US$/kg between 2020 and 2030 [6], and < US$7.11per kg in 2050 [26] to be economically viable. The European Union (EU) commission directive on the alternative fuel's infrastructural deployment recommend a H_2 refueling station at an interval of 300 km on the motorways and highways to mitigate the energy access issues [27][28].

VI. RESULT AND DISCUSSION

GH implementation is currently expensive, and it may not be within the reach of low income and developing nations, since it will take Germany about $USD 3820 million and a new unit cost of $USD 12.8 to double its current capacity, even though Germany has significant hydrogen transportation infrastructure. If 30% or more of GH is to be transported through the pipeline, then national centralized pipeline network should be implemented instead of a regional network. This will ensure lower cost, broader reach of the GH, higher use and penetration of GH, and increased access of GH. The cost of GH in 2020 is US$1.60/kg, and as GH technology improves, coupled with substantial interest in GH as a key net zero emission energy source, the price will decrease to US$0.70/kg according to Bloomberg New Energy Finance. However, GH should cost lower than 5.3 US$/kg and US$7.11per kg in 2030 and 2050, respectively, to be economically viable.

The refueling stations should be spaced 300km apart from each other. Despite the high cost of integrating hydrogen in the energy mix, GH is a game changer, because it will be an efficient storage of energy in the chemical energy form, which can be easily converted to heat and electrical energy using modern technologies. Because of the high heat value of hydrogen, it will be difficult to use it as fuel in the ICE of cars, as cooking fuel or in some mechanical machinery. However, hydrogen is used in fuel cells, which makes it suitable for future Electric Vehicles (EVs). It can replace electric furnaces in future, and it will be useful in chemical and metal refining industries. GH has the least carbon footprint and GHGs emissions. Green ammonia which can utilize the existing infrastructure of GH in Germany, is an important, alternative source of GH. With three $H_{2(g)}$ atoms and no carbon atom, two moles of $NH_{3(g)}$ can yield three moles of hydrogen ($2NH_{3(g)} \rightarrow N_{2(g)} + 3H_{2(g)}$) in the presence of perovskite and platinum group of catalysts, respectively. This is equivalent of 2:3 volumetric ratios. Thus, based on improvement on GH infrastructure, electrolysis, green ammonia, and fuel cell technologies, respectively, the overall cost of GH in 2020 came out to about $1.60/kg.

VII. CONCLUSIONS AND RECOMMENDATIONS

There are different methods of producing GH, but the most common one is electrolysis, which splits water into hydrogen and oxygen using electricity from renewable energy sources such as wind or solar power. Other useful methods include thermochemical biomass conversion, waste to energy, methane reformation, and biogas reformation with carbon capture. GH is a key enabler of the global transition to sustainable energy and net-zero emissions economies. Many countries and regions have announced ambitious plans and investments to scale up green hydrogen production and use, in the coming decades, with Germany as an exceptional example. High costs, low efficiency, infrastructure gaps, and regulatory issues are some of the challenges of implementing GH technology.

Renewable energy in Germany is growing and receiving attention from the Germans and the EU. The German government and the EU commission have incentivized and prioritized decarbonization of the environment, prevention of pollutant emission, elimination of biological toxins (Mercury, Lead etc.), and GHGs emission into the atmosphere and biosphere. Through constant research in energy, modern and efficient energy equipment should be used, as a compliance with energy standards and policy by energy users or consumers.

Green Hydrogen is embraced in Germany, as an of energy storage from variable energy input from various renewable energy sources like wind and solar energy, respectively. This GH electrolysis technology provides fluidity and reliability to the distributed generation in German Smart Grid (SG) and future Smart Energy system. The GH primary energy source can function as a battery, direct heater, direct boiler, and other residential, commercial, and industrial purposes. From the results retrieved from this research paper, the cost of GH production will reduce with respect to time provided efficient energy equipment is used, modern and reliable energy transmission system is in place, like efficient pipelines, and smart grid. Thus, based on this research, GH is hydrogen that is produced using renewable energy or from low-carbon power sources, with significantly lower carbon footprints and GHGs emissions than blue hydrogen (with Carbon capture) and grey hydrogen, which is derived from fossil fuels without carbon capture. GH is useful in the decarbonization of sectors like the transport sector that are hard to electrify, such as heavy industry, locomotives, long range transport, shipping, and aviation. It is also useful in the production of synthetic fuels and chemicals, storing and transportation of renewable energy over long distances.

Finally, the hydrogen infrastructure for the transportation sector in Germany, can serve as a model for other countries to use and further develop to suit their peculiar needs and Sustainable Development Goals (SDGs) with regards to energy access, energy storage and energy savings. Considering the study done in this work, the following recommendations are made:

- ❖ The spatial variations in hydrogen demand can be improved by demand modelling using any of the software mentioned in this study.
- ❖ Exploration of naturally occurring hydrogen, known as the White Hydrogen (WH) from places like the Philippines should be investigated.
- ❖ The Hydrogen Internal Combustion Engine (HICE), apart from Hydrogen Fuel Cell Vehicles (HFCVs), which is a modified traditional gasoline-powered internal combustion engine provides an opportunity for further research.
- ❖ Due to constrains associated with harvesting GH from renewable sources, other sources with less carbon footprint like biogas (through Steam Methane Reforming (SMR)) Hydrogen Production Technology (HPT) route shown in

Fig. 3 can be considered in the generation of GH in energy and power generation mix.

- Using Carbon capture and storage innovative technologies, natural gas pipelines for supplying GH (30% or more) will improve energy access and energy storage.
- The possibility of integrating GH in the industries should be investigated and implemented to lower overall cost of GH and increase GH demand.
- Optimization of GH production should be accelerated using Dynamic Programming (DP).

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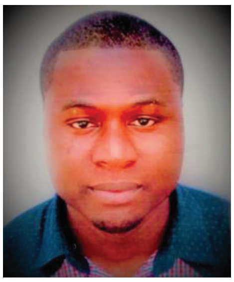

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