14th Annual International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), February 12-14, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240055
Published: February 12, 2024

Renewable Resources & Green Hydrogen

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Abstract

Over the past decade there has been a call for action to reduce the emissions which have contributed to global warming and climate change. Many countries and organizations have invested in renewable resources like solar, wind and hydropower to produce energy in a sustainable way. In recent years, an interest has been taken in hydrogen. This paper highlights the benefits of hydrogen and more specifically green hydrogen which is hydrogen produced using renewable resources. It highlights the current challenges such as production of hydrogen at large scale and the cost of production. During research, the benefits of hydrogen were discovered and the lack of knowledge especially in the public sector were observed. To help create awareness and highlight the future prospects of hydrogen, Microsoft Power BI data visualization tool was used to create an interactive dashboard which can be used to create awareness between the users and to encourage them to adopt renewable energies. Certain countries and companies were highlighted for taking the prominent role in the production of hydrogen and paving the way for others to follow with their findings. With the increase in awareness between communities, it is predicted that government and other entities will be encouraged to explore clearer energy such as hydrogen. It was recommended that in the future when the cost of hydrogen has decreased it can be used to tackle large sectors like heavy duty industrial and transportation.

Keywords
Green hydrogen, emissions, renewable resources, net zero, Microsoft Power BI

1. Introduction
In the current modernized and technological world, there is a deep concern regarding the impact of the emissions that have dramatically increased since the industrial revolution. The impact of the human contributions to the emissions have recently been recurring with more frequent extreme weather events and the rise in global surface temperature, leading to an increase in mortality rate of all living organisms. There has been an increase in demand for call to action for more environmentally friendly alternatives to the products and processes used. A heavy push with funding is placed on renewable energy such as wind, solar and hydropower with many countries adopting these to power their infrastructure.

Several mitigation policies and plans have been suggested through the global initiatives like the Paris Agreement. Entities have ventured into concepts like net zero energy and are on the path to making them reality. Similarly, in the last decade, the prospect of green hydrogen has risen to support the sustainable energy framework and achieve the Sustainable Development Goals. Green hydrogen is hydrogen produced using renewable resources meaning that there have been no emissions during the production. This paper will discuss the methods used for green hydrogen productions, application and the future prospects of green hydrogen. A data visualization tool will be used to develop a dashboard which will help create awareness for the public to not only be mindful of their emissions but to invest whether that is time or money in renewable energy and green hydrogen.

1.1 Objectives

The objectives of the research are to:

1. Highlight the emissions which are leading to greater impact on the living through a literature review survey of current progress and future prospects in the hydrogen sector
2. Create awareness of green hydrogen with positives and challenges through developing interactive visual dashboard using Microsoft Power BI.
3. Suggest future areas where green hydrogen can be adopted based on the results of the data analysis.

2. Literature Review

2.1. Emissions

With the rapid increase in population and technological advances in the last century, the emissions of harmful gases like greenhouse gases have increased in parallel. The impact of these unwanted cases has been more evident these last few decades with water availability, food production, ecosystem, and extreme weather changes. The Intergovernmental Panel on Climate Change (IPCC) which is a United Nations body responsible for monitoring the activities surrounding climate change have reported a rise in global temperatures witnessed with the average global surface temperature increasing by 1.1°C in 2011-2020 compared to 1850-1900. These are because of the introduction of different industries and factories. The Global Carbon Atlas Organization reports the top 15 countries around the world who contribute to the most carbon dioxide emission and is presented in Figure 1.

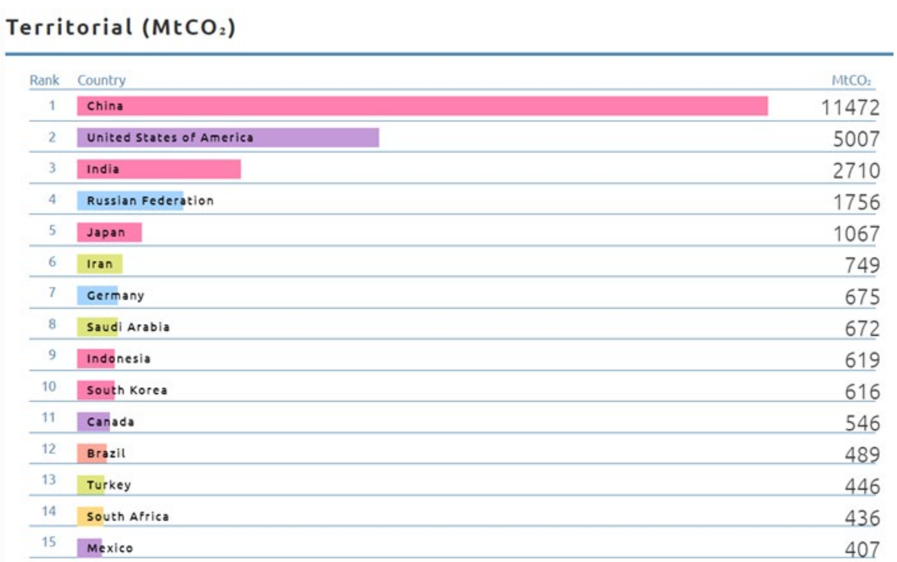

Figure 1. Top 15 countries with most carbon dioxide emissions as per the global carbon atlas organization

Research has shown that communities or regions who have contributed least to the climate change through emissions and carbon footprint, are more likely to be vulnerable to the impact of the changes. It was found that 3.3 – 3.6 billion people live in areas that are prone to be extremely vulnerable to climate change (IPCC). This shows that people and ecosystem are linked. Many losses have damages have been caused because of flooding, forest fires and increase in summer temperatures to the agriculture industry resulting in disruption of food production and supply. These food and water security are obstacles preventing many regions from meeting the Sustainable Development Goals. In addition, the human mortality rate due to the weather changes and increase in temperatures have increased in many countries around the world. Similarly, many animals and species are facing extinction or massive reduction in population. Figure 2 presents the current and future emissions scenarios that people from the next generations will face.

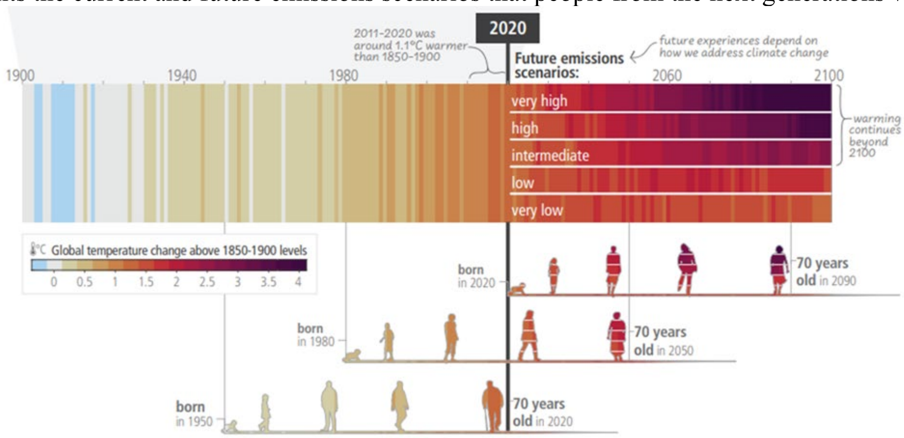

Figure 2. Temperatures faced by the future generations (IPCC)

From Figure 2, it can be deduced that unless immediate action is taken to reduce or eliminate emissions, the global temperatures will continue to increase, majorly impacting the living. The impact on the wellbeing of humans will be visible with the outspread of new infectious diseases, some of which are as a result of the glaciers melting. Another impact will be malnutrition due to food security. Displacement and mental health which are linked will be witnessed as people are forced to move due to events like floods and hurricanes.

Many government entities and countries have come together for initiatives like the UNFCCC, Kyoto Protocol, and the Paris Agreement. The Paris Agreement adopted by the United Nations pushes entities to develop policies to outline their goals and create transparency in communicating their actions against climate change. These are referred to as NDC and are submitted to the UNFCCC every 5 years. The hope is to observe a progression in the goals and policies for the countries in the successive years. The aim is to reduce emissions by 45 % by 2030 and by 2050 to be net zero. Some of these include policies against deforestation, technological development targeting more efficiency and reducing emissions from processes. IPCC reports that due to some of these mitigation measures there has been several gigaton of carbon dioxide reduction globally with at least 18 countries who have supported the cause by reducing consumption-based carbon dioxide for more than 10 years.

Recently as reported by the World Resources Institute, funding and focus has shifted to processes that focus on carbon removal or capturing. This means that any carbon produced is removed through certain methods resulting in a balance or equilibrium. As a result, a stationary point may be found in the climate change impacts.

To stop the further impact of climate change and global warming, ideally what is required is net zero carbon emissions. Researchers have explored different ways to introduce net zero carbon emissions in different industries like infrastructure or transportation. However, there are many complicated challenges and obstacles. The change requires converting from coal, gas and oil to renewable resources like wind, solar and hydropower. There has been an initiative called Race to Zero where many organizations have pledged to take immediate action to become net zero and half their global emissions by 2030. Therefore, over the last few decades several countries have introduced renewable energy sources to produce cleaner energy. The UN has called for action to go beyond just talks and hold entities to accountability for their pledges and commitments. They highlighted four areas which need to focus on to achieve net zero emissions such as environmental integrity, credibility, accountability and the role of governments. This is vital for non-state entities such as the private and financial sectors.

2.2. Renewable energy

Renewable energy sources (RES) are the key to a sustainable future (Dincer 2000). They provide the required energy to power cities and industries without harming the environment. As energy consumption has grown significantly with industrial development, it is crucial to shift towards renewable sources to reduce the negative impacts on the planet, human health, and the climate (Panwar et al. 2011). RES includes various forms, such as biomass, wind, solar, hydropower, marine, and geothermal energies (Qazi et al. 2019). They provide a sustainable and clean source of power that can be generated without diminishing natural resources or causing pollution (Qazi et al. 2019). According to pervious analysis showed that in 2017, fossil fuels supplied 73.5% of the energy worldwide while RES provided only 26.5%. Currently, society seeks to apply more sustainable and environmentally friendly approaches to minimize air pollution by automobiles and reduce emissions of greenhouse gases. A recent study predicted that the share of RES in 2100 would increase significantly between 30 % and 80% (Panwar et al. 2011). There are several opportunities provided by RES which include energy access, energy security, social and economic development, climate change reduction, and mitigation of environmental and health impacts (Dincer 2000).

Renewable energy applications in various systems have gained prominence due to their environmental benefits and potential for sustainable power generation. Currently, renewable sources are widely applied include building construction, agriculture and farming, industrial processes. Numerous studies highlight the significance of incorporating renewable energy sources into the development and design phases of green buildings (Zuo et al. 2012) (Ye et al. 2013) (Privitera et al. 2011). A study showed that over the past decades, there has been significant worldwide progress in the integration of renewable energy into building systems. The adoption of renewable energy sources within buildings contributes to decrease in the use of traditional energy and facilitates the transition to a more environmentally friendly, low-carbon economy. (Yuan et al. 2013). The US Energy Information Administration forecasted that from 2008 through 2035, the residential and commercial sectors' respective annual increases in energy consumption will be 1.1% and 1.5% (Gruenspecht 2011).

Moving to the agricultural sector, a comprehensive review paper highlighted the potential integration of renewable energy technologies into agricultural practices for power generation. It explained the diverse applications of renewable energy sources (RES) across multiple agricultural sectors. Examples included the use of renewable energy to power water pumps for irrigation, thereby extending the preservation of agricultural produce. Furthermore, renewable energy sources such as solar, wind, and geothermal energy were explored for their applicability in irrigation, greenhouse management, monitoring and control systems, as well as water pumping systems within the agricultural framework (Majeed et al. 2023).

On other hand, The United Nations has reported that renewable energy accounts for one-third of global energy consumption in the industrial sector. This energy is primarily used in energy-intensive industries such as metals, chemicals, petrochemicals, minerals, and pulp and paper. The high energy costs in these sectors make it challenging to improve energy efficiency, limiting potential carbon dioxide (CO_2) reductions to 15%-30%. With industrial production expected to quadruple by 2050, it is crucial for renewable energy to play a significant role in reducing greenhouse gas emissions. While renewable energy has gained attention in power generation and residential sectors, its use in industry remains limited, with biomass being the primary contributor. The analysis suggests that by 2050, renewable energy could make up 21% of energy use in manufacturing. This includes 37 exajoules from biomass and 10 exajoules from solar thermal and heat pumps. Solar thermal energy is expected to contribute 5.6 exajoules to industry, mainly in the food sector, while heat pumps are estimated to provide 4.9 exajoules, also primarily in the food sector (Solar Thermal World 2023).

A research paper conducted a study to assesses Denmark's potential to transition to a 100% renewable energy system, focusing on crucial technological changes and implementation strategies. The study utilizes the Energy PLAN model, a computer-based energy system modeling tool used for planning and evaluating various aspects of energy systems. The study addresses the challenges posed by intermittent renewable energy sources and outlines three key technological shifts: replacing oil-based transportation with electricity-based alternatives, integrating small, combined heat and power production plants and heat pumps, and utilizing electrolyzers alongside wind turbines for grid regulation. The analysis demonstrates that by implementing these three key technological changes, Denmark can indeed transition to a 100% renewable energy system. This transformation would require combining 180 TJ/yr. of biomass with 5000 MW of photovoltaics and between 15 and 27 GW of wind power. However, when considering energy savings and efficiency improvements, the required wind power capacity is reduced to approximately 15 GW. Achieving this goal would involve installing 500 MW/yr., a level that Danish manufacturers are currently capable of producing, resulting in an annual output of around 3000 MW of wind power (Lund 2007).

The researchers pointed out the adoption of renewable energy faces significant challenges in the form of policy, regulation, technology, societal attitudes, and financial constraints. Despite their growing popularity globally, renewable energy sources struggle against substantial subsidies provided by governments to fossil fuels and nuclear

power, which undermine their competitiveness. Government intervention is necessary to address market failures and create favorable conditions for renewable energy. Many countries need to develop human and institutional capabilities, research infrastructure, and investment opportunities to support the growth of renewable energy. The absence of supportive policies is a significant barrier, even in regions with abundant renewable resources. Overcoming these challenges requires systematic research to understand the barriers in different nations, which can vary based on national circumstances, global dynamics, and resource allocation. Developing nations face added complexity as they strive to expand energy access while pursuing economic, social, and environmental objectives (Kochtcheeva 2016).
A study reviewed the challenges in the Gulf Cooperation Council (GCC) region. Deploying renewable energy technologies in this region is challenging due to the ongoing need for financial support in manufacturing and intellectual property development. The innovation value chain, from research to commercial deployment, plays a crucial role, with the transition from government to private funding being particularly difficult. Achieving cost parity with conventional energy is essential for enhancing the economic competitiveness of renewable energy, especially when considering the frequently underestimated hidden costs of fossil fuels. Understanding private investor preferences, particularly regarding cost parity, is crucial for the successful adoption of renewable energy (Jamil et al. 2016).

The world increasingly recognizes the imperative of transitioning to renewable energy sources. In the ongoing pursuit of decarbonizing the energy sector, renewable sources have paved the way for a groundbreaking evolution, setting the stage for the rise of hydrogen. Creating a synergy between renewable sources like green hydrogen holds the key to a low-carbon future. Hydrogen is a clean energy source only emitting water vapor as a by-product. It serves as a great medium for storage and offers a decreased dependence on fossil fuels.

2.3. Green hydrogen

Hydrogen constitutes a sustainable and persistent energy source, strategically positioned to play a key role in the future of global energy. The demand for hydrogen is forecast to increase globally from 70 million tonnes in 2019 to 120 million tonnes in 2024. Hydrogen has important applications in various industries, including energy generation, transportation, hydrocarbon and ammonia synthesis, and metallurgy (Osman et al. 2022). A recent study highlighted the importance of hydrogen-based energy sources in achieving sustainability and long-lasting positive enhancements in the energy sector. It emphasizes the need for a long-term and sustainable supply of hydrogen-based energy that is cost-effective and environmentally friendly. Traditional energy systems, reliant on fossil fuels, are characterized by high capital investments, long implementation lead times, and uncertain future fuel costs, making them expensive and environmentally harmful. In contrast, green hydrogen generated using renewable energy sources, offer economic and environmentally friendly alternatives (Alzoubi 2021). The key benefits are the overall cleanliness and zero emissions of greenhouse gases (Germscheidt et al. 2021). As a results, it will enhance the air quality and promote a healthy atmosphere since green hydrogen is free from any contribution to air pollution or any role as a catalyst for climate change (Hassan et al. 2024). In addition, hydrogen possesses characteristics such as flexibility, adaptability, and low operating costs that make environmentally friendly hydrogen-based energy systems appealing. They can provide a stable and productive supply of energy for an extended period, promoting sustainability. Additionally, their small equipment size allows for quick implementation, making them responsive to changing energy consumption patterns. The article underscores the global need for sustainable energy development to achieve worldwide economic growth and sustainability. It stresses that the extensive deployment of hydrogen-based energy systems, particularly those based on renewable sources, is crucial for both emerging and established countries. Furthermore, hydrogen is predicted to be a key contributor to environmental sustainability, as it is ecologically friendly, generates no harmful exhaust, and can be easily distributed through pipelines. It has various applications in industries such as petrochemicals, food, microelectronics, and metallurgy, making it a versatile and sustainable energy carrier (Alzoubi 2021).

Hydrogen production methods encompass various techniques for extracting this valuable gas from natural resources, including water, fossil hydrocarbons, biomass, and hydrogen sulfide. The methods can be categorized based on the types of energy used: thermal, electrical, photonic, and biochemical. Green energy sources, such as renewables (solar, wind, etc.), nuclear, and recovered energy (industrial heat, landfill gas, etc.), can supply the necessary energy for hydrogen production. Water electrolysis stands as one of the fundamental methods for producing pure green hydrogen. It relies on the movement of electrons through an external circuit and operates under constant pressure and temperature conditions. Alkaline and Proton Exchange Membrane (PEM) electrolysis are two primary technologies used. Platinum or alternative catalysts are employed to enhance the reaction rate and current density. Water electrolysis approach is distinguished by the easy separation of hydrogen (H2) and oxygen (O2) (Younas et al. 2022). However, it is considered less attractive due to the high costs associated with hydrogen generation compared to conventional hydrogen production. Additional issues need to be taken into consideration regarding the intermittent nature of energy sources, rates of water consumption, and their efficiency (Nasser et al. 2022).

Another method involves plasma arc decomposition also known as plasma reforming, which uses thermal plasma to dissociate methane into hydrogen and carbon (Alzoubi 2021). This process is highly efficient and results in a 100% hydrogen yield with no CO2 emissions. The technique has several advantages, including superior energy efficiency, low operating costs, the ability to handle a wide range of volatile organic compounds, and flexibility in dealing with different contaminants. However, there are specific drawbacks linked to it, including heightened energy consumption, erratic plasma discharge, and a moderate equipment expense (Budhraja et al. 2023).

Another approach water thermolysis involves dissociating water into hydrogen and oxygen using high-temperature heat sources above 2500 K. Challenges include the separation of hydrogen and oxygen; however, high-temperature materials and rapid cooling methods help overcome these obstacles. Thermo-catalytic cracking of hydrogen sulfide from sources like the Black Sea can extract hydrogen and sulfur. In this process, catalytic separation membranes and metal-based reactions play a significant role. Moreover, biomass thermo-catalytic conversion converts biomass into hydrogen, with wood sawdust and sugar cane bagasse being viable sources. Thermochemical water splitting cycles, such as the SeI cycle, operate efficiently without catalysis. Furthermore, hybrid cycles combine thermal and electrical energy sources. In addition to these methods, high-temperature electrolysis, photo-electrolysis, bio-photolysis, dark fermentation, and artificial photosynthesis offer diverse routes to green hydrogen production. Therefore, renewable energy sources are essential to make hydrogen production environmentally friendly, potentially enabling a hydrogen-based economy to address climate challenges (Dincer 2012). Despite this, the approach encounters limitations including the demand for an efficient solar collector, the necessity for materials that can withstand acid and heat, and the requirement for an efficient and robust reactor design (Song et al. 2022).

A study examined the economic feasibility of large-scale PEM electrolyzers powered by wind or solar energy in 17 Polish regions. Using a Monte Carlo approach, it calculated the Levelized Cost of Hydrogen (LCOH) for 1-MW, 6-MW, and 20-MW electrolysis systems in 2020, 2030, and 2050. In 2020, LCOH ranged from €12.64 to €13.48 per kg (solar) and €6.37 to €9.70 per kg (wind). By 2030, 6-MW systems could drop to €4.12-€4.30 (solar) and €2.33-€3.06 (wind). In 2050, 20-MW systems could reach €1.95-€2.03 (solar) and €1.23-€1.50 (wind) due to technological advancements. The study suggests green hydrogen's competitiveness with gray and blue hydrogen by 2030 and 2050 in Poland. Uncertainty varies between solar and wind-based hydrogen, calling for support policies in some regions, and cost drivers shift over time, emphasizing electricity prices and utilization rates (Benalcazar and Komorowska 2022).

The paper reviewed NASA's research program initiated from 1999 to 2004, with the aim of developing hydrogen-powered aircraft for a greener, emission-free aviation system. This ambitious project faced challenges related to accommodating hydrogen tanks within the aircraft's fuselage, affecting its size and weight. While fuselage-mounted tanks offered safety advantages, they increased wing weight, impacting overall efficiency. Hydrogen-powered aircraft exhibited lower operating costs but required larger fuel tanks, necessitating placement inside the main body due to size constraints. Different tank configurations affected energy efficiency, making hydrogen more suitable for long-range aircraft. Engine and aircraft modifications for hydrogen resulted in a 25% increase in production and maintenance costs.

In addition, the author highlighted the significant opportunities presented by the use of hydrogen fuel in drone technology. Most drones currently rely on electric engines, necessitating efficient energy sources. Two methods for energy storage are employed: batteries and fuel cells (FC), with hydrogen as a potential fuel. Challenges include accommodating the bulky hydrogen cylinder, ensuring adequate airflow for FC cooling, and managing weight limitations. Hydrogen's high gravimetric energy density makes it an attractive option for aviation. However, its volumetric energy density is lower, requiring larger cryogenic storage systems. The focus is on proton exchange membrane fuel cells (PEMFCs) and various hydrogen production sources. Fuel cells hold promise in various applications, including space missions and aviation, offering high energy density and emissions reduction (Yusaf et al. 2023).

A recent study aimed to establish an upper limit on the potential hydrogen yield and estimate its application in the transportation sector, encompassing passenger ferries and automobiles. The investigation of hydrogen production potential considered factors such as waste composition, moisture content, heat loss, and carbon conversion efficiency.

Different scenarios were examined to calculate the annual hydrogen supply achievable through gasification alone and in combination with the water-gas-shift reaction. In the most favorable scenario, it was determined that up to 2700 metric tons of hydrogen per year could be generated. This quantity, if exclusively allocated to maritime operations, would be sufficient to power nine ferries and provide hydrogen fuel for ten high-speed passenger boat connections in the Hordaland region of Western Norway (Renkel and Lümmen 2018).

A research paper conducted a study to investigate the impact of hydrogen energy utilization on global stability and sustainable development. It assessed this impact through various parameters, including technological, sectoral, and practical application ratios. The findings have shown that green energy sources played a crucial role in sustainable hydrogen production, with sustainability ratios increasing as hydrogen energy utilization increased. The study suggested that to achieve the highest hydrogen-based sustainability ratio, a hydrogen energy impact ratio of 73.333% to 100% should be pursued. It emphasized the need for hydrogen energy strategies, policies, and programs to reduce the harmful effects of fossil fuel consumption and promote a green energy-based hydrogen system. Furthermore, the research highlighted the importance of balancing energy demand with green energy-based hydrogen production to enhance sustainable development. It called for increased investments in green energy-based hydrogen systems, particularly in developed countries (Midilli and Dincer 2007).

Through the literature review the significance of transitioning to hydrogen-based economies and technologies was highlighted while supporting for international collaboration and incentives among countries, scientists, researchers, and societies to promote sustainability and reduce the negative environmental impacts of fossil fuel consumption. Based on the collected information and the methods detailed in the next sections, Microsoft Power BI was used to present the available data to allow for an increase in awareness amongst the different stakeholders.

3. Methods

The main tool used in this paper is Microsoft Power BI, a software by Microsoft, is platform used for analytics and data visualization. The software was used to present the data collected by authors regarding the worldwide emissions, factors of hydrogen production, renewable energy and the current project with forecast in the upcoming years.

Power BI allows users to learn information through an interactive dashboard. It can be used for reporting and analyzing the data set to make informed decisions for any area. It can be used to present data in charts, maps and other interactive tools. For this research, the Power BI software will be used to create an interactive dashboard which can be used to raise awareness among users. The data will be analyzed to make recommendation regarding the future of renewable resources and green hydrogen. It will be used to present the past, present and predicted data. Power BI dashboard can also be used to customize the appearance of the visuals to adapt to the audience that it will be shared with.

The amount of data shown on the dashboard can be altered based on slicers, filters and drill applied on the data set. The data was presented with tools in Power BI such as charts, graphs and map visualizations with elements of navigation on the dashboard allowing for a more interactive experience for users. Conditional formatting was also utilized to present certain aspects of the data with a click of a button. Drill up and drill down methods can be used by the users to explore the different levels of detailed information allowing for an enhanced depth of understanding.

The data presented can be easily updated to keep up with the new information discovered as time passes. The software can be set to configure or carry out schedules data refresh based on the updated data sources. The report can be optimized by reducing the data model size and by using a summarized set of data rather than the whole lot. The interactive dashboard can be published and used in presentations or websites to help create awareness to the necessary audience. It can be evolved based on the input or feedback of users and can be tailored to the application where it is to be used.

4. Data Collection

To achieve the objectives of this paper, research was conducted to collect data from different official sources. Data regarding the emissions, hydrogen and renewable resources was collected in excel files from different databases. Data were gathered from organizational databases, specifically the data related to hydrogen production projects and emissions was obtained from the International Energy Agency. In addition, data on alternative fueling was collected from the U.S. Department of Energy, and data about green hydrogen plants was obtained from the Statista database. Since it was a large set of data, it was filtered and cleaned to extract the useful information necessary for the data visualization. The cleaning of the data included removing duplicates, carrying out additional calculations and group similar data for the modeling. Another method used was to create relationships or links between the data set so the presented data is cohesive. This process can be summarized with the three steps: collection, process and communication. Process step can be further divided into stages as shown in the diagram in Figure 3.

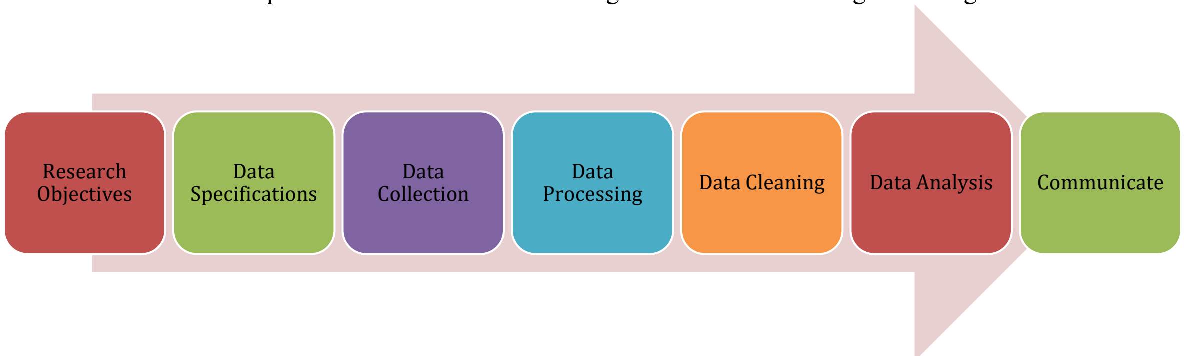

Figure 3. Data collection and analysis process

5. Results and Discussion

Using the Power BI software and the data collected from the different official databases from organizations, an interactive dashboard was created to communicate information about renewable resources and green hydrogen (Figure 4).

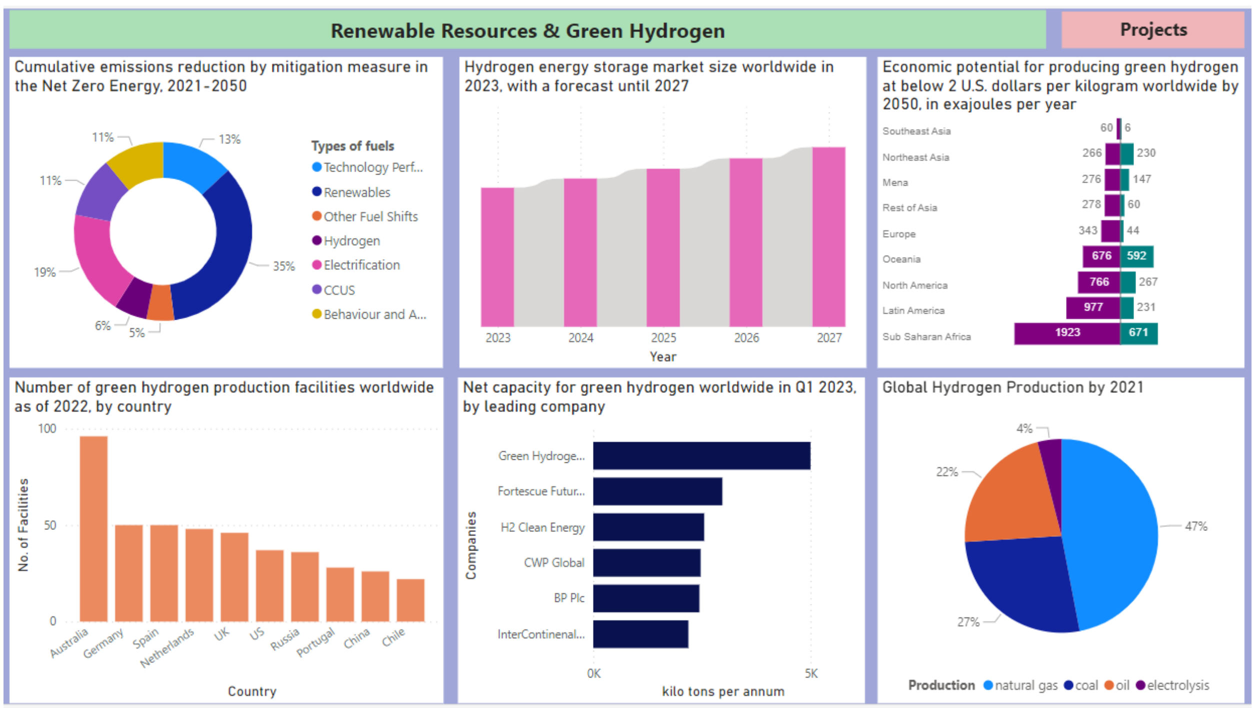

Figure 4. Main dashboard presenting the data collected on hydrogen

Renewable resources are a great source of energy which can help reduce emissions. Due to global warming, there is a focus on trying to find measures to mitigate the emissions from around the world. The idea is to make several industries like buildings net zero. As presented in the dashboard, it is forecasted that renewable fuels have the highest percentage with 35 % in reducing emission between the years 2021 – 2050. Following that is electrification, which covers industries that dominantly rely on fossil fuels for energy to find ways to use electricity. An example of this is switching the transportation industry from gasoline to electric vehicles. In an ideal scenario, the electricity used to charge the electric vehicles would be from renewable sources to further reduce the indirect emissions. The third highest mitigation measure found was through technology performance. It covers improvement of the technology used or introduction of new technologies which is more efficient and produces let harmful by products. Although hydrogen is only 6 %, many factors to that is the current methods used to produce hydrogen.

As per the chart on the left bottom of the dashboard, in 2021, hydrogen was produced majorly using natural gas (47 %) followed by coal (27 %) and then oil at (22 %). This highlights that although hydrogen itself is a very energy rich source, currently about 96 % is produced using non-renewable sources. This means that the hydrogen is not green. It is a major factor in why organizations are reluctant to dive into hydrogen fuel. Using electrolysis to produce hydrogen includes splitting water (H_2O) into hydrogen (H_2) and oxygen (O_2). It is referred to as green hydrogen when electrolysis is carried out using renewable energy sources like wind or solar power. This makes it a sustainable energy carrier with zero pollutants making it carbon neutral.

However, there are many countries who have taken initiative with hydrogen production and processing. As per the Figure 4 on the bottom right of the dashboard, in 2022, the country with the highest green hydrogen production facilities is Australia with 96, followed by Germany and Spain who have 50 each and then by Netherlands who has 48. Looking at specific companies, Green Hydrogen International is the leading company in 2023 with the highest net capacity for green hydrogen with approximately 5000 kilotons per year. Other leading companies are Fortescue Future Industries, H2 Clean Energy and CWP Global. This indicates the interest in developing and researching the possibility of have green hydrogen as a larger part of the world's energy contributor. The data on the dashboard also presents the forecast of worldwide hydrogen energy storage market size from the year 2023 to 2027. There is a gradual increase which will come about as we discover more about hydrogen as a source of energy and find ways to safely adopt them in the different industries. An advantage of hydrogen is that it can store the energy from the renewable sources so it can be used in time of high demand or when the output from the renewable sources is insufficient. However, some of the challenges is the upscaling of production and the cost of production.

Currently the economic side of producing green hydrogen is very high. This means that it is not feasible and not the most viable option for many to use hydrogen over other energy sources. However, with time as more research is done on this topic, scientists are bound to find ways in which the production of hydrogen is more economically feasible. The graph on the top right of the dashboard presents two scenarios (optimistic and pessimistic) for the economic potential of producing green hydrogen in exajoules per year at below $ 2 per kilogram by 2050. The data is presented for the different regions in the world. Based on the graph, the Sub-Saharan African region has the highest potential to produce economically feasible green hydrogen in both scenarios.

The interactive dashboard in Power BI has a button which when selected by a user allows them to move to another page which contain more detailed data about renewable energies and hydrogen projects. Figure 5 presents the world map on the Power BI dashboard with bubbles whose size reflect the number of projects in those specific countries.

The hydrogen projects in Germany illustrate a diverse distribution across various sectors as shown in Figure 6, with a total of 121 projects identified. These initiatives can be categorized into different domains based on their intended applications. High-power projects, numbering 27, primarily focus on generating electricity and energy production. High-mobility projects, with 21 in total, are centered on transportation and fuel cell technology. High-industry and high-chemicals projects, comprising 10 and 6 initiatives, respectively, target industrial and chemical applications. In the context of energy distribution, high-grids encompass 20 projects, while medium-grids account for 18 projects. Furthermore, high combined heat and power (CHP) initiatives amount to 13, contributing to efficient energy utilization. Low mobility projects are relatively scarce, with only 2 efforts identified. The collective presence of these projects highlights Germany's multifaceted approach to harnessing hydrogen's potential across sectors, reflecting the nation's commitment to sustainable and versatile energy solutions.

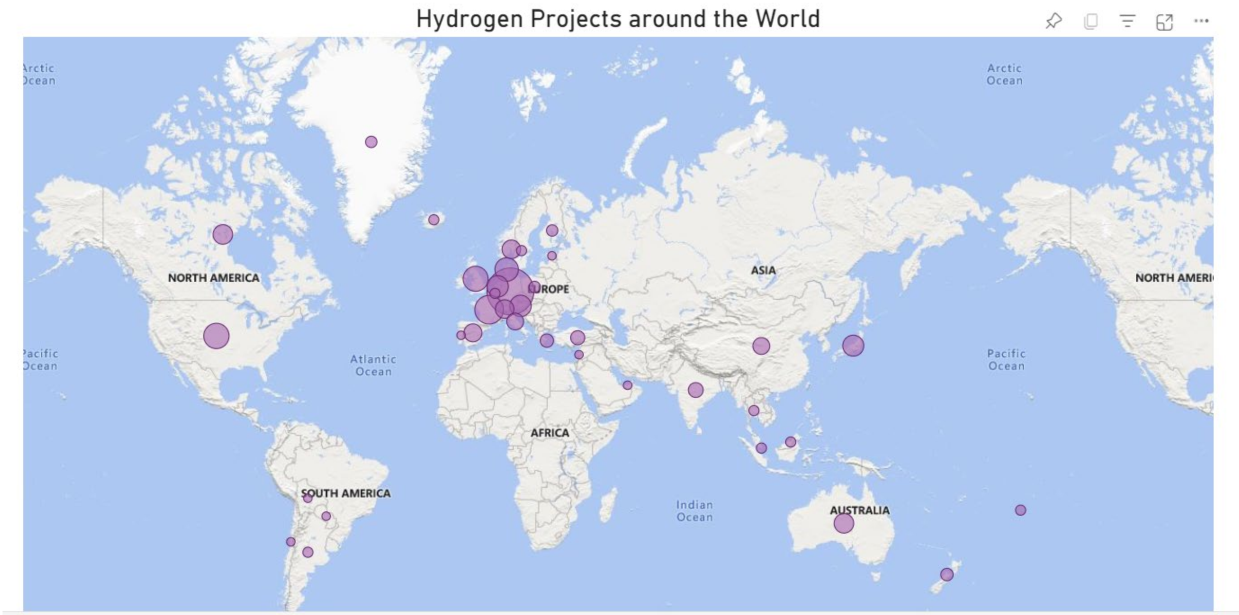

Figure 5. Number of hydrogen projects around the world

From the map, it can be deduced that the majority of the hydrogen projects are located in Europe, while the others are scarcely located on different continents. Selecting a bubble will give users the information regarding the end user sector which the hydrogen plant is used for majorly as shown by the example of Germany in Figure 6.

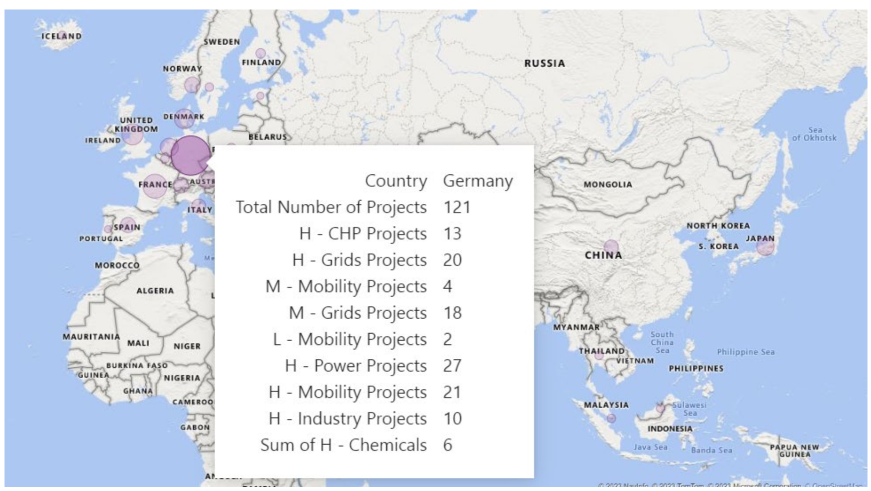

Figure 6. Number of hydrogen projects with the end user sector specified for the example of Germany

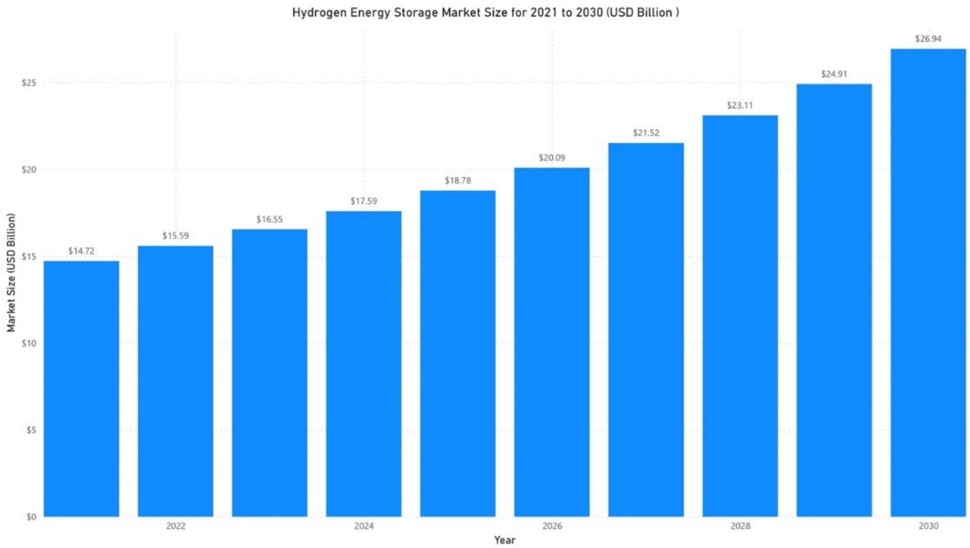

Figure 7. Hydrogen energy storage market size for 2021 to 2030 (USD Billion)

Moving on to explore the trajectory of the hydrogen energy storage industry globally from 2021 to 2030 reveals significant changes occurring in the energy sector. As shown in Figure 7, in 2021 the market size was at the value of $14.72 billion, the market grows steadily until it reaches a notable $26.94 billion in 2030. This represents a compound annual growth rate (CAGR) of approximately 8.6%. The indicated growth reflects the growing dependence on hydrogen as a critical element towards achieving environmentally friendly energy sources. Several factors contribute to this development as a result of the rising demand for efficient and flexible energy storage technology for integrating renewable sources into the power grid. Major contributions from international public and private sectors are driving research and implementation efforts, establishing hydrogen energy storage as an essential component in attaining carbon reduction goal and developing sustainable energy solutions.

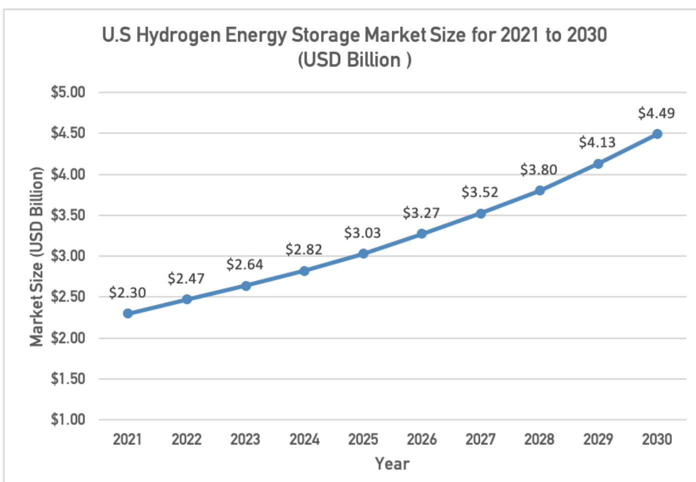

Figure 8. U.S hydrogen energy storage market size for 2021 to 2030 (USD Billion)

Moving on to further investigate the market size and focus on the U.S. hydrogen energy storage market from 2021 to 2030. The market size is projected to grow from $2.30 billion in 2021 to an anticipated $4.49 billion in 2030. The market is projected to expand from $2.30 billion in 2021 to $4.49 billion in 2030 as shown in Figure 8. The growth pattern of the U.S. market demonstrates a dynamic environment fueled by strong policy frameworks, significant investments, and a national commitment to mitigating carbon emissions. This is achieved through the government initiatives including tax credits and research grants, which have motivated private sector participation in the development of hydrogen infrastructure and technology. As a result, the United States has been motivated into a prominent position of leadership in the field of hydrogen energy storage. Given the nation's ongoing focus on clean energy solutions to address environmental concerns and ensure energy security, the hydrogen energy storage sector has become a promising option for investors seeking sustainable opportunities.

However, as mentioned previously, many challenges and obstacles prevent the adoption of hydrogen in many sectors. A major item is the high cost required not just for the research into the technological innovations surrounding green hydrogen but also to scale up production. Another area of concern is the integration of renewable energy sources with power grid to allow for a consistent and reliable source of energy supply. Energy will have to be stored especially with excess energy coming from the renewable sources which can be utilized during low peak production. This would require a major change in the infrastructure. Entities will need to invest in pipelines and storage facilities, to transport and store green hydrogen. For future, there is a possibility of international collaboration where green hydrogen can be traded and transported via global hydrogen infrastructure. All of the above developments will need to be backed by incentives, subsidies, and possibly tax break to encourage the adoption of greener and cleaner energy. Regulatory frameworks will need to be set up to allow for clear guidelines for the different companies. Lack of awareness between the public is another challenge so therefore tools like Power BI can be used to educate people on the benefits and potential of green hydrogen.

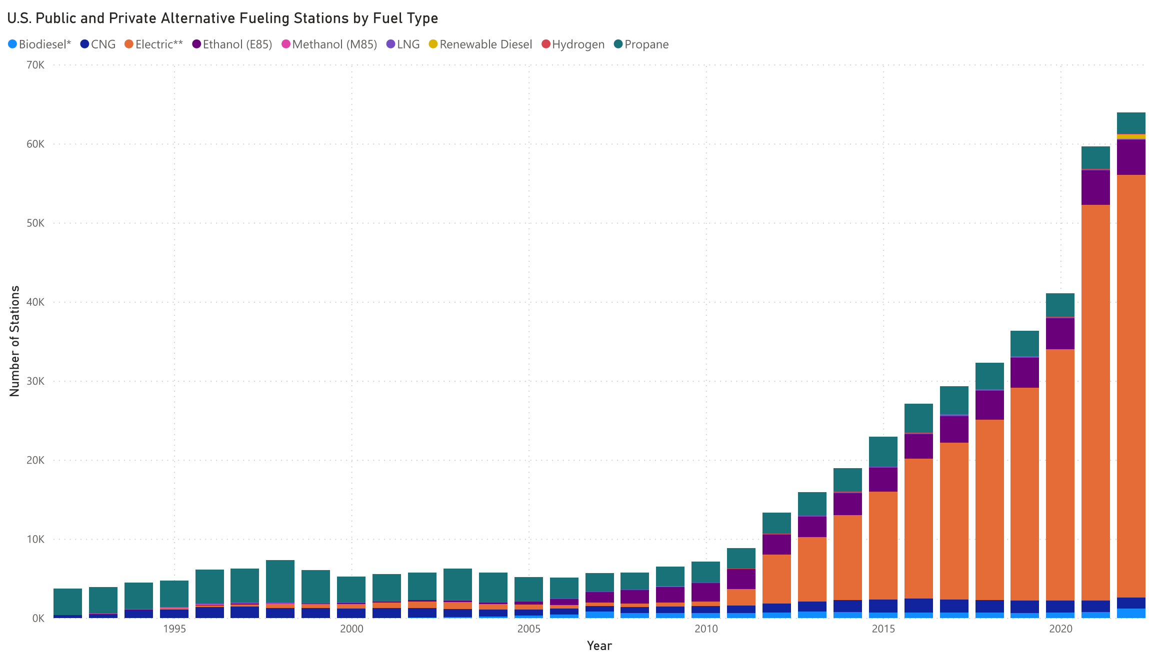

Figure 9. U.S. Public and Private Alternative Fueling Stations by Fuel Type

Figure 9 demonstrates a comprehensive overview of the number of alternatives fueling stations in the United States by fuel type from 1992 to 2022. The data for fuel types include biodiesel, compressed natural gas (CNG), electric, ethanol (E85), hydrogen, liquefied natural gas (LNG), methanol (M85), propane, and renewable diesel fueling stations. The overall trend in the number of alternatives fueling stations in the United States has shown steady growth. In 1992, there were only 3,691 alternative fueling stations in the country. By 2022, this number had grown to 63,966, representing an increase of over 1,600%. This analysis of alternative fuels indicates significant growth and transformation in the alternative fueling infrastructure. Notably, the expansion of biodiesel, CNG, and electric stations has been significant, but the hydrogen infrastructure has experienced the most substantial growth. The most significant growth in alternative fueling stations has been in the electric vehicle (EV) charging sector. In 2011, there were only 2,100 EV charging stations in the United States. By 2022, this number had grown to 53,492. This represents an increase of over 2,500%. Further investigation may indicate that the trends observed in hydrogen infrastructure offer valuable insights into the nation's efforts to adopt cleaner energy sources and reduce greenhouse gas emissions. Over the past three decades, hydrogen infrastructure growth in the United States has been remarkable. In the beginning of 1992, there were no hydrogen refueling stations in the country. However, by 2002, only two stations had been established. Fast forward to 2022, and the number had risen significantly to an impressive 72 stations. This substantial growth can be attributed to the growing recognition of hydrogen's potential as a clean energy source and the efforts to develop a robust hydrogen refueling network. However, the majority of hydrogen fuel stations currently generate electricity from non-renewable sources, as the current production process relies on fossil fuels. As a result, the hydrogen generation is environmentally unsustainable, leading to the release of greenhouse gases and limiting the clean fuel benefits of hydrogen. To address these environmental issues, there is a pressing need for an increase in green hydrogen production. Nevertheless, a key challenge lies in minimizing the expenses associated with building and operating alternative fuel stations. Despite developments in hydrogen infrastructure, economic barriers persist, hindering the establishment and operation of a comprehensive refueling station network. Overcoming these economic barriers is crucial to making hydrogen a realistic and sustainable energy solution.

The data indicates a positive trend in the adoption of AFVs in the United States. Hydrogen-powered vehicles have shown steady growth, highlighting their potential as a viable clean energy option. While electric vehicles have gained substantial traction, other alternative fuels also play significant roles in reducing emissions and promoting sustainability. As the nation continues to address environmental concerns and energy security, the adoption of AFVs is likely to remain a crucial part of the solution. Nevertheless, hydrogen has shown promising growth, particularly in recent years, suggesting its potential as a clean energy solution. Clean Cities coalitions continue to be instrumental in fostering the adoption of alternative fuels and vehicles across the nation, emphasizing the need for ongoing collaborative efforts to promote sustainable transportation.

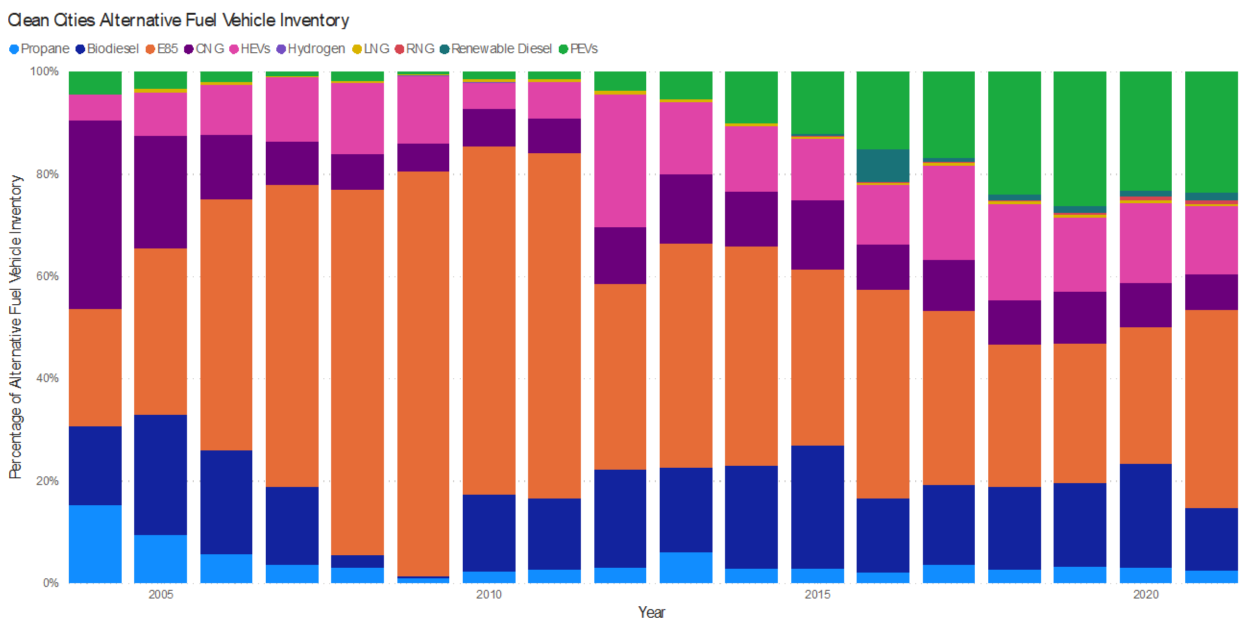

Figure 10. The Clean Cities Alternative Fuel Vehicle Inventory

The clean alternative fuel vehicle inventory shows in Figure 10 provides data on the percentage of alternative fuel vehicles (AFVs) in operation in the United States. The inventory is compiled by the U.S. Department of Energy's Clean Cities program, which is a voluntary public-private partnership that works to reduce petroleum consumption and improve air quality. The most common type of AFV in operation is the plug-in electric vehicle (PEV), which includes both electric vehicles and plug-in hybrid electric vehicles. In 2021, PEVs accounted for over 20% of all AFVs in operation. Other types of AFVs include hybrid electric vehicles (HEVs), compressed natural gas (CNG) vehicles, and biodiesel vehicles. Additional exploration may uncover that hydrogen adoption showed a notable increase over the study period. In 2004, hydrogen vehicles constituted a mere 0.01% of the total inventory, while PEVs accounted for 4.46%. By 2021, hydrogen's presence grew to 0.07% of the inventory, while PEVs surged to a significant 23.48%. When comparing hydrogen to PEVs, it is clear that PEVs maintained a substantially larger share of the alternative fuel vehicle market throughout the study period. However, hydrogen's growth should not be understated, especially in recent years.

The growth in the number of AFVs in operation is due to a number of factors, including the rising cost of gasoline, the increasing availability of AFVs, and government incentives for the purchase of AFVs. AFVs offer a number of benefits over gasoline-powered vehicles. AFVs are more fuel-efficient, which can save consumers money on fuel costs. AFVs also produce fewer emissions than gasoline-powered vehicles, which can improve air quality and reduce greenhouse gas emissions. However, there are also some challenges associated with the adoption of AFVs. One challenge is that the cost of AFVs is often higher than the cost of gasoline-powered vehicles. Another challenge is the limited availability of public charging infrastructure for AFVs.

6. Conclusion & Recommendations

To conclude, the issue of global warming and climate change have become increasingly relevant with the impact now more visible to the human population. Several international organizations have pushed for investment in renewable energy like green hydrogen. This papers looked into the benefits of green hydrogen which range from being carbon neutral to being a great source of energy storage. Data was collected from organizational databases and filtered. It was communicated through the Microsoft Power BI software which is a data visualization software. It was used create an interactive dashboard which presented information on emissions reduction, production of hydrogen, economical potential of green hydrogen and forecasted data relevant to use of green hydrogen. From the data it was summarized that hydrogen is a great source which can help make industries like transportation reduce emissions. However, at the current time the challenges include producing hydrogen at a large scale and at an economically feasible price. 96 % of world's hydrogen in 2021 was produced using non-renewable resources. However, with a push on sustainability around the world, many researchers have started to look into ways in which hydrogen can be produced, stored and utilized for different industries using renewable energies only. The forecasted date reflected that the hydrogen storage market size is bound to continue increasing with the technological advancements and new information gathered about hydrogen. The dashboard was also used to present data on countries which have the highest number of hydrogen facilities and companies which are leaders of hydrogen producers currently.

Further research was carried out on specific countries like the US where the growth in the number of alternative fueling stations in the United States is a positive development. In addition, the data shows that the number of AFVs in operation is growing steadily. It is a sign that the country is moving towards a more sustainable transportation system. However, there is still more work to be done. One of the biggest challenges facing the alternative fueling industry is the high cost of building and maintaining alternative fueling stations. This is especially true for EV charging stations, which can be very expensive to install. The article discussed many challenges surrounding adoption of green hydrogen such as but not limited to cost, grid integration, technological advancements, developing infrastructure and lack of market development. Another challenge facing renewable energies and green hydrogen is the lack of public awareness. Many people are not aware of the benefits or the potential of green hydrogen as an energy source. The government can play a role in addressing these challenges by providing subsidies and other financial incentives for the construction and maintenance of alternative fueling stations and funding projects for hydrogen. The government can also raise public awareness of alternative fuel vehicles and green hydrogen through education and outreach campaigns. While challenges remain, the data suggests a promising future for hydrogen as a key component of the global energy landscape. Continued investments and policy support are crucial for ensuring the long-term sustainability and growth of hydrogen infrastructure.

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