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Hydrogen Fueling Stations Road Map for Gulf Cooperation Council Countries

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Abstract
Recent technological advancements have brought hydrogen fuel to the forefront of discussions. This paper explores the technological advancements that have led to the development of cleaner and more renewable hydrogen energy, focusing on reducing carbon emissions. The importance of Hydrogen Fuelling Stations (HFS) in supporting the adoption of Electircal Fuel Cell Vehicles (EFCV), contributing to economic growth, and enhancing energy security is highlighted. The global hydrogen roadmap is explored, specifically focusing on the USA, Europe, and Asia (Japan, Korea, China). The benefits of building hydrogen stations, such as reducing carbon emissions, advancing research and development, and creating public awareness, are discussed. The locations of hydrogen stations in the Gulf Cooperation Council Countries (GCCC) (Iraq, Kuwiat, Saudia Aribia Kindom, Bahran Kingdom, Qatar UAE, and Oman), including Phase 1 and future plans, are also presented. Finally, the paper highlights the importance of continued research and development in the hydrogen energy sector to address global environmental challenges.

Key Words: Hydrogen, renewable energy, carbon emissions, technology, sustainability.

1. Introduction

Advancements in technology have seen advancements in hydrogen energy due to the need for cleaner and more renewable energy. This has been evidenced by the aims of the HyWays project covering countries such as Finland, France, and Germany in Europe in utilizing fuel for transportation. Researchers and other professionals have been focused on creating sustainable fuel with a primary focus on reducing carbon emissions. According to Bairrão et al. (2023), there are many sources from which hydrogen can be produced, including wind and solar power. The energy can, therefore, be utilized in applications such as powering automobiles. Besides, there has been advanced storage for hydrogen fuel, such as solid-state hydrogen storage, that has aided the embracement of hydrogen fuel (Jehan & Fruchart, 2013). Today's growing hydrogen infrastructure, including hydrogen fueling stations, has also supported the advancement and acceptance of hydrogen energy, especially in GCCC. Advancements in technology have led to the development of cleaner, renewable hydrogen energy with improved production, storage, and infrastructure in the GCCC to reduce carbon emissions.

a. Importance of a Hydrogen Station

The adoption of hydrogen stations has had significant advantages, including fuel cell vehicles that provide a safer and cleaner environment. Some people are shifting to fuel-cell vehicles for reasons such as affordability and sustainability (Qudrat-Ullah, 2022). Furthermore, hydrogen stations contribute to the growth of the economy, as it supports built infrastructure such as road networks (Alazemi & Andrews, 2015). For instance, countries such as Korea have good transport infrastructure due to the increasing demand for hydrogen cell vehicles and the creation of backup power systems (Stangarone, 2020). Besides, hydrogen stations are important because they support energy security at the expense of overreliance on fossil fuels.

b. Hydrogen Roadmap Along the World

The development of the hydrogen industry has been evidenced across many parts of the world, with the increasing need to curb carbon emissions, reduce global warming, and create a safe environment.

c. USA, Europe, Asia (Japan, Korea- China)

USA's Department of Energy (DOE) has recently focused on advancing fuel technology. The National Clean Hydrogen Strategy and Roadmap provides some key facts about hydrogen energy and the advantages of hydrogen fuel, such as having a cleaner environment (Lebrouhi et al., 2022). The focus of the US is on energy leadership and security as well as the creation of employment opportunities. In Europe, the REPowerEU has developed a plan to produce millions of tons of hydrogen fuel to support the automotive industry. The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) has also been working towards deploying hydrogen and fuel cells in the coming years (Lymperopoulos et al., 2019).

Asian countries have also embraced hydrogen cell technology, including Japan, Korea, China, and India. Japan's administrative government has acted toward creating a full-scale international hydrogen supply chain in the coming years (Song et al., 2021). Similarly, Korea and China have foreseen increased hydrogen fuel supply by the end of 2030 (Shin, 2022). India has also focused on developing hydrogen fuel in recent years. The India and Pakistan Green Hydrogen Economy Roadmap outlines the need for hydrogen energy in the country's energy mix (Gondal et al., 2018).

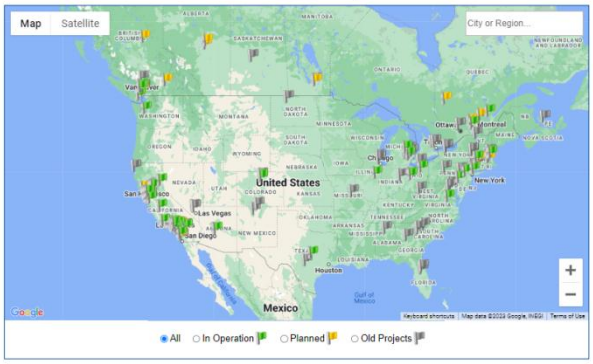
d. **Hydrogen Stations or Hydrogen Planes**

As fuel cell technology is continually being embraced, the development of refueling stations has been a hot issue. One of the first known hydrogen stations in the GCCC was opened in Dubai in 2017 (Graves, 2017). The Al Futtaim Motors station has recorded small operations, especially since the only call was the Mirai car from Toyota. The shift towards fuel cell vehicles could still take years. The US has lagged in the adoption of hydrogen fuel technology as compared to other countries in the GCCC (Trends, 2022). This is because research and development of hydrogen technology have been in progress over the past few years. The stratigy of the USA is to reduce using fossil fueles, use 10 million metric tonnes of clean hydrogen by 2030 and increase the amount every 10 years untill it reach 50 MMT anually by 2050 (Department of Energy). To achive this stratigy, therefor, there are around 50 open retail hydrogen fueling stations (

Figure 1), which serive 70 fuel cell buses, and more than 13,000 fuel cell vehicles (Department of Energy, 2022)

In Europe, the first phase of hydrogen energy strategy have been selected for 10 European countries. According to Stiller (2008), ‘’The purpose is to detect realistic starting points for hydrogen use and facilitate modelling of further deployment of hydrogen use and supply infrastructure’’.

Currently there are around 187 fuelling stations that can fill up the EFCVs within three minutes for ranges of 500-700 km (H2 MOBILITY, 2023).



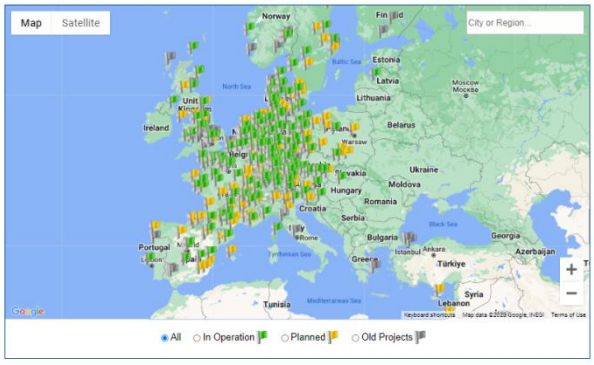


Figure 1: Hyrogen fuelling stationMap, in the USA at the A and Europ B (h2stations.org)

China has construced of over 250 hydrogen refueling stations, about 40 percent of the global total hydrogen fuelling stations, servicing buses and heavy-duty trucks (Xinhua, 2022). Currently over 6,000 vehicles on the road, accounting for 12 percent of the global total. More planes for eveloping producing hydrogen from renewable energy which expected to reach 100,000 tonnes to 200,000 tonnes annualy by 2025, in addition to continue exploring storage and transportation.

Japan Aims to built 1,000 Hydrogen Stations by 2030 (Hydrogen Central, 2021).

Currently their are about 160 hydrogen stations and expected to rise that number to 320 staions by 2025.

In Korea, first hydrogen fuel cells activities started in 2006-2009, with 30 passenger cars 4 buses and 10 stations (Yong Gun Shul, 2014). Currently, there are 100 hydrogen refuelling stations operating with a cost of around US $5.67and US $7.02/kg (includes 10% VAT), which is substantially cheaper than gasoline, diesel, or LPG on a cost/km basis (

Figure 2) (ntralink, 2022). In 2019 Korea announced that hydrogen Roadmap aims to have 5.9 million fuel cell cars and 60,000 fuel cell buses on the road by 2040 beside by 1,200 hydrogen refuelling stations. The announcement of Korea’s Green New Deal in July 2020 (ntralink, 2022).

Figure 2: Hyrogen fuelling stationMap in Asia

2. Benefits of Building Hydrogen Stations

There are many benefits associated with the building of hydrogen stations, which are more than the provision of the means for fueling fuel cell vehicles, including;

a. Reduce Carbon Emissions

Hydrogen fuel is a clean, renewable energy source that has the potential to lower greenhouse gas emissions and enhance air quality. The carbon footprint of hydrogen fuel may be further minimized by producing it using renewable energy sources like hydropower, solar energy, and wind energy. According to Mordor Intelligence (2021), the yearly average solar radiation within the region is relatively equal to 1.1 barrel of oil equivalent per m^2, around 8200 kWh/m^2 in Kuwait, which is the highest, and the lowest 6400 kWh/m^2 in Oman . So that is not wondering that in 2020 the solar pannls held a share of more than 93.57% of the total Middle Eastern solar energy installed which expected to play a vital role in future (Mordor Intelligence,(2021).

b. Keeping up with Modern Technology (Built Communications between Research Centers around the World)

From a research standpoint, the construction and operation of hydrogen gas stations may spur creativity and result in the discovery of new technologies and methods that can improve the efficiency and dependability of the hydrogen fueling approach. For instance, the development of solid-state hydrogen storage as an alternative to liquefied and compressed hydrogen has been in research. Researchers may also use data from hydrogen fuel stations to examine fuel cell vehicle performance and find patterns and innovative plans.

c. Aware Society About Hydrogen Energy Benefits and Hydrogen Facilities

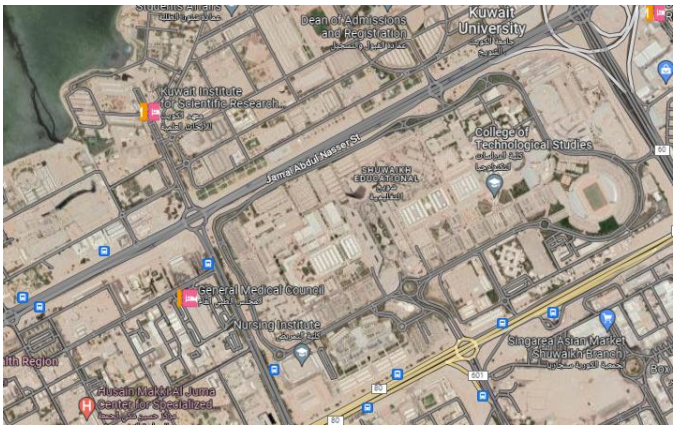
There are many applications of hydrogen energy and requirement, such as Fuel Cells Electrical Vehicles, hydrogen industries, power plants, heat in building, hence in this report only concentrate at FCEV. Because of the hydrogen energy FCEV is a new technology in GCCC, building hydrogen fueling stations is also important because it can create public awareness and enhance researchs and education regarding the benefits of hydrogen energy. As a result, people can embrace the new technology and be interested in shifting from traditional fuels such as fossil files. Furthermore, the building of hydrogen plants can call the attention of environmental globle advocates and technologies, who may help raise awareness about greenhouse gases and improve air quality. As such, developing these stations can help create a more informed society and a sustainable environment.

3. Locations of Hydrogen Stations

FCV Roadmap appeared in several countries around the world, such as the USA ,Europe, Korea, Japan and China (netinform). All plans for applying and construction hydrogen fuel stations in these countries began in several stages, starting with building small stations, evaluating them, conducting studies, and then shifting to deploying fuel stations completely and connecting them to highways. For GCCC hydrogne fuelling stations it would more likely to start at the same way.

a. Phase 1

Many factors could influence the setting up of hydrogen stations, including cost and customer convenience in addition to demonstration the road map of hydrogen Equipment and FCEV. However, location is the most important consideration, as many other factors are relatable, including traffic directions, residential and non-residential areas, and social composition (Iojă & Tudor, 2012). Even so, the first step toward building a hydrogen gas station is research. There are many research centers, especially due to the need for research and development in hydrogen energy technology. Kuwait Institute for Scientific Research (KISR) and College of Technological Studies (CTS) are the institutions researching the need for hydrogen fuel energy. KISR uses 10 kilowatts photovoltaic panels and 6 kilowatts wind turbines to produce and store hydrogen (H2) as an energy carrier which can be use later whith the fuel cell to produce electricity. The station is being used to study the energy management technologies in order to reduce the cost and increase the reliability of renewable energy technologies in Kuwait (KISR). Automotive and Marine at College of Technological Studies, aims to preparing the students to occupy positions and provid them the latest automotive knowledge, technological skills that make them function effectively as technicians in the automotive and marine technology fields (CTS, 2023). Both KISR and CTS are government sectors and may work in conjunction to build the first hydrogen fuelling station develop best energy management technologies. CTS location is expected to be the be the most optimize site for the first HFS due to the college's modus operandi that allows it to attract the public, automotive companies and the hydrogen industry companies, hence the KISR is verey close to CTS (figure no:1).



The only contires between the GCCC that built hydrogen fuelling stations are Kingdome of Saudia Aribia (Saudi Aramco) and UAE (Figure 3), in Dharan and in Dubai repectivly (h2stations.org, 2023). Dhahran is a city close to the city of Dammam, where King Fahd University of Petroleum and Minerals and the College of Technology are located and on the Riyadh highway and also close to the Kingdom of Bahrain, which gives it several advantages for spreading and displaying hydrogen fuel stations in Kingdom Of Saudia Aribia. UAE

hydrogen fuelling station regards the first hydrogen fuel station opens in GCCC (LeAnne Graves, 2017) which is in Toyota's Al Badia center in collaboration with French hydrogen station firm Air Liquide . The station is capabilt to serive three of the Fuel cell electrical vehicales, allowing government gain a better understanding of hydrogen FCVs.

Figure 3: The location of the current fuelling stations in GCCC contries

b. **Phase 2**

The second phase of promoting the use of hydrogen fuel is to build stations at strategic locations on the highway allowing it travelling longer distance. Wang et al. (2022) indicated that the GCCC has an extensive highway network connecting major cities and towns. For example, the King Fahd highway connects Saudi Arabia and Bahrain, a distance of more than 20 kilometers. These highways are toll roads, and drivers ought to pay for accessibility. Therefore, building stations along the highway networks could call for an assessment of traffic conditions, zoning regulations, security, safety, and the region's layout.

More location for the hydrogen fuelling station at the bords between the GCCC contries that allow FCEV traveling between the GCCC contries and give more knowloge how this new technology work. It suggested to be two stations in Kuwait, at the high way at the Kingdom of Saudian Aribia, south and Iraq at north boad. Coinciding with theis stations in Kuwait, it would be more likely locat one in al Khafji city as well as to another one in at Salwa Area, which the bord of Kingdom of Saudia Aribi with Qatar, and also can serive the highwar tile UAE board. UAE plan to make network hydrogen stations, of 10-12 stations for full national coverage (LeAnne Graves, 2017), so it connecting it with Oman at the southern Boards. Research centers and acadimint instiuts and universities in Kingdom of Bahrain, Qatar and Oman, can determain the location of the first hydrogen location, in each country, so it can bringe the comunication for clean hydrogen energy between the GCCC contries.

c. **Phase 3**

Before FCEVs can be widely marketed and sold, hydrogen fueling stations must be available near consumers' homes and workplaces with enough supply capacity to fill their vehicles (Alazemi & Andrews, 2015). The last phase of developing successful hydrogen fueling stations is to ensure that the stations in various towns and cities are interconnected. Some gas stations ensure a shared fuel supply, where gas is stored at a common location and distributed through a pipeline (Fan et al., 2017). Hydrogen can also be stored at a central location, and the fuel can be distributed across various stations. Besides, customers can earn loyalty points and redeem rewards at any fueling station, encouraging more loyalty to the gas station. Connecting fueling stations could help embrace the new technology and the shift to a cleaner and safer gas option.

4. Stations Size and Techniques

One of the primary considerations in building hydrogen fueling stations is the station's size, and the most important factor in determining size is the need for storage space. Currently, hydrogen is typically stored in gaseous or liquid form, which requires a significant amount of storage space. To address this issue, researchers are exploring the possibility of solid-state hydrogen storage, which could increase hydrogen storage density and reduce the amount of storage space required. Increasing the density of hydrogen storage could help reduce the size of fueling stations and make them more feasible for deployment in urban areas, where space is often at a premium. This research is crucial to developing a sustainable hydrogen fueling infrastructure that can support the widespread adoption of hydrogen fuel cell vehicles and help to decarbonize the transportation sector.

5. Supports

Hydrogen is a safe and clean gas that may be used in various applications, including powering automotive and backup power systems.Linde, Air Liquide and othere H2 is a global company offering industrial gases, including to local chamicals and automotives companies in GCCC. Hydrogen has been cited as a clean gas that promotes a green environment (Liu et al., 2022). Furthermore, Linde, a gases and engineering company, provides and distributes hydrogen gas, stating its usefulness in the generation of power (Stokes & Banken, 2015). Nonetheless, Toyota, a large automotive manufacturer, has approved the viability of hydrogen gas as it has produced a hydrogen fuel cell vehicle, the Toyota Mirai (Pielecha et al., 2018). Cummins is also a US-based company that produces hydrogen fuel cell systems applicable in automotive and industrial systems.

6. Conclusion

Hydrogen energy has advanced significantly in recent years, primarily focusing on creating a sustainable fuel source that reduces carbon emissions. The adoption of hydrogen stations has significant advantages, including providing a safer and cleaner environment, supporting the economy and infrastructure, and ensuring energy security by reducing reliance on fossil fuels. The development of the hydrogen industry has been evident across many parts of the world, including the US, Europe, Japan, Korea, China, and India, with different countries pursuing hydrogen technology advancements. Although hydrogen fuel is still in its early stages in the GCCC, the opening of the first known hydrogen station in late 2017, along with the advanced research and development of hydrogen technology, sets the pace for the growth and adoption of hydrogen fuel in the region. Building hydrogen fueling stations has many benefits beyond merely

providing a means of fueling fuel cell vehicles, including reducing carbon emissions, keeping up with modern technology, and creating public awareness of hydrogen energy benefits and hydrogen facilities.

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