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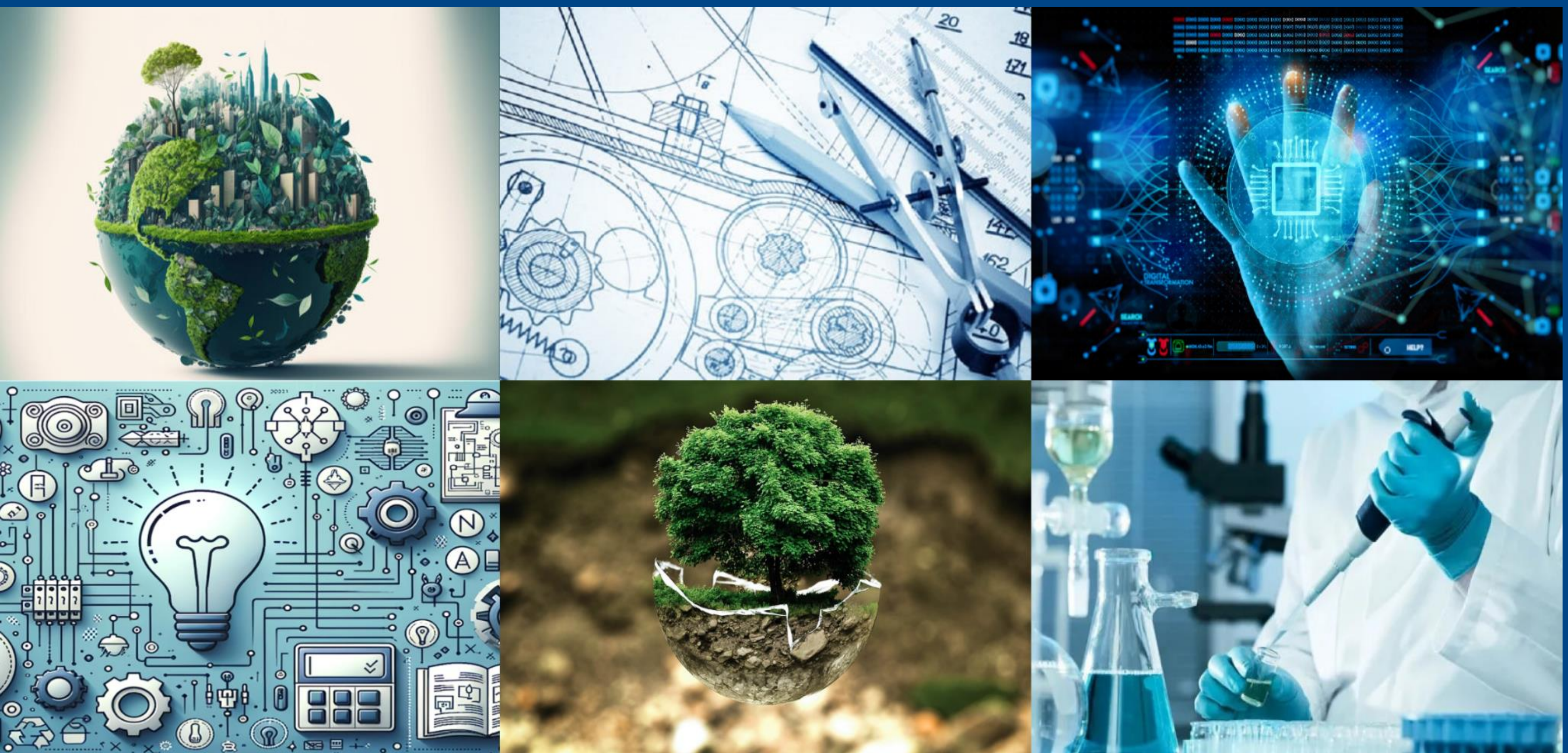

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Future Green Fuels and Green Fuel Technology (Hydrogen Fuel Cell)

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ABSTRACT: The climate changes that are becoming visible today are a challenge for the global research community. The stationary applications sector is one of the most important energy consumers. Harnessing the potential of the renewable energy worldwide is currently being considered to find alternatives for obtaining energy by using technology that offer maximum efficiency and minimum pollution. In this contest, new energy generation technologies are needed to both generate low carbon emissions, as well as identifying, planning and implementing the directions for harnessing the potential of renewable energy sources. Hydrogen fuel cell technology represents one of the alternative solutions for future clean energy systems. This paper investigates fuel cell technology, an efficient and environmentally friendly method for generating electricity by harnessing the energy content of hydrogen or alternative fuels. Fuel cell produce electricity with water, heat, and power as the only by-product when hydrogen is used as fuel, making them a clean and sustainable energy option.

I. INTRODUCTION

Hydrogen is the simplest and most abundant element of the universe. It is major component of water, oil, natural gas and living matter. Despite its simplicity and abundance, hydrogen rarely occurs naturally as a gas on earth. It is almost always combined with other elements.

The development of clean energies is a critical component of developing low carbon technologies for green industries. In the clean energy market chain wind, solar and tidal energy are the main generators of electricity. Moreover, the need for a viable solution to the oil-based economy has been demonstrated by the continuous and steady depletion of crude oil price (1). The world's energy demand is that lockstep with economic growth, more or less. Many areas across world, such as East Asia, Europe and the Gulf Region, have seen rapid economic growth in recent decades. Rapid urbanization resulted in a significant rise in the living condition of major communities as well as a significant increase in global energy demand. To solve this issue, a sustainable and renewable energy based power efficient solution is needed. Hydrogen fuel cell power production in the car industry and stationary power plants is becoming an ever more effective alternative in various potential innovations. 1. The fuel cell is the best option for overcoming the challenges of resource sustainability. 2. A hydrogen fuel cell is a electrochemical cell that convert chemical energy into usable electricity via an electrochemical reaction.

II. PRODUCTION OF HYDROGEN FUEL

Since pure hydrogen is not naturally available in large quantities on earth, it demands primary energy to obtain on an industrial level. Some frequent methods of production are steam methane reforming and electrolysis.
Production through steam methane reforming-

- Extraction of hydrogen from methane
- Liberating carbon dioxide and monoxide into atmosphere.
- These gases help in the greenhouse effect and contribute the change of climate.

Production through electrolysis-

- Separation of oxygen and hydrogen atoms
- These process can use solar, hydro, biomass, wind, geothermal, fossil fuels, and nuclear energy
- It is cost effective method.

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III. PRINCIPLES OF FUEL CELL

There are various types of FC systems. However, the principle of their function is similar. For a fuel cell system, three pillars are required: an anode, a cathode, and an electrolyte. FC's are categorized by the type of electrolyte material used. An FC can be composed of hundreds of individual cells, but each has the three same fundamental components. The electrolyte is located between the cathode and the anode. Figure 1 depicts a schematic of a polymer electrolyte FC (PEMFC) operation diagram (2). This FC type is also known as a proton exchange membrane FC. The PEMFC is what is most commonly used in mobile power applications, such as vehicles. While the electrolyte material used varies depending on the type of FC, the general function of the FC is as follows—fuel (pure hydrogen) is fed into the anode compartment of the fuel cell while air or pure oxygen is fed into the cathode side of the FC. On the anode side of the cell, electrons are separated as the gas tries to make its way through the electrolyte membrane. The membrane acts as a filter to separate the electrons and the hydrogen ions while only allowing the hydrogen ions to pass through. In the cathode compartment, the hydrogen ions that passed through the membrane combine with the oxygen atoms from the air supply to produce H2O as a by-product; heat is also produced as a by-product (2). Unlike internal combustion engines, where the fuel is mixed with air and fuel, there is separation of the fuel and the oxidant with no combustion of the fuel in an FC. Therefore, FC's do not produce the harmful emissions that internal combustion engines produce.

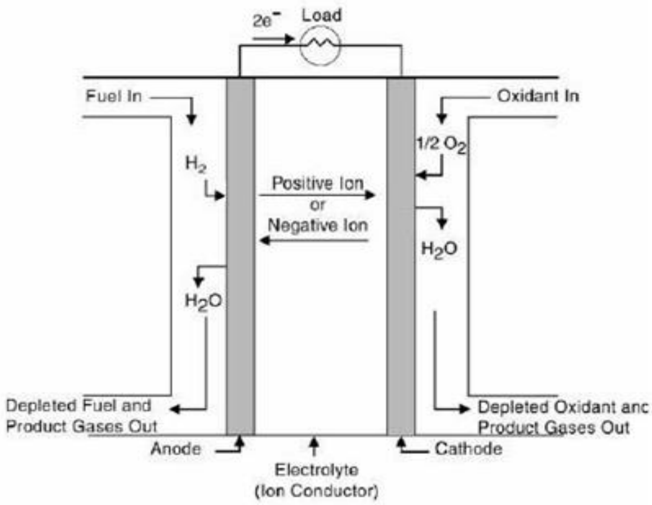

Fig 1. Fuel cell operation diagram

IV. TYPES OF FUEL CELL

Fc systems are classified by the type of membrane they use. Table shows some of the more common FC's.
Fuel cell

- Solid oxide fuel cells
- Direct methanol fuel cell
- Phosphoric acid fuel cell
- Polymer electrolyte fuel cell
- Alkaline fuel cell

V. HYDROGEN FUEL CELL TECHNOLOGY

The fuel of the future is hydrogen. Hydrogen is now widely regarded as a non-polluting energy source because it does not affect the climate when derived from renewable sources. Hydrogen fuel cell is one of the promising technologies for the production of pollution free energy. The electrochemical reaction of hydrogen with air (oxygen) in the hydrogen fuel cell transforms hydrogen or hydrogen-based fuels directly into heat and electricity. Figure 2 shows the typical representation of fuel cell reaction.

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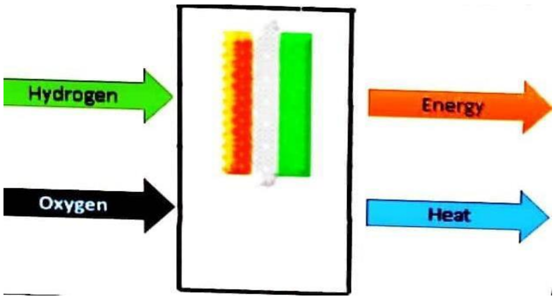

Fig 2. Representation of fuel cell reaction

An ion transmitting electrolyte, a cathode, and an anode are the main elements of a fuel cell, as seen schematically in Figure 3. A material must meet a number of requirements in order to serve as an electrolyte in a fuel cell. Described that an electrolyte should has high stability, melting and boiling points, and less toxicity. The types of electrolytes are varied into three main categories i.e. solid, liquid and gases. Moreover, the reactions are taking placed on the catalyst side of cathode and anode of a fuel cell. The oxidation and reduction reaction are carried out on anode and cathode respectively. The electrodes (catalyst layers) contain catalyst particles to speed up the cell's reaction cycle. An electrode usually has a thickness of 5– 15 m and a charge of 0.1–0.3 mg/ cm 2.

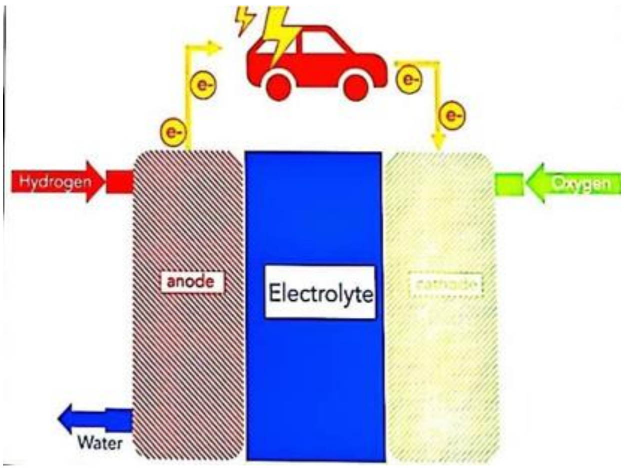

Fig 3. Regenerated picture of hydrogen fuel cell components based on production and storage.

Hydrogen can be produced mainly via three sources i.e. electrolysis of water, fossil fuels and renewable energy resources. Currently, half of the hydrogen fuel is produced using fossil fuel methodology, particularly steam reforming of methane. In this reaction, the hydrocarbon source such as methane is reacted at very high temperature with water to produce hydrogen energy gas along with other by products.

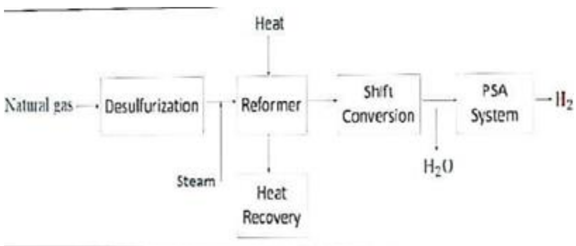

Fig 4. Process flow of steam reforming

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Secondly, the production of hydrogen is carried out by using renewable energy resources such as biomass. But both of the above method causes high of emissions of greenhouse gases. However, the most environmentally friendly process for the production of hydrogen fuel is the electrolysis of water [2]. Moreover, it is the most efficient process to produce a pure hydrogen fuel gas. In this process, water is splitter into hydrogen and oxygen gases by the application of 237 kJ of electrical energy. Following is the electrochemical reaction that takes place during the splitting of water molecule and schematically shown in Figure.5

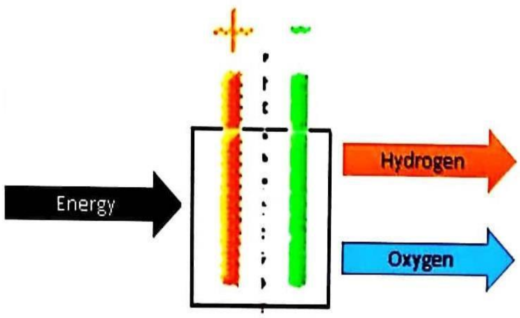

Fig 5. Representation of electrolysis

After the production of hydrogen gas via electrolysis, it is converted into energy by the oxidation of hydrogen in a hydrogen fuel cell. A fuel cell behaves like a battery. But one significant difference is that batteries store energy, while fuel cells will consistently generate electricity as long as fuel and air are available (3). Different types of hydrogen fuel cells may use any hydrogen-rich fuel. Following is the electrochemical reaction that takes place and previously shown in Figure 2 as well.

$$2H_2 + 0_2 \rightarrow 2H_20 + \text{Energy (0.1 to 3 MW)}$$

It is important to understand the operating segments to evaluate the significance of all the phenomena that occur in a fuel cell. Some major components of hydrogen fuel cell include electrolyte, cathode, anode, and catalyst layer [3]. In Figure 5, it can be seen that hydrogen produced from hydrogen rich source is fed to the anode side of the fuel cell whereas oxygen in terms of air is fed to the cathode side of cell. A porous carbon shield is used as the electrodes of a hydrogen fuel cell, on which the catalyst layer is embedded. The function of anode coated catalyst layer is to separate the electron from the hydrogen gas. The electrons are transported towards the cathode with the help of electrolyte solution and electric circuit. These electrons are then combined with oxygen gas that is entering from the cathode and as a result energy (electricity) of 0.1 to 3 MW and water (byproduct) are produced.

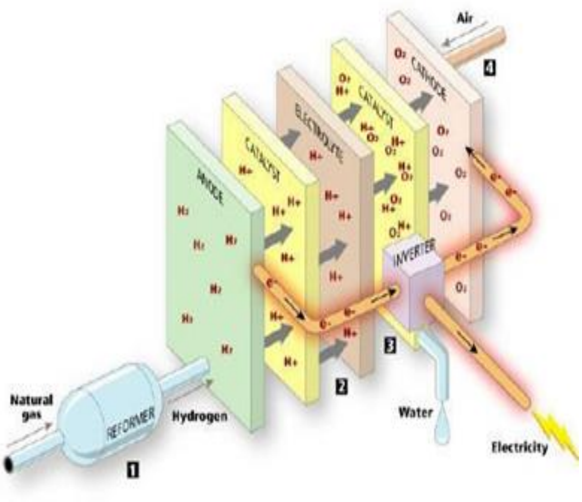

Fig 6. Schematic diagram of hydrogen fuel cell

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Electrochemical reaction that occurs at the anode is the oxidation reaction whereas reduction reaction is occurred at anode.

At anode - $H_2 \longrightarrow 2H^+ + 2e^-$

VI. OPPORTUNITIES FOR HFCVS

I. Opportunities Associated with HFCVs

The HFCVs offer several advantages and opportunities compared with conventional in ternal combustion engine vehicles. These advantages and opportunities stem from the unique characteristics of hydrogen as a fuel and the efficient and clean operation of fuel cell technology. This section highlights some of the advantages and opportunities associated with HFCVs:

• Zero emissions: HFCVs produce zero tailpipe emissions as the only byproduct ofthe electrochemical reaction is water vapor. This makes HFCVs an environmentally friendly alternative to conventional vehicles, contributing to improved air quality and reduced greenhouse gas emissions.

Energy efficiency: Fuel cells can achieve higher energy conversion efficiencies com-pared with internal combustion engines. The direct conversion of chemical energy into electrical energy in fuel cells results in less wasted energy, leading to greater overall efficiency and reduced energy consumption.

• Extended range and quick refueling: HFCVs typically offer longer driving ranges compared with battery electric vehicles. Hydrogen fueling stations can refill a fuel cell vehicle in a matter of minutes, similar to the refueling time for conventional vehicles . This addresses concerns about range anxiety and long recharging times associated with battery electric vehicles.

• Scalability and flexibility: Hydrogen fuel cell technology can be scaled for various applications, from small portable devices to large-scale power generation. It offers flexibility in energy sources as hydrogen can be produced from diverse resources such as renewable energy (e.g., solar and wind) or by reforming fossil fuels. This scalability and flexibility enable the decarbonization of various sectors, including transportation, power generation, and industrial processes.

• Energy storage and grid integration: Hydrogen can serve as an energy storage medium. Excess electricity generated from renewable sources can be used to pro-duce hydrogen through electrolysis, which can be stored and later used in fuel cells to generate electricity. This integration of hydrogen fuel cells with renewable energy sources supports the development of a sustainable and resilient energy system, en-abling the utilization of intermittent renewable energy and helping to balance the grid.

• Fast refueling infrastructure deployment: Compared with the widespread deploy-ment of electric vehicle charging infrastructure, establishing hydrogen refueling in-fra structure is relatively quick. Existing natural gas pipelines can be repurposed for hydrogen transportation, and new hydrogen refueling stations can be built using mod-ular and scalable designs. This provides an opportunity for accelerated infra-structure development, especially for long-haul transportation and heavy-duty applications.

• Quiet operation and comfort: Fuel cell vehicles produce significantly less noise compared with conventional vehicles with internal combustion engines. This leads to quieter and more comfortable driving experiences, reducing noise pollution in urban areas.

• Economic development and job creation: The development and deployment of hy-drogen fuel cell technologies and infrastructure offer opportunities for economic growth and job creation. The hydrogen sector encompasses research and develop-ment, manufacturing, the installation and maintenance of fuel cell systems, hydrogen production and distribution, and the operation of refueling stations .The HFCVs offer advantages such as zero emissions, high energy efficiency, extended range, quick refueling, scalability, flexibility in energy sources, energy storage capabilities, fast infrastructure deployment, quiet operation, and economic development opportunities .These advantages and opportunities position HFCVs as a promising and sustainable solution for the transportation sector and the broader transition to a low-carbon economy.

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VII. HFCVS' CONTRIBUTIONS TO A SUSTAINABLE ENERGY ECOSYSTEM

The HFCVs have the potential to contribute significantly to the development of as ustainable energy ecosystem. Here are some ways in which HFCVs can contribute to a sustainable energy ecosystem .

• Renewable energy integration: HFCVs can facilitate the integration of renewable energy sources, such as solar and wind, into the transportation sector. Excess electricity generated from renewable sources can be used for hydrogen production through electrolysis. This enables the storage of renewable energy in the form of hydrogen ,which can then be used in HFCVs to generate electricity. By utilizing hydrogen produced from renewable sources, HFCVs can help balance the intermittency of renewable energy and contribute to the efficient utilization of renewable resources.

• Grid balancing and energy storage: HFCVs equipped with hydrogen fuel cells can act as distributed energy storage systems. During periods of high electricity demandor low renewable energy generation, HFCVs can provide stored energy by generating electricity from stored hydrogen. This enhances the grid stability, reduces the strain on the electrical grid, and improves the overall energy management. The stored hydrogen can be dispatched for power generation or to supply other energy-intensive sectors during peak demand periods.

• Decentralized power generation: HFCVs, when coupled with stationary fuel cells ,can enable decentralized power generation. Hydrogen produced from renewable sources can be used not only for fueling vehicles but also for stationary fuel cells that generate electricity. This decentralized approach to power generation can reduce transmission losses and enhance energy resilience, particularly in remote areas or during natural disasters where the traditional power infrastructure may be disrupted.

• Fuel cell combined heat and power (CHP) systems: HFCVs equipped with fuel cells can contribute to combined heat and power (CHP) systems. The waste heat generated by the fuel cell during electricity generation can be captured and used for various heating applications, such as residential and commercial space heating or industrial processes. This increases the overall energy efficiency and reduces the need for separate heating systems, leading to energy savings and lower greenhouse gas emissions.

• Renewable hydrogen production: The production of hydrogen for HFCVs can be achieved using renewable energy sources, ensuring that the entire fuel cycle is envi-ronmentally friendly. By utilizing renewable energy in hydrogen production through electrolysis, HFCVs can achieve a truly sustainable transportation solution. This renew-able hydrogen can be produced on site or at centralized facilities, further promoting the use of clean energy sources.

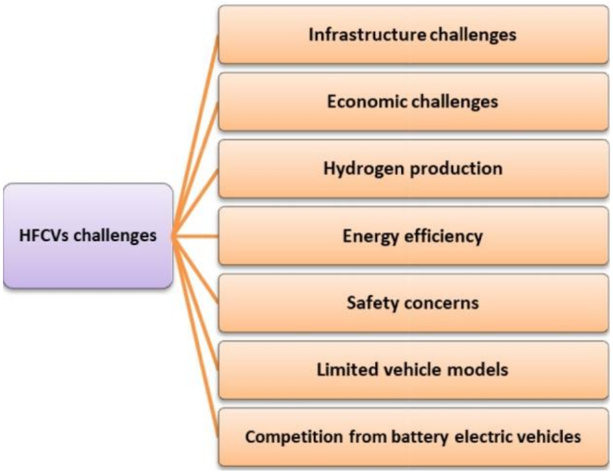
• Circular economy approach: HFCVs can contribute to a circular economy by utilizing hydrogen produced from various sources, including renewable energy and waste streams. For example, hydrogen can be generated from biogas produced from organic waste or from the electrolysis of water using excess renewable energy. This integration of HFCVs with circular economy principles can minimize waste, promote resource efficiency, and reduce the overall environmental impact of the transportation sector.

• Reduction of greenhouse gas emissions: HFCVs have the potential to significantly reduce greenhouse gas emissions in the transportation sector. As HFCVs produce zero tailpipe emissions, they can help mitigate climate change and improve air quality .When hydrogen is produced from renewable sources, the overall life cycle emissions

VIII. CURRENT CHALLENGES OF HFCVS

The HFCVs are propelled by electric motors, but instead of being powered by a battery,like a conventional electric vehicle (EV), they generate electricity from a chemical reaction between hydrogen (stored on board in fuel tanks) and oxygen (from the air), facilitated by a device called a fuel cell. The only byproducts of this process are electricity, which isused to drive the vehicle, and water vapor, which is released into the environment, making HFCVs a zero-emission transportation solution.

However, while the prospect of a vehicle that emits nothing but water vapor is tantaliz-ing, the path to the mass adoption of hydrogen FCVs is fraught with a variety of challenges as shown in Figure 7 and described in detail in this section.



• Infrastructure: One of the most significant challenges for HFCVs is the lack of a wide-spread hydrogen refueling infrastructure. Unlike gasoline stations, which are abundant in many areas, hydrogen refueling stations are relatively scarce and limited to certain regions. Establishing a comprehensive hydrogen infrastructure requires significant investments in the construction of new refueling stations, transportation, and storage facilities.

• Economic challenges: Currently, the costs associated with owning and operating an HFCVs are substantially higher than those for a conventional internal combustion engine vehicle or even a battery electric vehicle (BEV). High vehicle prices, largely due to the cost of the fuel cell systems, and expensive hydrogen fuel (resulting from the high costs of production, storage,

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Hydrogen production: The production of hydrogen for fuel cell vehicles poses challenges in terms of cost, energy efficiency, and environmental impact. The most common method of hydrogen production is through SMR, which relies on natural gas as a feed stock . This process produces CO2 emissions, which negate some of the environmental benefits of fuel cell vehicles. Developing and scaling up sustainabl and low-carbon hydrogen production methods, such as electrolysis using renewable energy sources, is crucial but currently faces challenges in terms of cost and scalability.

• Energy efficiency: While fuel cell vehicles are more energy-efficient than traditional internal combustion engine vehicles, they are less efficient than battery electric vehicles. The energy required to produce, transport, and store hydrogen, as well as the energy losses in the fuel cell system itself, result in a lower overall energy efficiency compared with battery electric vehicles. Improving the energy efficiency of fuel cell systems and optimizing the entire hydrogen production and distribution process is essential.

• Safety concerns: Hydrogen, being a highly flammable gas, raises safety concerns related to storage, handling, and refueling. While HFCVs undergo rigorous safety testing and are equipped with multiple safety features, concerns remain regarding the potential for leaks, the behavior of hydrogen in various accident scenarios, and the infrastructure ability to handle emergencies. Ensuring strict safety standards and regulations, as well as public awareness, is crucial for addressing these concerns.

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• Limited vehicle models and availability: Currently, the availability of HFCVs is limited, with only a handful of models on the market. The limited vehicle options make it challenging for consumers to find suitable choices that meet their preferences and requirements. Expanding the range of available vehicle models and increasing their availability in different regions are necessary to promote wider adoption.

• Competition from battery electric vehicles: Another major challenge for HFCVs comes from battery electric vehicles (BEVs). BEVs are currently ahead in the race for clean transportation. They benefit from better consumer awareness, more developed charging infrastructure, and rapidly improving battery technology, which has led to significant reductions in vehicle costs and improvements in driving range. While hydrogen HFCVs hold great promise as a sustainable transportation solution, the challenges they face are significant. Addressing these challenges requires a collaborative effort from industry stakeholders, governments, research institutions, and infrastructure developers. Continued investment in research and development, improvement in production processes, expansion of refueling infrastructure, and supportive policies can help overcome these barriers and drive the widespread adoption of HFCVs as a clean and sustainable transportation option.

IX. ADVANTAGES

- No vehicle emissions: hydrogen fuel cell produce only water vapor as a byproduct, and no carbon dioxide emissions during operation.
- Renewable energy: hydrogen can be made from renewable energy source.
- Energy storage: hydrogen fuel cells can
  store large amount of electricity for extended periods.
- Fuel economy: hydrogen fuel cells have a fuel economy that's about twice that of gasoline vehicles.

X. DISADVANTAGES

- Cost : hydrogen fuel cells are expensive to produce, store, and transport.
- Storage: hydrogen is difficult to store because it is many conditions requirements, like temperature, and is often stored as compressed gas or liquid.
- Transportation: hydrogen is expensive to transport, and there's not much infrastructure in place yet.
- Sensitivity to temperature: hydrogen fuel cells can be sensitive to change in temperature.
- Flammability: hydrogen is highly flammable.
- gasoline vehicles.

XI. CONCLUSION

This paper presents a literature review of hydrogen fuel cell technology and its evolution to the present. It provides a critical overview of recent traditional and contemporary research on manufacturing and storage process. Type of implementations of hydrogen fuel cell technology. For the past fifteen years, hydrogen and fuel cell technologies have improved significantly. Globally, this field continues to pose major obstacles (technical, commercial, economical and infrastructure-related) that must be addressed before fuel cells can achieve their full potential. With the ability to supply food, transportation, and power system utilities, hydrogen could play an essential part accompanying energy in the reduced economy.

It is not subject to the underlying requirement of instant stockpile balance, and thereby facilitates parallel pathways to further carbon reduction by supplying low carbon stability and preservation. It was also seen that five major types of hydrogen or hydrocarbon based fuel cells for has the operating range of temperatures and efficiencies ranges from 70 to 1000 oC and 40 to 60% respectively. All in all, the single largest obstacle in realizing the hydrogen and fuel cell promise is to develop a concentrated, reliable, and coherent energy framework. Countries must create and implement on a complete framework for hydrogen fuel cell technology that provides the lengthy certainty required to make substantial, revolutionary commitments.

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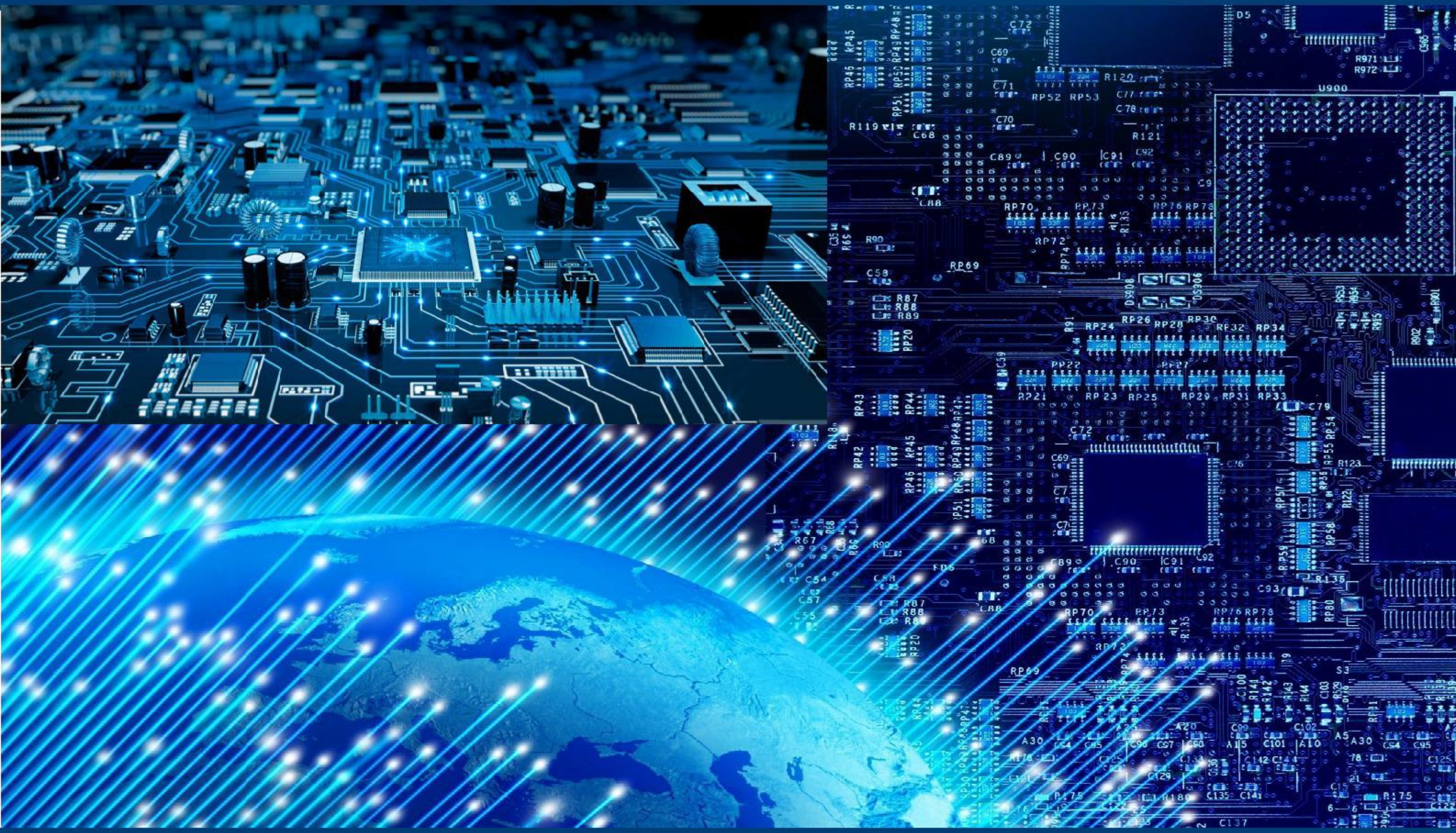

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