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Study of Hydrogen Fuel Produced from Solar Energy

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Abstract: *Many nations are now experiencing a large disparity between power demand and production. In 2020, developing countries such as India would face a 4.3 percent energy shortfall. There are several limitations and drawbacks connected with traditional (non-renewable) energy supplies (coal, natural gas). Conventional (non-renewable) energy sources cannot be renewed in our lifetimes, and their cost and availability are its most significant drawbacks. Non-renewable resources have the disadvantage of producing greenhouse gases and causing environmental damage as a by-product. Countries are currently focusing on renewable energy sources to fulfil the demand for power (Geothermal energy, Biomass, wind energy and hydrogen cell). There are several advantages connected with renewable energy supplies, such as availability, zero carbon emissions, and so on Hydrogen fuel cells utilize hydrogen as a fuel in an electrochemical process that creates energy by combining hydrogen and oxygen. Hydrogen fuel cells have various benefits over other power sources, including being easily accessible, emitting no pollution, being extremely effective, and having a short charging period. We will cover the importance of hydrogen fuel cells, some common attributes of hydrogen, and certain methods used to manufacture hydrogen, as well as their general classification on the basis of production, in this study work.*

***Key Words*: Conventional energy, Hydrogen fuel, zero carbon emissions, a short charging period, Geothermal energy.**

1. INTRODUCTION

Hydrogen is the first element in the periodic table of elements, with atomic number 1, is non-metal, colourless, odourless, highly reactive, and inflammable, and has all of the characteristics needed to be a future energy source and a fuel for our cars. Hydrogen-fueled space rockets, as well as autos and other modes of transportation, are examples of hydrogen vehicles. The Hydrogen energize engine with its chemical reactions taking place which in turn provides mechanical energy which used to powerize electric motors. It is carbon free and hence ecologically benign, as opposed to traditional energy sources (coal, oil, and natural gas). The countdown for conventional energy sources has already begun, since they are now being depleted. As a result, hydrogen is an excellent choice for meeting human energy needs in the future. In addition to the aforementioned characteristics, hydrogen's abundance makes it difficult to employ as an energy source or fuel. Although hydrogen is abundant in both organic and inorganic substances on Earth, such as water and hydrocarbons, it is rare in the free and molecule state. As a result, elemental hydrogen is manufactured artificially, and its safe and environmentally friendly manufacturing is critical. When it comes to environmentally friendly hydrogen generation, renewable energy, particularly solar energy, is the natural choice for the input energy.

Fig.1. Hydrogen Fuel for vehicle application

1.1 Hydrogen as a Potential Fuel

Human beings have need energy to survive throughout history. Energy was originally found in the form of fire, which met most of our requirements. Later, we learnt about the power of fossil fuels, and our demand for energy has risen ever since.

Coal, natural gas, petrol, diesel, and other high-demand fuels were used in excess as demand and supply increased. All of these fuels are known as fossil fuels, and they are the sole source of energy for our autos, factories, and other energy-intensive applications. To put it another way, we became increasingly reliant on fossil fuels, harvesting coal, oil, and gas more intensively to meet our energy demands, lower fuel costs, boost production of the commodities we required, and sustain our society's high standards of living, among other things. However, the negative consequences of these practises were not so pleasant. However, like with any prescription treatment, aggressive mass research of fossil fuels resulted in some major negative effects:

(1) Fossil fuel stocks are rapidly depleting.

(2) The global problem of global warming, which is caused by environmental harm caused by greenhouse gas emissions, which are a by-product of fossil fuel burning.

(3) Future plans to provide green fuels for environmental healing and energy from renewable sources.

Solar, wind, geothermal, biomass, waves, tides, and hydropower were all studied as part of the strategy to replace non-renewable energies with renewable energies. Renewable energy sources have the benefit of being both sustainable (i.e., they can never be depleted) and abundant (i.e., sun, wind, and hydro); they may also be either free of greenhouse gas emissions (i.e., solar, wind, and hydro) or less polluting (i.e., biomass) (e.g., biomass). Renewable energy has a number of drawbacks, including the inconstancy of accessible energy and limited prospective energy sources. For example, there is no set wind pattern in wind energy; it fluctuates over time, and the intensity of solar radiation falling on the Earth's surface changes over time in solar energy.

The increase in global energy consumption can also be observed in this graph. In the absence of fossil fuels, we require an extremely powerful energy source that is both sustainable and environmentally benign and capable of powering all of the world's energy-intensive industries. Hydrogen fuel came into focus after multiple brainstorming sessions since it can be utilized as a fuel in internal combustion engines as well as a source of energy. To put it another way, hydrogen may be utilized as both an energy transporter and a motor fuel. Because electricity and heat are the two most common uses of primary energy sources, such as fossil fuels and solar, wind, and other renewable sources, they are often utilized.

1.2. Some Common Properties of Hydrogen

The name "hydrogen" comes from the Greek terms "hydro" (which means "water") and "genes," which means "creator." It was given this name by a well-known French scientist because when it burns, it "creates water." Under normal circumstances, hydrogen is a colourless, odourless, tasteless, and harmless gas. It moves through the phase at 423 degrees Fahrenheit. Hydrogen has the lowest density per unit volume of all the elements in the periodic table. Because of the leakage issues, these qualities make hydrogen storage difficult for scientists and engineers. The same qualities allow hydrogen atoms to permeate the molecular structure of certain metals, making them "brittle," particularly in the presence of physical stressors such as high temperatures or pressures. Hydrogen's combustion qualities make it an excellent fuel and energy carrier. It has nearly three times the energy content per unit mass of gasoline, often called as high heating value. The quantity of energy produced when a fuel is totally burnt is known as the high heating value. Hydrogen ignites across a wide range of concentrations, from roughly 4% to 74%, and just a modest amount of energy is required to start the process. According to physicists, hydrogen accounts for more than 90% of all atoms in the universe.

When hydrogen is mixed with oxygen in a combustion or electrochemical conversion process, energy is produced, and water vapour is produced as a byproduct. Fire, explosion, and ignite on contact with air are the primary threats connected with hydrogen leaks due to its extremely reactive traits and features. In the presence of air, hydrogen is instantly ignited when it comes into contact with sources of heat, such as open flames, electrical sparks, or static electric discharge. The flame of most hydrogen fires is characterized by a torch or jet beginning at the hydrogen discharge point. Because hydrogen flames burn fiercely and produce little radiant heat, they are difficult to see with the human eye. Because the flames might be mishandled, this condition can be harmful. Because of its fuel properties, such as low density and high diffusivity, which cause explosions under pressurised conditions, the risk of hydrogen exploding is high; however, the blast energy resulting from its explosion is typically less than that resulting from the equivalent energy content of other fuels. In a confined space/pressurized environment, explosion is primarily triggered by the development of pressure waves followed by the formation of sound waves induced by sufficiently fast combustion. A hydrogen explosion might do a lot of harm. Furthermore, while hydrogen is odourless and benign in nature, it may cause asphyxia by diluting the oxygen content in the air required for human breathing. The risk of asphyxiation (a situation in which one is deprived of oxygen.

Because the amount of hydrogen that may generate an oxygen-deficient atmosphere is far within the flammable range, fire and explosion are significant threats compared to asphyxiation. Liquid hydrogen, in addition to the aforementioned fire dangers, poses an extra threat due to its exceptionally cold (cryogenic) temperature. However, when it comes to safety, hydrogen offers a number of benefits over conventional fuels. Hydrogen fires are considered to be safer than flames employing conventional fuels since the former has a much faster flame speed and dissipates sooner than the latter, allowing hydrogen to burn swiftly even in liquid form. Because of hydrogen's fast-burning properties, other materials adjacent to the flame are less likely to catch fire, lessening the risk of emission of harmful gases.

2. Study of Hydrogen Production Method

Hydrogen is thought to be the ideal alternative for a carbon-free fuel that can be easily obtained from a variety of chemical compositions such as water, HC fuels, Hydrogen sulphide, biomass, and so on. Because hydrogen is not readily available in the environment, it must be dissociated in order to produce energy. There are four types of energy that may be used to power a hydrogen generation process: thermal, electrical, photonic, and biological energy. These types of energy can be derived from primary energy sources (fossil, nuclear, and renewable) or recovered energy sources via a variety of routes. Most scientists did extensive research and came up with an alternate type of ammonia, which has a high hydrogen concentration and can be utilised directly in an IC engineThey are now performing a brief research on the energy and energy efficiency of a solar–hydrogen–fuel cell hybrid energy system, and they are receiving encouraging feedback. Overall energy efficiency values for the system vary from 0.88 percent to 9.7 percent, with minimum and maximum overall energy efficiency values of 0.77 percent and 9.3 percent, respectively, according to the researchers.

Apart from that, no catalysts are used in the single-step thermal composition of methane. From concentrated solar energy and methane, the process creates hydrogen-rich gas and high-grade carbon black (CB).

Because solid carbon is segregated, it provides an unusual way for possibly cost-effective hydrogen generation from solar energy without generating carbon dioxide. Solar decarbonization of fossil fuels may also create hydrogen, with energy efficiency of 32.5 percent for solar decomposition of natural gas, 46 percent for sun steam reforming of natural gas, and 46 percent for solar steam gasification of coal. Although the first approach has a lower energy efficiency than the latter two, it is a carbon dioxide-free technique of hydrogen production.

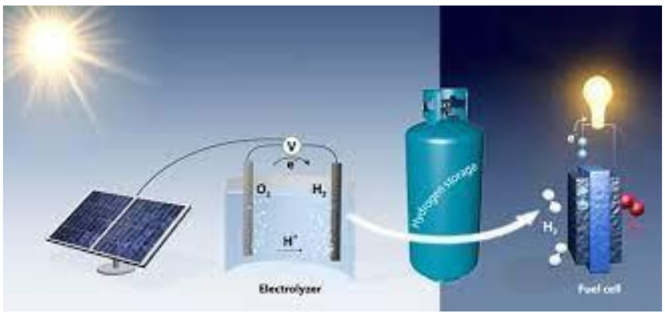

Fig.2. Hydrogen generation using solar via Electrolysis

2.1 Classification of Hydrogen production:

1. Electrical Energy :

Method:

1. Electrolysis
2. Plasma arc decomposition

Material Resources:

1. Water
2. Natural gas

Brief Description:

1) Using a direct current to drive electrochemical processes, water is decomposed into O2 and H2.

2) To make hydrogen and carbon soot, clean natural gas (methane) is passed through an electrically generated plasma arc.

1. **2. Thermal energy:**

Method:

1. Thermolysis
2. Thermo-catalyst
3. Thermochemical processes

Material Resources:

1. Water
2. H2S cracking
3. Biomass
4. Water splitting

Brief Description:

1. Steam is heated to over 2,500 K, at which point the water molecules thermally disintegrate.

2. H2S is thermo-catalytically fractured from the sea or from other industrial processes.

3. Thermo-catalytic biomass to hydrogen conversion

4. Chemical reactions (whether redox or not) are carried out in a cyclical manner, with the end effect being water molecule breaking.

3. Photonic energy:

Method:

1. PV electrolysis
2. Photo-catalysis
3. Photo-electrochemical method

Material Resources:

Water

Brief Description:

1. PV panels provide electricity, which is used to power the electrolyser.

2. To create hydrogen from water, complex homogeneous catalysts or molecular devices with photo-initiated electron collection are used.

3. Photovoltaic electricity is generated by a hybrid cell, which drives the water electrolysis process.

3. Renewables for Hydrogen Production

The input sources for hydrogen generation include thermal and electrical energy, both of which are provided by solar energy. Renewable energy sources, unlike fossil fuels (coal, oil, and natural gas), which emit greenhouse gases such as carbon dioxide and contribute to global warming, are recognised as ecologically friendly and long-term energy sources. In addition, fossil fuels are limited and rapidly depleting resources. Here's a quick rundown of a few well-known renewable energy technologies for generating power and heat. In terms of renewable energy sources, electrolysis, thermolysis, photo-electrolysis, and photosynthesis are all discussed.

Solar energy serves two purposes:

1. Using a photovoltaic system to convert sunlight into energy

2. Using concentrating collectors to generate heat.

Solar radiation is diverted to the tune of 30% by the Earth's atmosphere. The Earth's surface receives roughly 3:9 1024 MJ incident solar energy per year after reflection by the atmosphere, which is nearly 10,000 times higher than current global energy usage. As a consequence, harnessing just 1% of photonic energy would be sufficient to meet all human energy requirements.

Photovoltaic systems, as previously said, are a revolutionary means of generating power since they utilise free solar energy. Although the intermittent nature of solar radiation restricts its applicability, it can still be useful in some circumstances.

Photovoltaic systems, as previously said, are a novel technique of generating electricity since they rely on free solar energy. Solar energy may be stored in a battery bank during off-sunshine hours, despite the intermittent nature of solar radiation. Photovoltaic systems can provide continuous electricity throughout the day as stand-alone systems or as part of a grid-connected system. A silicon solar cell's efficiency typically varies between 12 and 15%. With GaAs solar cells, however, it can be as high as 25–30%. The former is less costly than the latter, which is mostly utilised in space.

The total efficiency of a photovoltaic (PV) system may also be calculated by adding the efficiencies of its various components, such as the solar cell, module, and battery. PV technology has two disadvantages: poor efficiency and expensive solar cell charges, both of which may be overcome with proper study. Solar thermal technology, on the other hand, has progressed. Many different types of solar collectors can be utilised depending on the required temperature.

The most basic is the flat-plate collector (FPC): solar radiation strikes a flat transparent surface, which is subsequently transported to an equal-size absorbing/collecting surface, which is generally made of Cu or Al metal. Because of its excellent heat conductivity (Cu) and low cost, Cu or Al metal is favoured (Al).

Several solar collectors' working temperatures, concentration factors, and power capacities are mentioned below.

Solar collector	Concentration factor	Temperature (°C)	Power capacity
Flat-plate collector	1	<200	<1 MW (thermal)
Vacuum-tube collector	3	<300	<1 MW (thermal)
Concentrating solar collector (trough type)	40–80	<350	<50 MW (electrical)
Field mirror collector	200–700	<1,500	<150 MW (electrical)
Parabolic collector	1,000–2,500	<2,500	<100 kW (thermal)/E_{mh}

3.1. Table of Corresponding Power Capacity wrt to its Temperature.

A riser made up of several metal tubes is linked to the receiving surface, which is a black metallic surface sandwiched between a metal box and a glass surface. The appropriate insulator is used to insulate the metal box (for example, glass wool). To receive solar flux, the glazed surface is exposed to the sun. The metal box is angled away from the horizontal at a latitude that corresponds to the best solar flux position.

The incoming solar energy is absorbed on the receiver surface after passing through the glass. The heat is transferred to the water in the riser, which is then pumped up to a storage tank. On both ends, top and bottom, the storage tank is linked to the riser. When heated water rises from the bottom to the top of the riser, it circulates inside the riser and flows to the storage tank using a combination of thermo-siphoning and gravity. It's worth noting that the amount of thermal energy received is proportional to the surface area of the receiver.

With a concentration factor of 1, a thermal output of up to 1 MW may be generated at temperatures up to 200 _C by connecting flat-plate collectors in series. The other collectors are those who concentrate their efforts. They have a higher concentration factor, power, and working temperature. In the next sections, we'll look at how solar energy may be used to make hydrogen.

The vacuum-tube collector differs from the flat plate collector in that it does not need a riser, instead relying on tubes. When exposed to the sun, an absorber plate heats up and transfers the heat to a chemical through a heat pipe. The material is prone to converting from a liquid to a gaseous state. Heat is then transported from the heated vapour/gas to the water in the tank. To restrict convective heat losses from the absorber surface to the environment, a vacuum is established within the evacuated tube. Depending on the required hot water temperature, the number of tubes can be raised or lowered. Tubes can be readily removed from the water heater for maintenance, which is one of the benefits.

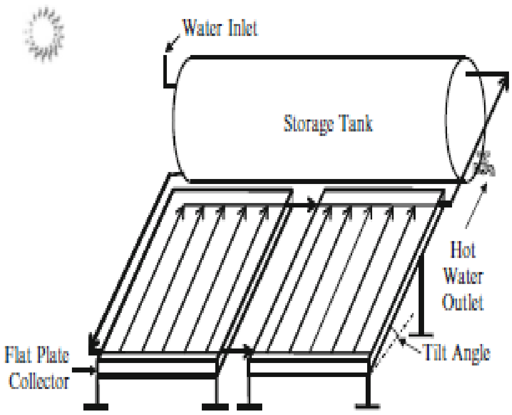

Fig.3. Solar Panel structure

4. Solar Hydrogen Production

Hydrogen should be created utilising sustainable energy sources such as solar energy to be a cost-effective and long-term solution. Because H2 may be produced directly from abundant and renewable water and sunlight, photo-catalytic water splitting is the most promising technique for this purpose. If developed with economic feasibility in mind, this technology might be the ultimate solution to future energy and environmental challenges.

Solar hydrogen generating has a high investment cost when compared to fossil-fuel-based hydrogen production systems. Hydrogen generation in a regenerative approach, such as photochemical water splitting, has been studied. As a cost-effective and efficient technique of manufacturing hydrogen, photo-catalytic water splitting has been devised, in which sunlight is absorbed and water is quickly divided into hydrogen and oxygen. Many efforts in photo-catalytic water splitting have concentrated on improving the efficiency and stability of the photoactive materials in order to meet the needed efficiency objective for commercialisation.

Catalysts that increase the reduction of protons to molecular hydrogen, enhanced by direct excitation by a photo-sensitizer, are required for the reductive side of this process. Molecular platinum and palladium-based systems have recently been developed as heterogeneous catalysts. Supramolecular complexes with large turnover rates and volumes show promise in photocatalytic hydrogen production. Direct sunlight or solar-based power are the energy inputs for a hydrogen-evolving process in an aquatic setting. Photo-induced hydrogen producing technologies are described and explained in this book. Sun-driven water splitting provides a number of advantages in terms of long-term energy usage.

Solar energy must be transformed into a form that can be stored. The first half of this chapter gives an overview of the many methods for creating hydrogen by dissociating water with light energy. Water splitting photo-electrochemistry and photo-catalytic reaction processes are being explored. There is a discussion of current developments and new contributions to light-based hydrogen generating systems. Photo-catalytic water-splitting devices for hydrogen and oxygen production are completely designed and scaled up. Students learn the fundamentals of photo-electrolysis and photo biological methods, as well as specific examples, at the end of the course.

4.1. General Classification of Solar Hydrogen Production

Solar-powered hydrogen generation may be divided into four categories:

(1) photovoltaic

(2) thermal energy

(3) photo-electrolysis

(4) bio-photolysis.

Low-temperature applications and high-temperature applications, commonly known as concentrated solar energy, are two ways to use solar thermal energy. Low-temperature uses of concentrated solar thermal energy include photovoltaics, photo-electrolysis, and bio-photolysis, whereas high-temperature applications include solar thermolysis, solar thermochemical cycles, solar gasification, solar reforming, and sun cracking.

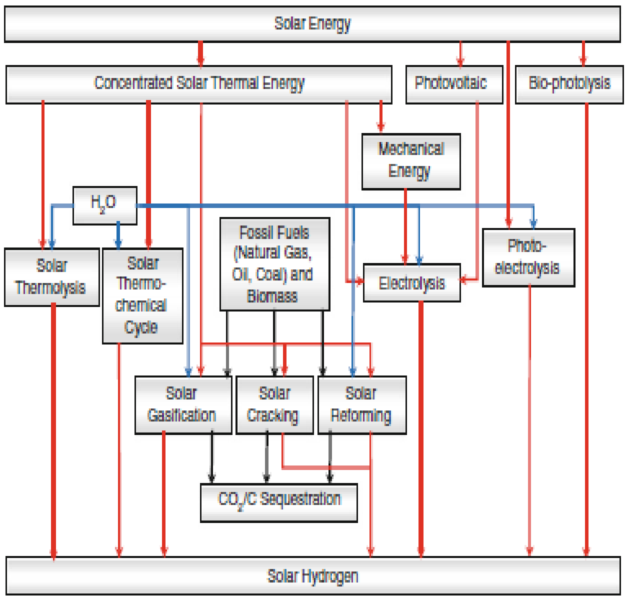

Fig.4.1. Solar Hydrogen Formation Methology

1. Photovoltaic-Based Electrolysis

Photovoltaic (PV) panels were used to make hydrogen by electrolyzing water with the power produced by the PV cells. A current generated by solar cells can be used to electrolyze water. Because the hydrogen produced by this process is not economically viable due to the high cost of PV technology, more study is needed in this field. The electrolysis produced oxygen as a byproduct.

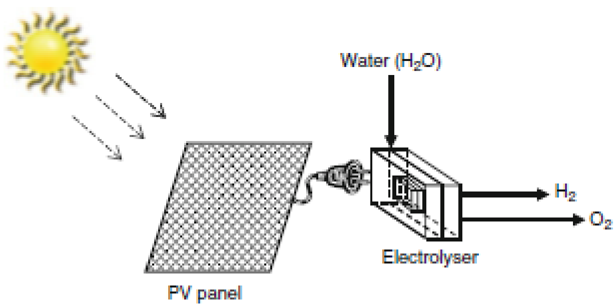

Fig.4.1.1. Photovoltaic- Based Electrolysis

2. Hydrogen Production Using Concentrated Thermal Energy

This diagram also shows the chemical sources of hydrogen, including water for solar thermolysis and solar thermochemical cycles, fossil fuels for sun cracking, and a combination of fossil fuels and H2O for solar reforming and solar gasification. All of these technologies rely on concentrated solar radiation's thermal energy as a high-temperature energy source since they involve endothermic processes.

Water thermolysis, or single-step thermal dissociation of water, can be written as

$$H2O \longrightarrow H2 + ½ O2$$

Thermochemical Cycles

Water splitting thermochemical cycles have an advantage over thermolysis in that they do not have the difficulty of H2/O2 separation and can operate at extremely low peak temperatures (1,200 K). Below is a diagram of a two-step thermochemical cycle based on metal oxide redox reactions.

$$MxOy \longrightarrow xM + y/2\ O2$$

Second step (non-solar):

$$xM + yH2O \longrightarrow MxOy + yH2$$

MxOy represents the proper metal oxide, whereas M represents the metal. The solar thermal dissociation of the metal oxide to the metal or lower-valence metal oxide is the first endothermic phase. Metal hydrolysis, which creates H2 and metal oxide, is the second non-solar exothermic reaction.

The net reaction is (H2O $\longrightarrow$ H2 + ½ O2), but because H2 and O2 are formed in different steps, the need for high-temperature gas separation is thereby eliminated.

3. Hydrogen Production from Fossil Fuel Decarbonization

Solar thermochemical processes such as sun cracking, solar reforming, and solar gasification can be used to produce hydrogen from fossil fuels.

The comprehension of the sun cracking process is aided by the heat degradation of natural gas (NG), oil, and other hydrocarbons, which may be represented by the simplified net reaction:

$$CxHy \longrightarrow xC + y/2\ H2$$

Some of these methods are already in use by a large number of people. In internal combustion, the heat supplied by burning the feedstock as the process heat results in contamination of the gaseous product; in external combustion, the heat supplied by burning the feedstock as the process heat results in reduced thermal efficiency due to the irreversibility associated with indirect heat transfer.

4. Solar Cracking of Methane

A prototype solar reactor for solar methane cracking. It consists of a graphite cavity receiver (a cubic blackbody absorber with a 20-cm length) and a quartz window that allows concentrated solar energy to flow through the aperture (9-cm diameter). The inside chamber of the reactor is swept by nitrogen, isolating it from the oxidising environment outside. The four tubular graphite zones of the solar absorber, which are positioned in parallel and vertically, shatter methane. Each reaction zone has its own gas supply, which feeds the reactor with a combination of Ar and CH4. Two concentric graphite tubes make form the reactor tube.

The gas intake is a 12-mm outer diameter, 4-mm inner diameter inner tube, whereas the gas exit is a 12-mm outer diameter, 4-mm inner diameter outer tube (24-mm outer diameter, 18-mm inner diameter). Through the annular gap between the outer and inner tubes, a gas combination of Ar and CH4 flows into the inner tube.

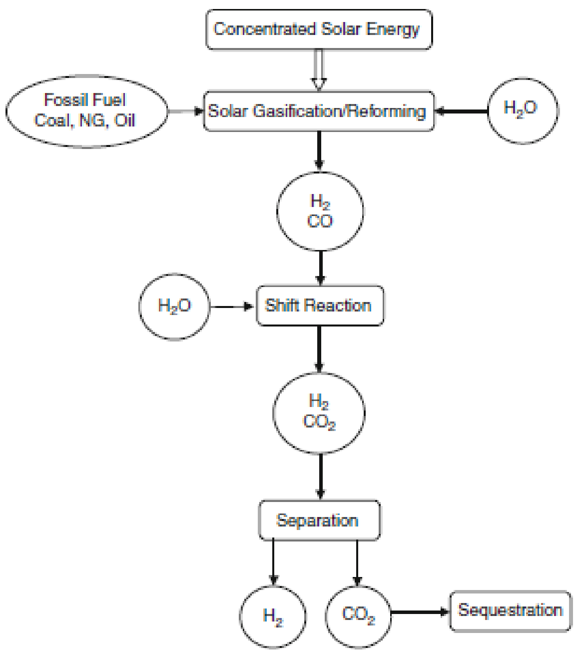

Fig. 4.4.Hydrogen Extraction based on Solar Cracking Methane

5. CONCLUSIONS

- It is studied that, Hydrogen is a superior fuel alternative for automobiles and other vehicles, and it can entirely fulfil the energy demands of both urban and rural areas.
- As we know hydrogen isn't available individually and is found in both organic and inorganic component.
- Solar hydrogen production technology is appealing as an input energy source in many accessible hydrogen production technologies; that is, solar energy is free and abundant, and its environmental impact is significantly reduced because solar is a sustainable source of energy.
- While photochemical and PV-based hydrogen generating methods are well-established, biological hydrogen production and bio-photolysis methods require more study in order to increase their efficacy.

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