Hydrogen Horizons: Navigating the Future of Renewable Energy

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Abstract: With the pressing need to reduce carbon emissions from energy systems and lessen the effects of climate change, hydrogen energy emerges as a flexible and sustainable replacement for fossil fuels. This essay examines the potential of hydrogen energy as a transformative solution in the global quest for sustainable and clean energy sources. It is commonly known that reliable renewable energy sources like hydrogen are critical for a sustainable future. Therefore, it is important to understand the production methods, applications, and technological advancements in hydrogen energy. By discussing the current energy crisis, the hydrogen economy, and world-leading hydrogen businesses, this paper provides a holistic view of hydrogen energy.

Keywords: renewable energy, hydrogen economy, transportation.

1. Introduction

In recent years, climate change has been a focal point for leaders and countries around the world. The quest for sustainable and environmentally friendly energy sources has become a paramount concern in the 21st century. Fossil fuels, despite their historical dominance in the global energy landscape, are increasingly untenable in the face of urgent environmental imperatives. The combustion of coal, oil, and natural gas is a major source of greenhouse gas emissions, contributing significantly to global warming and air pollution. Amidst the complex climate crisis, hydrogen energy emerges as a compelling alternative, exploring a new era of clean, efficient, and versatile energy solutions.

Hydrogen energy can be harnessed in several forms—ranging from direct combustion for power to electricity generation. With future technological advancements in electrolysis, fuel cell technologies, and hydrogen storage, Hydrogen fuel would be positioned as a cornerstone for a decarbonized energy system. This paper delves into the current state of energy consumption worldwide, the multifaceted potential of hydrogen energy, as well as the business side of developing hydrogen energy.

2. The Energy Consumption Landscape and The Need For New Energy Sources

2.1. Primary Energy Consumption

As the population continues to grow and people continue to get richer, the amount of energy consumed also continues to increase. In recent years, global energy consumption has been growing at a rate of 1-2% each year. [1]

In 2022, the total amount of primary energy consumption in the US totaled 100.41 quadrillion Btu. Out of which, 87% of the energy came from nonrenewable energy sources, namely petroleum, natural gas, coal, etc. While only 13% of the total energy consumed came from renewable sources. [1]

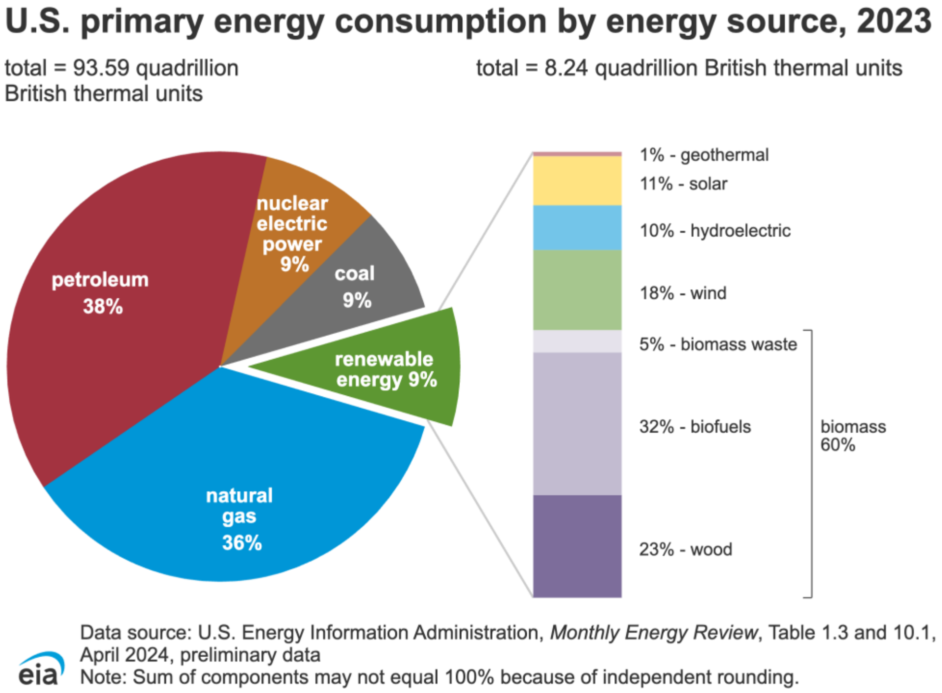

Figure 1: U.S. primary energy consumption by energy sources, 2022 [2]

2.2. The Inefficiency in Energy Transport and Energy-use

To categorize, Energy-use can be split into five different sectors: electric power, transportation, industrial, residential, and commercial. In 2022, electric power accounted for 37.8 quads of energy-use in the US, the highest of the five sectors. However, due to energy loss that occurs with electrical systems, only about 35% of the 37.8 quads will be used in the form of electricity. [2] This suggests that for every three portions of electricity, only one portion of electric power is consumed, making electric power an inefficient and relatively wasteful energy source.

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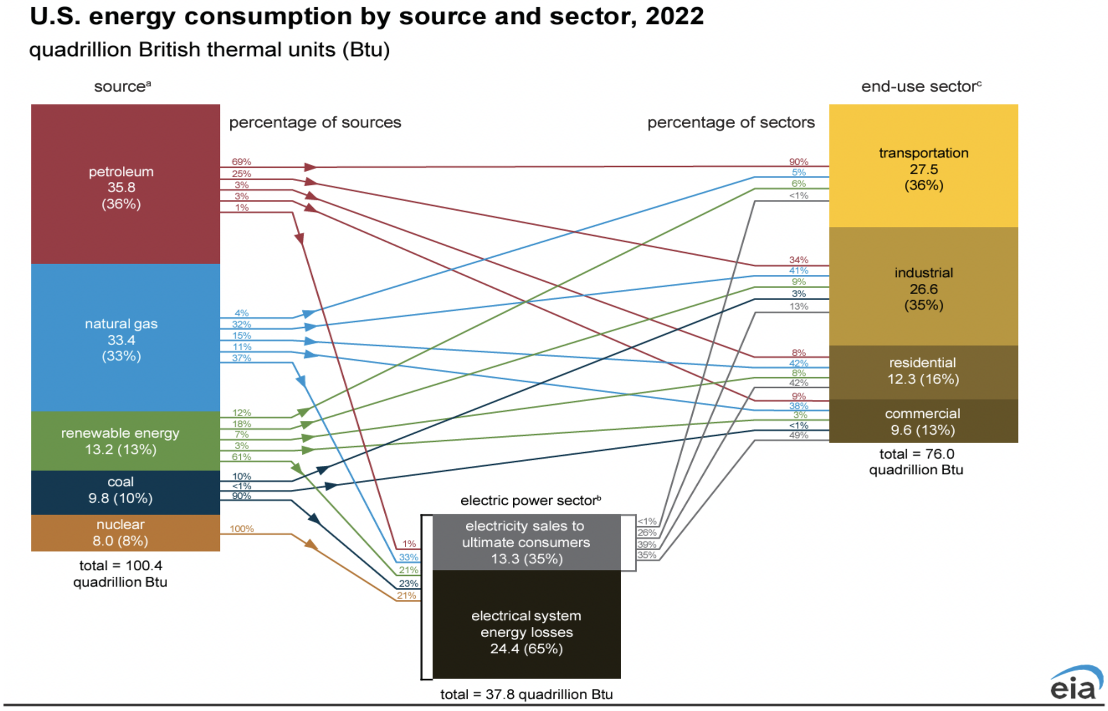

Figure 2: U.S. energy consumption by source and sector, 2022 [3]

2.3. End-use

Apart from the Energy-use sectors, energy consumption can also be categorized by their end-use sectors. These consist of transportation, industrial, residential, and commercial. End-use sectors differ from energy-use sectors because they consume primary energy and electricity produced by the electric power sector. Interestingly, in 2022, the transportation sector was attributed to the most energy consumed out of the end-use energy sectors in the US, with the industrial sector being a close second. [3] According to data collected by the Eia [3], more than 90% of the energy consumed by the Transportation sector and more than 75% of the energy consumed by the Industrial sector comes directly from non-renewable primary energy sources.

From all the data presented, we can clearly see that despite recent efforts to diminish fossil fuel consumption, the world still primarily relies heavily on non-renewable energy sources. With consequences such as global warming, pollution, and land degradation; transitioning our energy systems away from fossil fuels towards low-carbon sources of energy has become critical.

3. The Hydrogen Economy

As we search for new solutions and new renewable energy sources, many ideas have been used and tested, but we have yet to find a sustainable energy source that could really substitute the use of fossil fuels. From wind energy to hydro energy, humans have been constantly searching for new energy options since the 1970s. For the US, many would say that renewable energy started receiving serious attention after the oil crisis in 1973 and 1979. Despite the efforts, the world has yet to discover an alternate energy source capable of supplementing fossil fuels. However, with the recent improvements and advancements in the hydrogen economy, many think that hydrogen energy will be a game-changing energy source in the future.

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First, it is important to understand the areas where Hydrogen energy will be especially beneficial. Many scholars believe that hydrogen will serve as the primary energy storage technology, the central heating fuel, and the leading transportation fuel for cars, trucks, airplanes, and more.

3.1. Transportation Sector

As mentioned previously, the transportation sector accounts for a large amount of the energy consumed yearly. Therefore, finding a replacement for the internal combustion engines (ICE) is important to reducing this carbon footprint. Currently, as data recorded by EV-Volumes [4] suggests, it is forecasted that electric vehicle sales will exceed 14.1 million in 2023, a 34% growth from 2022.

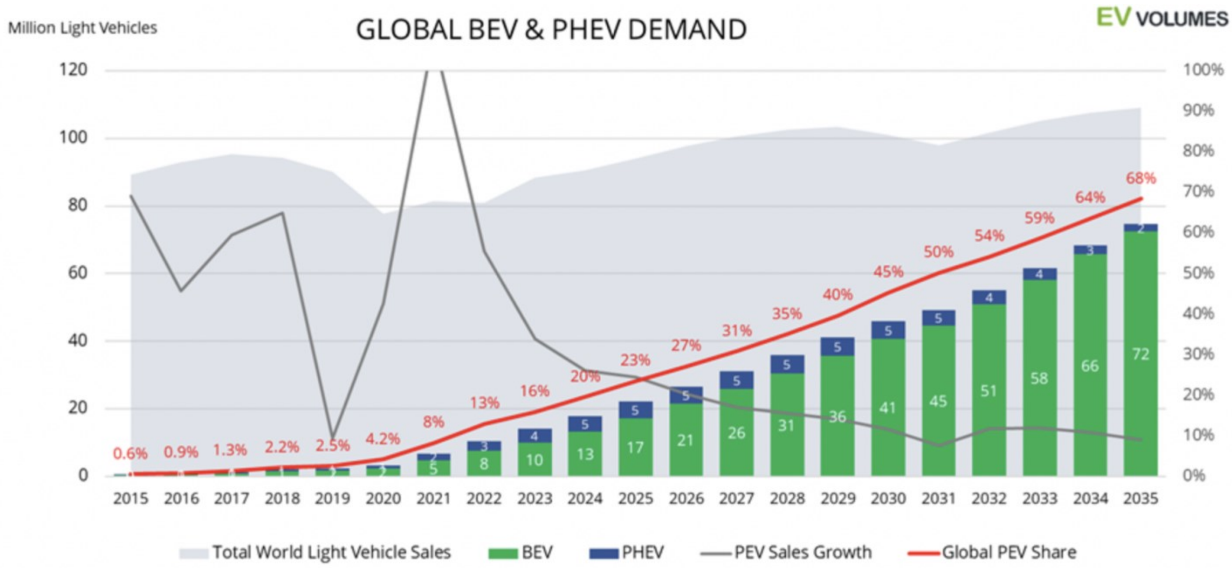

Figure 3: Global BEV & PHEV Demand [4]

As battery electric vehicles have risen in popularity in recent years, many may think that these vehicles will be sufficient replacements to substitute ICE vehicles. Nevertheless, many flaws remain in the concept and idea of these EVs, and limitations such as range and efficiency hinder its future to replace ICEs. Therefore, Fuel cell electric vehicles (FCEVs), which consume hydrogen and oxygen from the air and release water vapor, will be a great alternative for long-range travel and heavy-duty transportation. FCEVs are able to travel a longer distance as well as maintain a shorter fueling time. This is because, as opposed to adding batteries to BEVs, increasing the hydrogen storage of FCEVs is a more cost-competitive option past 300km. The International Energy Agency (IEA) has released its Global EV Outlook 2023 report, which includes data showing that the number of hydrogen fuel cell electric cars (FCEVs) on the road worldwide grew by 40% in 2022 compared to 2021, totaling more than 72,000 vehicles. [5]. Additionally, FCEVs have a shorter fueling time of 5 minutes compared to BEVs, which can take over 8 hours for long-distance charging [6]. Range and fueling times are essential to long-range freight trucks, which account for around 25% of transportation-related CO2 emissions.

3.2. Heating and Building

Another important contributor to CO2 emissions is the Heating and Building sector, which includes district heating and cooling, water heating, cooking, etc. These common practices visibly influence our daily lives. According to data collected in 2016, 17.5% of the greenhouse emissions can be attributed to residential and commercial buildings [6]. Therefore, finding green energy sources for heating and building is crucial in reducing carbon emissions. One of the main solutions for reducing CO_2 emissions in this sector has been electrification, replacing fossil fuels with heat pumps. Heat pumps are 3 to 5 times more efficient than fossil fuels and are completely carbon-free when powered by renewable energy sources.

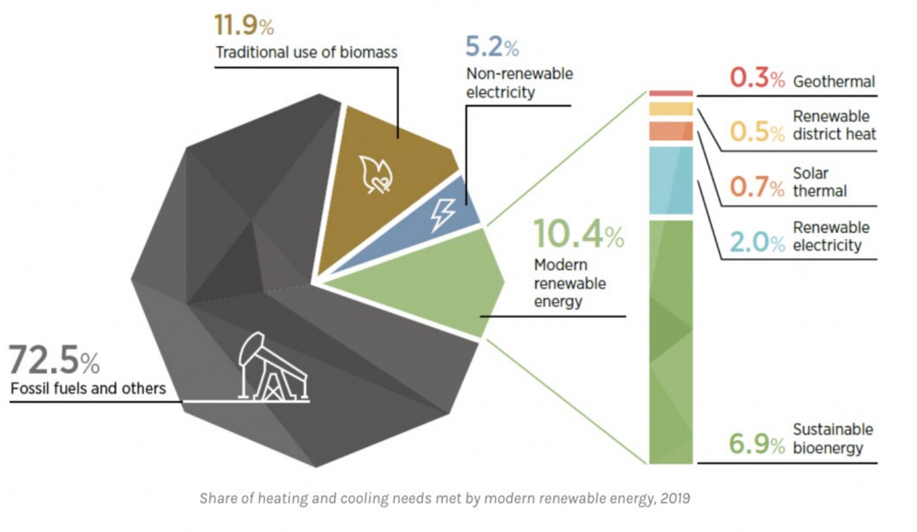

Figure 4: Share of heating and cooling, 2019 [7]

However, replacing fossil fuels for heating and building isn't as simple as it may sound. It is important to note that electric heating is a lot more costly than using fossil fuels. Furthermore, it is unlikely that Hydrogen will be more cost-effective than electrification for low-grade heating in the long term. This is due to the low-efficiency rate of using hydrogen. Some critics say the electricity needed for hydrogen to heat a home is five times that of an efficient heat pump. [6]

With that said, when hydrogen is blended into the existing natural gas grid, it can serve as a transitional fuel source for decreasing carbon emissions in the heating and building sector while electrification works to become cost-competitive. According to the IEA, blending up to 20% of hydrogen can be achieved without major modifications to the current infrastructures, this could lead to the reduction of 145 Mt of CO_2 [6].

While low-grade heat will eventually be completely electrified, there are also certain other areas where electrification may be very challenging to use. It is important to note that in the industry sector, electrification is unable to serve high-grade heat, especially processes that exceed 400 degrees Celsius. Therefore, operations such as cement production would be unable to be replaced with electrification. Take cement production as an example, it takes up 7% of the world's global CO_2 emissions, 40 % of which comes from the combustion of fuels to heat kilns to 1450 degrees Celsius [6]. This is where the combustion of pure hydrogen can greatly help reduce CO_2 emissions.

4. Case Study of The Hydrogen Business

4.1. Air Liquide—A Front Runner in the Hydrogen Business

Air Liquide is a French multinational company that services industrial gases, and services for Industry and Health. They are present in 73 countries and have approximately 67,100 employees. They serve more than 3.9 million customers and patients worldwide. With its initiatives in hydrogen applications, Air Liquide has been one of the leaders in the hydrogen energy industry. In Q3 of 2023, the company

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brought in approximately 8,611 million euros in sales, the majority coming from the Americas and Europe [8].

4.2. Normandy Basin

Air Liquide has several goals and specialties when it comes to reducing CO2 emissions with hydrogen. To begin with, the company has started the construction process of Air Liquide Normand'Hy, which will be the world's biggest renewable hydrogen production unit [9]. It has an initial capacity of 200 megawatts, which is equal to the annual energy consumption of around 253,000 French households. By breaking down water molecules to separate hydrogen from oxygen through a process of water electrolysis, the production plant aims to produce up to 28,00 tons of hydrogen.

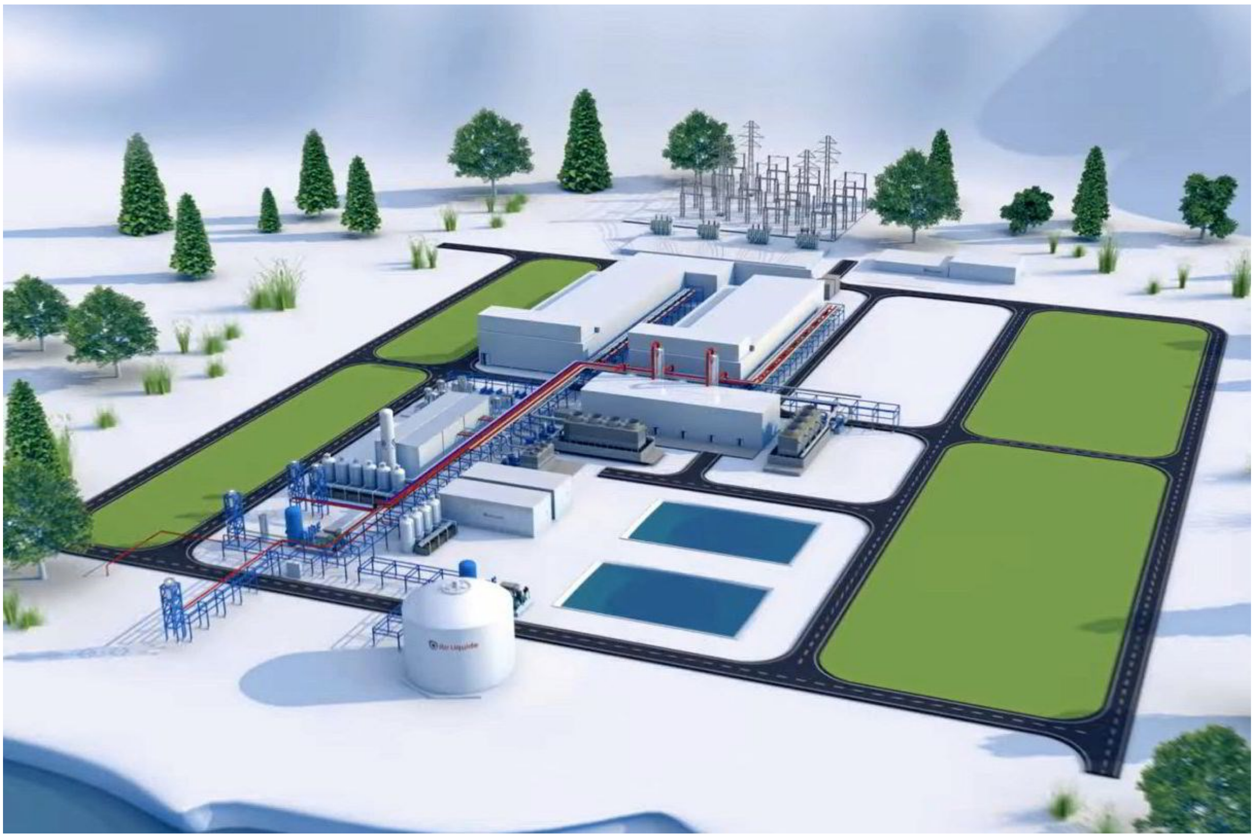

Figure 5: Model of Air Liquide Normand'hy Electrolyzer [9]

The Air Liquide Normand'Hy will be a key part of achieving the goal of decarbonizing the Normandy Industrial Basin. This project has gained interest from the French government and is considered to be an Important Project of Common European Interest. The project received 190 million euro in support from the French Government`, as part of the "Plan de Relance" [10].

To achieve its goal of supplying large-scale renewable hydrogen energy, Air Liquide has many partnerships to help them deliver their goals. The company has recently entered a joint venture with Siemens Energy to develop large-capacity electrolyzers. This strategic partnership is crucial to developing the European hydrogen sector, which Air Liquide is leading. By utilizing both companies infrastructure and expertise, this joint venture aims to allow the manufacturing of low-carbon hydrogen at industrial scale and competitive cost. The electrolyzer will be located in Port Jerome, a place where Air Liquide has had a presence since the 1970s and has rolled out several technologies [9].

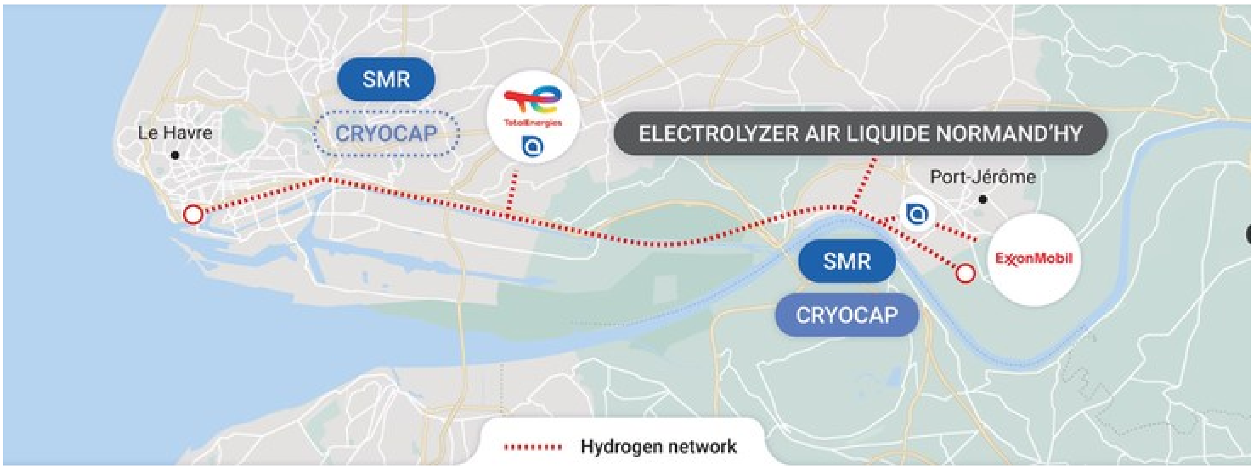

Figure 6: Roadmap in Normandy Basin Air Liquide [11]

In 2015, Air Liquide rolled out its Cryocap^{tm} technology, a world first by using cryogenics to capture up to 98% of the CO2 released during the creation of hydrogen [9]. Air Liquide can now capture and lower even more carbon emissions from both its own locations and those of its clients thanks to Cryocap^{tm}. However, there are still concerns about the carbon emissions involved in the electricity used by the electrolyzers. To solve this problem, Air Liquide plans to use electricity that comes from solar farms and wind turbines located near the site. This way, up to 250,000 tons of CO_2 emissions per year will be prevented, equivalent of 25,000 people's emissions

Just a bit down from the site, the regional industrial ecosystem will be connected to the Air Liquide Normandy'hy, allowing green hydrogen to be distributed to the other industries. Air Liquide plans to partner and work with other industrial companies that use hydrogen in their production. It is important to slowly replace the hydrogen being supplied with renewable hydrogen, as this allows the carbon emissions of industrial players to be reduced.

4.3. In the Skies

Not only is Air Liquide decarbonizing the hydrogen process and other industries, but they are also aiming high in the aviation sector. The plan is to use liquid hydrogen to replace traditional fossil fuels for aircrafts. However, using hydrogen to decarbonize air transport is a huge task, various factors such as airport organization, or the building of the supply chain for liquid hydrogen all make replacing decarbonizing the aviation sector a challenge. In October of 2022, a "net-zero CO2" target for 2050 was favored by 193 states of the International Civil Aviation Organization (ICAO). Even though aviation today only contributes 2% of the world's CO2 emissions, decarbonization is still very challenging [12].

When it comes to aircrafts, things can get quite more complicated, factors like energy intensity, on board weight and volume all make finding an alternative energy source very difficult. Currently, the only fuel that is able to meet the various requirements and be price competitive is fossil kerosene.

In recent years, many have been interested in the use of biofuel and e-fuels. However, to achieve the net-zero goal objective, low carbon and renewable hydrogen will be essential. As for biofuels, their limited availability will make them unable to meet the growing need for fuel. Meanwhile, the production process of e-fuel involves large amounts of hydrogen and carbon emissions. Consequently, because of scarcity and high costs, biofuel and e-fuel may be a good alternative for long-haul flights, while renewable hydrogen is best suited for medium-short haul flights [12].

There are many reasons why Air Liquide believes liquid hydrogen will be a great alternative fuel for aviation. The main reason in using liquid hydrogen is that it is 800 times denser compared to air

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hydrogen, allowing it to meet the onboard volume requirements for any aircraft [12]. This dense form of hydrogen also allows for faster re-fuel times. In fact, Air Liquide has already been working with industry players to reach the goal of 15 minute refuel times for aircrafts requiring 3.5 tons of liquid hydrogen [12].

Figure 7: First piloted liquid hydrogen flight [13]

One major breakthrough the company had was in September 2023. Partnering with Air Liquide, a start-up called H2FL accomplished the first piloted flight of a four-seat aircraft powered by a liquid hydrogen tank and fuel cell, which was a first for the world. [13]. This incorporated all the features needed for a commercial flight, such as transient mode, pressure regulation, filling, and heat recovery. The aerospace sector has the ability to duplicate, expand, and definitively share this experience in order to expedite the implementation of aviation powered by hydrogen. Airbus has stated that it plans to introduce a hydrogen-powered production aircraft to the market by 2035 under its ZEROe programme, as shown in Figure 8 [14]. The aircraft manufacturer unveiled a fuel cell-equipped turboprop prototype system at the end of 2022 [14]. Despite the many advancements and innovations, we are still far-fetched from a world of hydrogen-powered commercial planes zooming across the sky. The hydrogen aviation market is growing gradually. Until 2030, we will most likely see various initiatives pop up in this demonstration phase.

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Figure 8: Future Airbus hydrogen plane [14]

The International Air Transport Association (IATA), which represents 300 airlines globally, recently released a roadmap that reaffirmed the objective of seeing the first hydrogen-powered regional flights operate by 2030 [15]. Short-haul flights (less than 2,000 km) will then start to operate. Eventually, in 2040, 200-seat aircraft with a 4,000 km range are expected to go into service [15].

4.4. Olympics

In June 2023, Air Liquide became the official hydrogen supporter of Paris 2024 to reduce carbon emissions. With transportation being one of the biggest causes of CO2 emissions, hydrogen is one of the various solutions needed for climate change. Air Liquide will be working with Toyota to put out 500 hydrogen-powered vehicles (Toyota Mirai) at the 2024 Olympics and Paralympics [16]. With its minimal charging times and great range, these cars are a great way to reduce carbon emissions at the Paris Olympic Games. The company will be supplying renewable hydrogen fuel for all of the hydrogen-powered vehicles at the event. Its expertise in renewable hydrogen production will help decarbonize the transport at Paris 2024. Air Liquide has been launching and developing some important projects, such as the Olympics, to offer practical solutions to the various challenges posed by climate change.

5. Conclusion

The exploration of hydrogen energy as a significant contender in the race to replace fossil fuels opens a promising road toward achieving a more sustainable and resilient global energy system. As we look toward the future, it becomes clear that the journey to a hydrogen-powered society will be marked by continuous improvements and innovations across several domains. The scalability of hydrogen production, particularly green hydrogen, hinges on advancements in electrolysis technology and renewable energy capacities. Technological advancements are crucial for increasing the production of hydrogen and improving its efficiency and cost. Concurrently, to fully utilize hydrogen in a variety of applications, advancements in distribution networks and storage technologies are essential. Reducing manufacturing costs and putting supportive policies in place, international cooperation for

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knowledge exchange, and collective problem-solving are all crucial to developing the Hydrogen Economy.

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