



HYDROGEN FUEL

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Abstract:

The growing energy demand and increasing environmental concerns have resulted in a shift towards sustainable energy sources. Hydrogen fuel is one of the most promising sources of clean energy. The production, storage, and use of hydrogen as a fuel have been the subject of intense research and development over the last few decades. In this research paper, we review the current state of research on hydrogen fuel, focusing on its production, storage, and use. We examine the advantages and disadvantages of hydrogen fuel and discuss the challenges that need to be addressed for its widespread adoption. Finally, we provide an outlook on the future of hydrogen fuel as a sustainable energy source.

1. Global view of fuel cells and clean energy technologies

1.1. Need for clean energy technologies

The need for clean energy technologies has become increasingly important in recent years due to several factors. First, the world's population continues to grow, increasing the demand for energy. Second, fossil fuels, which are currently the primary source of energy, are finite and will eventually be depleted. Finally, the burning of fossil fuels is a major contributor to climate change and air pollution, which pose significant risks to human health and the environment.

To address these challenges, there has been a growing interest in renewable and sustainable energy sources. Clean energy technologies, such as wind, solar, and hydropower, have the potential to provide reliable, cost-effective, and low-carbon energy. However, these technologies are not without their challenges. For example, wind and solar power are intermittent and require energy storage to provide reliable power. Hydropower can be impacted by droughts and changes in water availability. In addition, renewable energy technologies can be expensive to implement and require significant upfront investment.

Hydrogen fuel is a promising clean energy technology that can address some of these challenges. Hydrogen is a clean-burning fuel that can be produced from renewable sources and used in a variety of applications. Hydrogen fuel cells, which convert hydrogen into electricity, are

highly efficient and produce only water as a byproduct. Hydrogen can be used in transportation, power generation, and industrial processes, providing a versatile and low-carbon source of energy.

1.2 Fuel cell markets

Hydrogen fuel cells are a promising technology for generating clean and efficient electricity. They have the potential to be used in a wide range of applications, from transportation to stationary power generation. In recent years, the global hydrogen fuel cell market has experienced significant growth, driven by increasing demand for clean energy and government incentives for renewable technologies. In this paper, we will discuss the current state of the hydrogen fuel cell market, including market size, major players, and key drivers and challenges.

Market Size:

The global hydrogen fuel cell market has been growing steadily over the last few years. According to a report by Allied Market Research, the global hydrogen fuel cell market was valued at \$2.5 billion in 2020 and is projected to reach \$27.5 billion by 2030, growing at a CAGR of 28.4% from 2021 to 2030. The transportation sector, particularly fuel cell electric vehicles (FCEVs), is expected to be a major driver of growth, with increasing demand for zero-emission vehicles and the expansion of fueling infrastructure. In addition, the stationary power generation sector is also expected to grow, as fuel cells become a more cost-effective and reliable alternative to traditional power sources.

Major Players:

The hydrogen fuel cell market is currently dominated by a few key players, including:

1. **Ballard Power Systems:** A Canadian company that designs and manufactures fuel cells for various applications, including transportation and stationary power generation.
2. **Plug Power:** An American company that designs and manufactures fuel cells for material handling equipment, backup power, and other applications.
3. **Toyota:** A Japanese automaker that has been a leader in developing fuel cell vehicles, including the Toyota Mirai.
4. **Hyundai:** A South Korean automaker that has also been investing heavily in developing fuel cell vehicles, including the Hyundai Nexo.
5. **Doosan Fuel Cell:** A South Korean company that designs and manufactures fuel cells for stationary power generation and other applications.

Key Drivers and Challenges:

The hydrogen fuel cell market is being driven by several factors, including:

1. Government support and incentives for renewable technologies, particularly in countries such as Japan, South Korea, and Germany.
2. Increasing demand for zero-emission vehicles, particularly in Europe and Asia.
3. The potential for hydrogen fuel cells to provide reliable, cost-effective, and low-carbon power for a variety of applications.

However, there are also several challenges that must be addressed for the hydrogen fuel cell market to continue to grow, including:

1. High upfront costs and the need for infrastructure development, particularly for fueling stations and hydrogen production facilities.
2. Limited availability of hydrogen fueling infrastructure, particularly outside of Europe and Asia.
3. Competition from other renewable technologies, such as batteries and solar power.

2. The DOE Hydrogen and Fuel Cells Program

2.1. Hydrogen production and delivery

Hydrogen production and delivery are critical components of the hydrogen fuel economy. Hydrogen can be produced from a variety of sources, including fossil fuels, renewable energy sources, and water electrolysis. The production method used can have a significant impact on the carbon footprint of hydrogen, with renewable energy sources and water electrolysis being the most sustainable options.

2.1.1. Hydrogen Production Methods

2.1.1.1. Steam Methane Reforming (SMR)

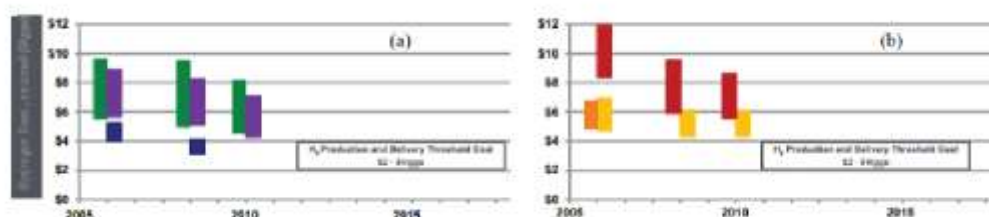


Fig. 1. Projected high-volume cost of hydrogen production (delivered):
 (a) distributed production (near term) ■ bio-derived liquids ■ electrolysis ■ natural gas reforming
 (b) central production (longer term) ■ electrolysis ■ biomass gasification ■ nuclear

Steam methane reforming is currently the most common method for producing hydrogen. It involves reacting methane with steam in the presence of a catalyst to produce hydrogen and carbon monoxide. The carbon monoxide is then reacted with water to produce additional hydrogen and carbon dioxide. This method is relatively inexpensive and can be scaled up to produce large quantities of hydrogen, but it is also carbon-intensive and contributes to greenhouse gas emissions.

2.1.1.2. Electrolysis

Electrolysis involves passing an electric current through water to separate the hydrogen and oxygen atoms. This method can be powered by renewable energy sources such as solar, wind, and hydroelectric power, making it a sustainable option for hydrogen production. However, electrolysis is currently more expensive than steam methane reforming and requires significant infrastructure for water and power supply.

2.1.1.3. Biomass Gasification

Biomass gasification involves heating organic materials such as wood, crop residues, and animal waste in the absence of oxygen to produce a gas mixture that contains hydrogen, carbon monoxide, and carbon dioxide. This method can be carbon-neutral or even carbon-negative, depending on the source of the biomass. However, it is currently not a widely used method for hydrogen production due to technical and logistical challenges.

2.1.2. Hydrogen Delivery Methods

Once hydrogen is produced, it must be transported to fueling stations or end-users. There are several methods for delivering hydrogen, including pipelines, trucks, and ships.

2.1.2.1. Pipelines

Hydrogen can be transported through pipelines, much like natural gas. However, the pipeline infrastructure for hydrogen is currently limited, and significant investment would be required to develop a robust pipeline network.

2.1.2.2. Trucks

Hydrogen can also be transported by trucks, either in compressed gas form or liquid form. However, this method is not as efficient as pipelines and can be costly due to the need for specialized trucks and infrastructure.

2.1.2.3. Ships

Finally, hydrogen can be transported by ships, either in compressed gas form or liquid form. This method is mainly used for long-distance transport of hydrogen between countries or continents, and it requires specialized infrastructure and vessels.

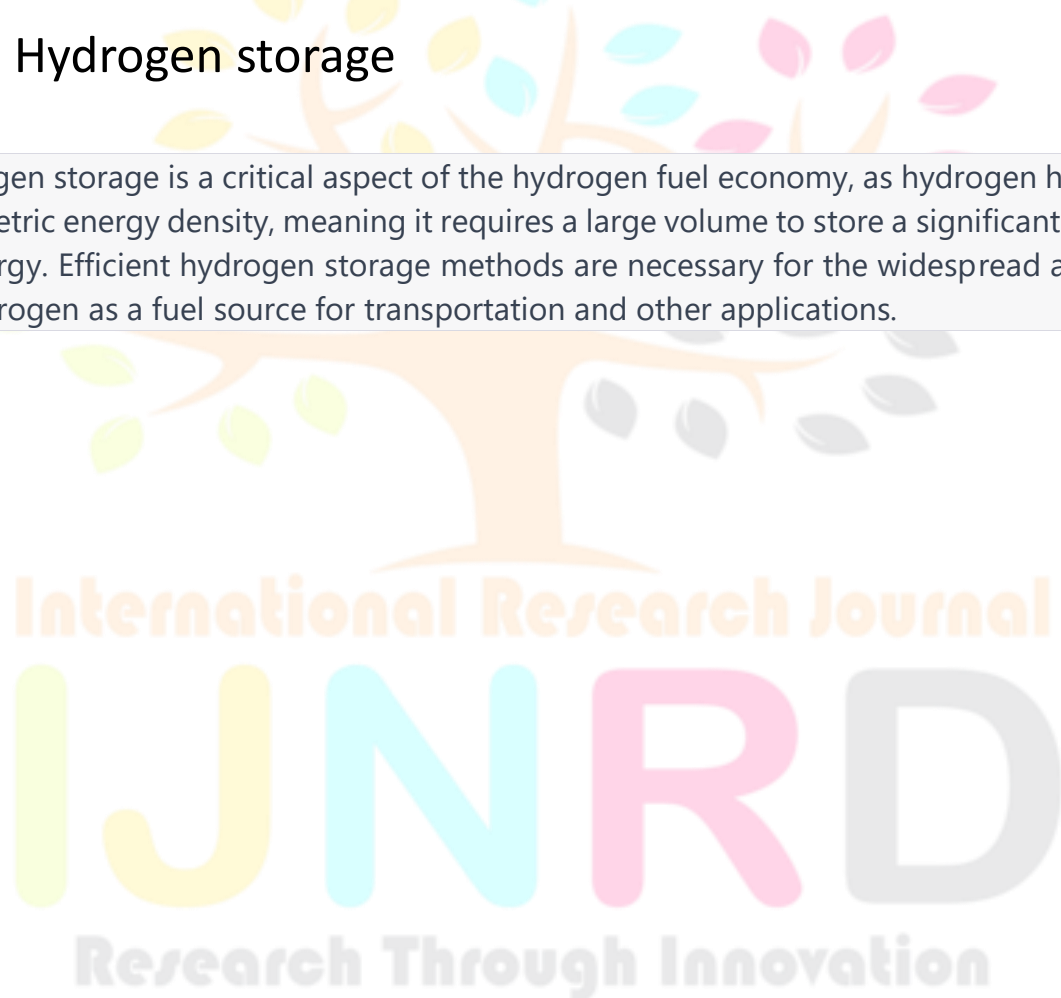
2.1.3. Challenges and Opportunities

The production and delivery of hydrogen present several challenges and opportunities. One of the main challenges is the high cost of hydrogen production and delivery, particularly for sustainable methods such as electrolysis. The limited infrastructure for hydrogen delivery is also a significant challenge, particularly for long-distance transport. However, the growing demand for zero-emission vehicles and the increasing availability of renewable energy sources present significant opportunities for the growth of the hydrogen economy.

Governments and industries around the world are investing in the development of hydrogen production and delivery infrastructure, with a particular focus on renewable energy sources and electrolysis. As the cost of renewable energy continues to decline, the cost of sustainable hydrogen production is also expected to decrease. In addition, the growth of the hydrogen economy is expected to create new job opportunities and drive economic growth.

2.2. Hydrogen storage

Hydrogen storage is a critical aspect of the hydrogen fuel economy, as hydrogen has a low volumetric energy density, meaning it requires a large volume to store a significant amount of energy. Efficient hydrogen storage methods are necessary for the widespread adoption of hydrogen as a fuel source for transportation and other applications.



2.2.1. Hydrogen Storage Methods

There are several methods for storing hydrogen, including compressed gas, liquefied gas, metal hydrides, and chemical storage.

2.2.1.1. Compressed Gas

Compressed gas storage involves storing hydrogen at high pressure in tanks made of materials such as carbon fiber, steel, or aluminum. This method is relatively simple and inexpensive but requires a large volume of storage tanks and does not provide high energy density.

2.2.1.2. Liquefied Gas

Liquefied gas storage involves cooling hydrogen to -253°C to liquify it, reducing its volume and increasing its energy density. This method provides a higher energy density than compressed gas storage but requires cryogenic storage tanks, which can be expensive.

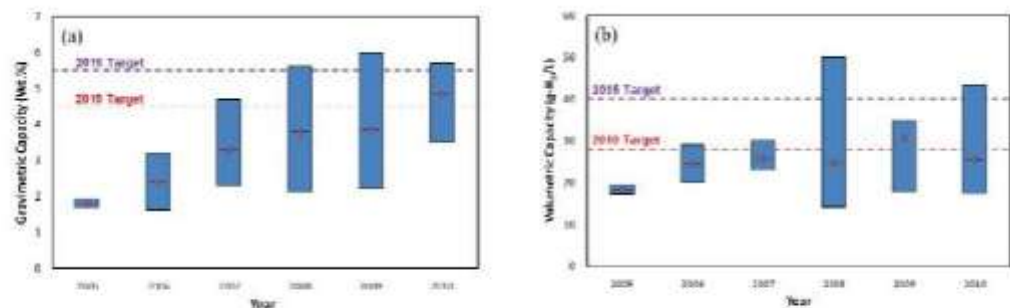


Fig. 2. Projected capacities for complete H₂ storage systems for chemical, metal hydride, sorbent, and physical storage technologies: (a) projected ranges of system gravimetric storage capacity, (b) projected ranges of system volumetric storage capacity. The red and purple lines correspond to 2010 and 2015 DOE targets, respectively. The height of the bars corresponds to the number of technologies examined in a given year.

2.2.1.3. Metal Hydrides

Metal hydrides are materials that can absorb and release hydrogen. Hydrogen is stored in the interstitial spaces between the metal atoms. This method provides high storage capacity and can be reversible, meaning the hydrogen can be released and stored again. However, it is currently expensive and requires significant research and development.

2.2.1.4. Chemical Storage Chemical storage involves chemically bonding hydrogen to another substance, such as ammonia or methanol. The hydrogen can then be released by a chemical reaction. This method provides high energy density and can be used for long-term storage. However, it is currently expensive and requires significant infrastructure for production and storage.

2.2.2. Challenges and Opportunities

Hydrogen storage presents several challenges and opportunities. One of the main challenges is the high cost of hydrogen storage, particularly for high-density storage methods such as metal hydrides and chemical storage. The limited availability of hydrogen storage infrastructure is also a significant challenge, particularly for transportation applications.

However, the growing demand for zero-emission vehicles and the increasing availability of renewable energy sources present significant opportunities for the growth of the hydrogen economy. Governments and industries around the world are investing in the development of hydrogen storage technologies, with a particular focus on metal hydrides and chemical storage. The development of efficient and cost-effective hydrogen storage methods is critical for the widespread adoption of hydrogen as a fuel source.

3. Analyses of hydrogen fuel cell in india

3.1. Current Status of Hydrogen Fuel Cell Technology in India

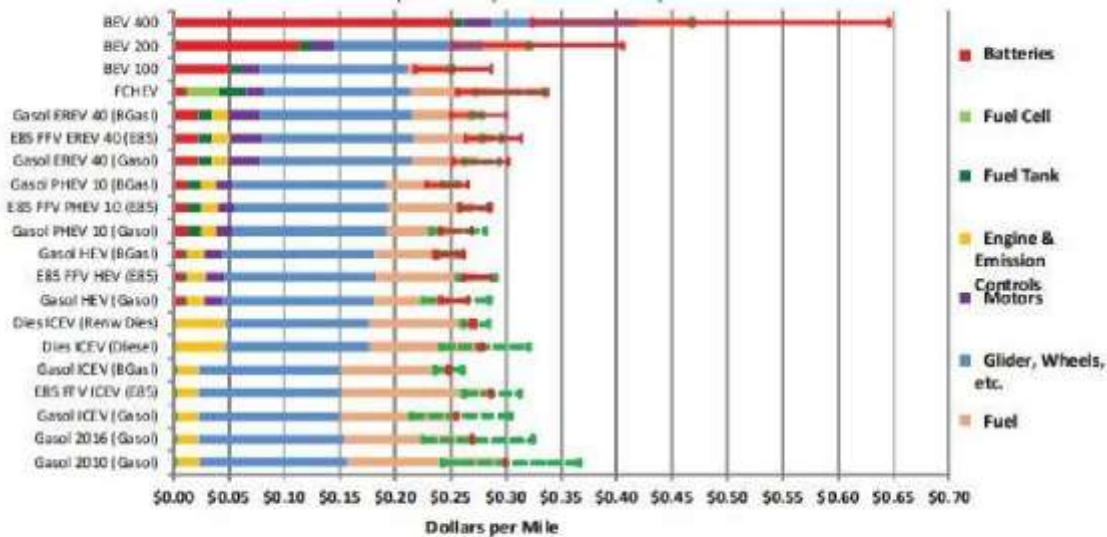
Hydrogen fuel cell technology is still in its early stages of development in India, and the country lags behind other developed nations in terms of research and development. However, the Indian government has recognized the potential of hydrogen fuel cell technology and has taken several initiatives to promote its adoption.

In 2018, the Indian government announced the National Hydrogen Energy Roadmap, which aims to create a hydrogen-based economy by 2030. The roadmap focuses on the use of hydrogen in transportation, power generation, and industrial applications.

3.2. Hydrogen Fuel Cell Vehicles

Hydrogen fuel cell vehicles (FCVs) have the potential to significantly reduce greenhouse gas emissions from the transportation sector. In India, several automakers, including Tata Motors and Mahindra & Mahindra, have announced plans to develop FCVs.

However, the lack of hydrogen refueling infrastructure is a significant barrier to the adoption of FCVs in India. Currently, there are only a few hydrogen refueling stations in the country, and they are concentrated in a few cities. The Indian government has announced plans to set up a network of hydrogen refueling stations across the country, but the implementation of these plans has been slow.



Component cost per mile. All platforms assume technology available in 2030 except where noted.

3.3 Power Generation

Hydrogen fuel cells can also be used for power generation. In India, several companies, including Reliance Industries and Indian Oil Corporation, are exploring the use of hydrogen fuel cells for backup power and remote power generation.

The Indian government has also announced plans to use hydrogen fuel cells for power generation in remote areas without access to grid electricity. However, the implementation of these plans has been slow due to the high cost of hydrogen fuel cells and the lack of hydrogen production and delivery infrastructure.

3.4. Industrial Applications

Hydrogen fuel cells have several potential industrial applications in India, including in the chemical, pharmaceutical, and steel industries. However, the adoption of hydrogen fuel cells in these industries has been slow due to the high cost of the technology and the lack of awareness about its benefits.

The Indian government has announced several initiatives to promote the adoption of hydrogen fuel cells in these industries, including the creation of a hydrogen-based steel production plant. However, the implementation of these initiatives has been slow due to the lack of infrastructure and the high cost of the technology.

4. Summary

The Fuel Cell Technologies Program continues to promote and strengthen its R&D activities. It is continuing to validate the technology in hydrogen stations, fuel cell vehicles, distributed generation, forklifts, and backup power. Analysis efforts explore not just upfront costs of hydrogen and fuel cell systems – although those are very important – but also life cycle costs, and the analyses are used to guide research, development and demonstration (RD&D) efforts. The Program continues to leverage other hydrogen and fuel cell activities in the US and globally to multiply and maximize the impact of our efforts.

5. REFERENCE

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