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Future of Nanotechnology in Solar Energy and Hydrogen Energy

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

As we are moving towards a more technological future. The demand for greener energy is increasing and with this, new challenges are being faced relating to the production and use of renewable energy. To tackle this problem and bridge the gap between the production and consumption of renewable energy, nanotechnology is advancing. This Paper gives the basic summary of nanotechnology and its manufacturing and aims to introduce several significant applications of nanotechnology in renewable energy systems. It includes the theoretical study of solar energy, hydrogen energy and applications of nanotechnology in these sector. This study will help us understand, what role nanotechnology will be playing in the advancement of renewable energy.

Keywords: Nanotechnology; nanoparticles; renewable energy; solar energy; hydrogen energy.

1. INTRODUCTION

The worldwide energy consumption approximately is 30 TW, which is likely going to increase with the time. Our three main sources of energy are the nuclear energy, renewable energy and the most common one is the burning of the fossil fuel. The increasing of the energy demand per day is causing a strain on the fossil fuels, and researchers say that, if we continue

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burning out the fossil fuel at the current rate, it will be depleted by 2060. Burning of fossil fuel also leads to the increase in carbon footprint which further leads to global warming, which is another big problem faced by mankind. Nuclear energy seems to be a good alternative which can provide a constant source of energy, but it comes with a high risk. Nuclear energy comes from the fission reaction which takes place between unstable elements at the atomic level. This energy comes with a high level of radiation which is harmful on exposure to life. Therefore, this risk can't be taken. This leaves us with renewable energy, which is more promising [1].

Renewable energy, defined as energy derived from resources that are naturally regenerated on a human time frame, is critical for developing nations' socio-economic progress. Nanotechnology has the potential to make renewable energy resources greener, more inexpensive, and more dependable. This can assist developing nations in overcoming their energy supply issues and moving toward energy self-sufficiency while lowering their reliance on non-renewable, polluting energy sources [2].

Today, developing countries like India are shifting towards solar and hydrogen energy, India is fulfilling the Paris Agreement objectives by diversifying its electricity sources and incorporating renewable energy into its system. In its nationally decided obligations to the 2015 Paris Agreement, the government vowed to reach 40 percent installed renewable energy capacity by 2030 and cut emissions intensity by 33-35 percent below 2005 levels. While renewable energy is unquestionably preferable to current fossil fuel-based electricity, it is not a panacea for all of our energy concerns. Renewable energy is encouraged, however it is not a sufficient step to meet the Paris Agreement's targets. Talking about hydrogen energy, the current transportation and storage of hydrogen energy limits it use in our day to day life. While the efficiency and the cost of solar cell has limited it use to only 9.8% of the total energy generated in India. Depending at these renewable energy for a sustainable long term energy use would not be possible until and unless we find a way to overcome the limitations and one promising way to do this is by using nanotechnology [3].

Nanotechnology is an area of science that deals with the study, construction, design, and use of a functional material by manipulating the system via control of matter at the size of 1-100 nm for physical, electrical, chemical, mechanical, optical, and magnetic characteristics. The use of nanotechnology in renewable energy has a number of advantages, including enhanced storage capacity, improved lighting and heating efficiency, and a reduction in pollutants created by other energy sources.

It is also used to increase energy generating efficiency, notably in the form of photovoltaic (PV) cells, or to create novel energy generation technologies. Among other renewable energy uses, it is used to increase wind and geothermal power generation, energy storage, illumination, and hydrogen fuel cells. We will look at some of nanotechnology's applications in solar energy harvesting and hydrogen energy enhancement to investigate the advantages or function of nanotechnology in the field of renewable energy.

2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY

2.1 Manufacturing of Nano-materials

There are two main approaches to nanoparticle fabrication and production: bottom-up methods, which start with nothing and build up atom by atom, and top-down methods, which take large bulk materials and shrink them down until they reach the nanoparticle size range (which most local standards define as less than 100 nm, but a few countries accept much less than one thousand nm). These methodologies are applicable to both small-scale and large-scale fabrication. We'll look at both the general and specific techniques that are utilised to make nanoparticles. We'll look at some of the tactics for making nanoparticles below, although we'll focus on each of the general classes rather than each specific method [4].

2.1.1 Top- down method

Top down approach involves the breaking up or shearing up a bulk material with the help of mechanical, thermal or chemical energy to transform the material into particles in the nano-scale range. This method can be used to create a much higher volume of nanoparticles—and are often used for mass manufacturing. There are many different techniques that fall under the category of top down approach like Laser Pyrolysis, Ionic/electronic irradiation**,** photo-lithography, Nano-imprint lithography (NIL), electron beam lithography (EBL), Grinding, shearing and ball milling etc. Some more advance than other [5].

2.1.2 Bottom-up method

Bottom-up strategies are methods for creating an atomic structure from the ground up by depositing atoms under specific conditions to create a desired structure. These are frequently self-assembly techniques. Because periodic growth occurs and specific crystal networks emerge as a result, many of these strategies are referred to as nucleation-growth approaches, which refers to the production of an 'atomic nucleus' from which the remainder of the structure grows. Physical vapour deposition (PVD), chemical vapour deposition (CVD), and atomic layer deposition (ALD) are the three main or most commonly utilised techniques that fall under this technology (ALD) [6].

3. HARVESTING OF SOLAR ENERGY

One of the most abundant source of renewable energy is the solar energy. In just one minute, the sun provides enough energy to meet the world's energy demands for a year. It emits around 95% of its output energy as light, part of which is invisible to the human eye. That is why the sun appears to be the earth's ultimate energy source. The amount of solar energy received by the planet varies depending on the season, with the most incoming solar energy receiving during the summer months. Solar energy is an alternative energy source that has the potential to alleviate these issues. It is a resource that is freely available in every country on the planet, and it poses no damage to the environment or the climate through pollution or greenhouse gas emissions. The photovoltaic cells are responsible for the production of energy. A P-V cell is made up of p- type (emitter) and n-type (base) semiconductor usually silicon. The photon particles hit the solar cells the electrons from the p-type semiconductor gets energized and start moving towards the n-type semiconductor. These moving electrons can help us power our daily energy needs. Many such solar cells are put together to form a solar panel which is used to capture the solar energy [7].

3.1 Types of Solar Cells

There are various types of solar cells which help us in harvesting the solar power, few of which are described below

- Polymer-based PV solar cell (OPV)

A polymer solar cell is a type of flexible PV solar cell made of polymers, which are big molecules with persistent structural units that use the photovoltaic effect to create an electric current from sunlight. The effective field formed across the junction between two different organic materials, known as the donor and acceptor molecules, separates excitons into free electron–hole pairs in this kind. This kind is created in response to the growing demand for low-cost renewable energy sources, as one alternative for producing energy from light at a cheap cost. Solar cells of this sort are commonly utilized [6-8].

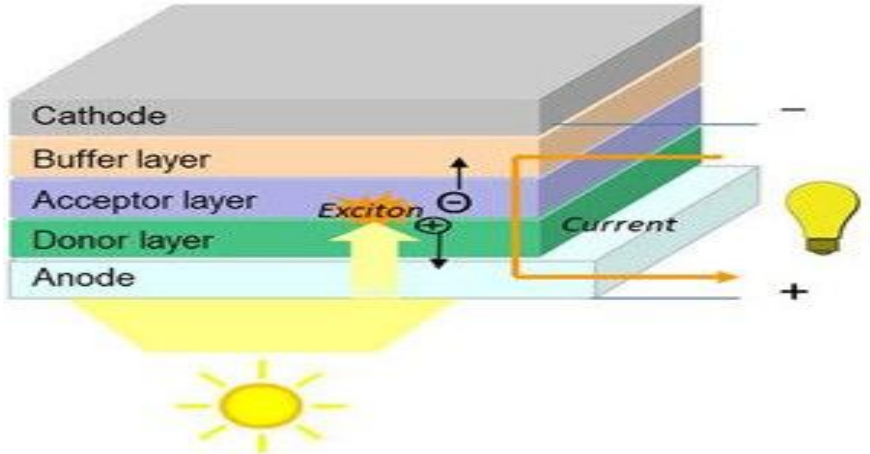

Fig. 1. Organic polymer based PV solar cell

- Dye-sensitized solar cell (DSSC)

A dye-sensitized solar cell is a thin-film solar cell that belongs to the thin-film solar cell family. It is based on a photo electrochemical system with a semiconductor produced between a light-sensitized anode and an electrolyte. These cells function by combining a dye sensitizer with a Nano-crystalline wide-band gap semiconductor as a photo-anode to enable optical absorption and charge separation. This type of solar cell is commonly preferred because it is simple to make using traditional roll-printing techniques, is semi-flexible and semi-transparent, allowing for a variety of applications in the glass industry, and is very cost effective due to the low cost of the majority of the materials required to make this cell.

- Crystalline-silicon cell

An n-type ingot is used in these solar cells, which is created by heating silicon chunks with tiny quantities of phosphorus, antimony, or arsenic as a dopant. The n-type ingot is connected to a p-type silicon layer that contains boron as a dopant. In a method, the n-type and p-type ingots are fused together to form a junction. Mono-crystalline solar panels and cells (mono-Si) are made up of single crystals, whereas polycrystalline panels and cells are made up of many crystals (multi-Si or poly c-Si) [8].

3.2 Drawbacks and Limitation

Solar energy although found in abundance has its own limitation and drawbacks when we put it into practical use. One of the limitation is the requirement of land to setup a solar power plant structure and also the location. The availability of solar radiation can vary depending on location. Some places, such as the South-West, there are significantly more solar radiation than other location, such as the North-east. This would mean that solar energy generation is dependent on certain locations where the systems would need to be installed. Not to the efficiency of the solar currently, most well-known brands for residential solar panels have an efficiency between 15 - 21 percent. In other words, the majority of energy from the sun's rays isn't being captured by solar panels, having such a low efficiency and high cost of installation does not bolster the use of solar panel in our daily life.The big challenge in using these devices is that the clear weakness in the absorption properties of the conventional fluids which leads to reduce the efficiency of these devices.

The cost of PV devices has changed over time, as seen in the graph below. Except for the module, the balance of system (BOS) provides information on all of the components of a solar PV device. Although the price is dropping by the day, the cost per kWh of energy generated by solar power remains greater than that of conventional sources such as coal and nuclear power. Given these obstacles, measures must be done to build a safe, efficient, and cost-effective solar energy collecting technique. One of the ways which these problems can be tackled by is by merging or nanotechnology with the solar energy harvestment [9].

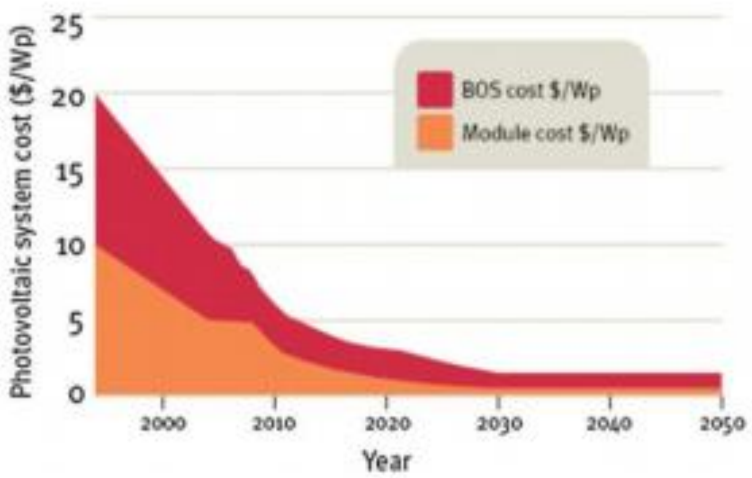

Fig. 2. Cost reduction of photovoltaic device

3.3 Role of Nanotechnology in Solar Cells

Nanotechnology may be able to assist solar cells overcome their flaws and limits. It has the potential to break through present performance constraints and significantly increase solar energy collecting and conversion. A variety of physical phenomena have been observed at the nanoscale that potentially improve solar energy collecting and conversion. It has been demonstrated that nanoparticles and nanostructures improve light absorption, increase light conversion to energy, and provide improved heat storage and transfer. The use of materials such as lead-selenite is another way that nanotechnology will improve solar cell efficiency. When a photon of light strikes these materials, more electrons (and hence more electricity) are liberated. Furthermore, every solar technology's cost is a significant factor in its success. The cost of converting solar energy to electricity is equivalent to the cost of fossil fuels. Semiconductors' materials Solar energy may be converted into electricity using photovoltaic (PV) cells. Light is converted into power using photovoltaic technology. The following are the key benefits of using nanomaterials in solar power plants: [4,10].

1. Improve photovoltaic solar electricity generation with nanotechnology

The thermodynamic efficiency limit of 80% is much above the capabilities of existing solar systems, whose laboratory total performance is now at 43%. To create transformational changes in the way solar cells are conceptualised, planned, implemented, and manufactured, an integrated, interdisciplinary, experimental, and theoretical effort is now required. Nanotechnology can help improve the performance of PV tools in a variety of ways, including but not limited to the following:

- Enhanced light coupling: It will improve the performance of PV devices by increasing the amount of light that reaches the active light sensitive material. Photonic crystals, plasmonic guiding, and other Nano size coupling structures may significantly minimise reflection losses, and light capture can be significantly accelerated. A critical area of study is developing techniques for economically combining such systems into multilayer heterostructure devices [4].
- Engineered interfaces: Interfaces that are well-designed can improve light collecting and trapping, govern the flow of photocarriers, and play a key role in various technologies. Interfaces, on the other hand, can be a source of inter-diffusion, flaws, and contaminants, lowering overall performance. It's crucial to improve our understanding of carrier dynamics at interfaces, as well as our ability to alter interfaces between different materials. There is evidence that using carbon nanotubes and other nanowires as a bonding agent into the solar cell junction interface can improve multi-junction solar light transmission and energy conversion efficiency [4].

2. Helps in absorption of different wavelength of light

Transparent solar cells: transparent solar cells have broadened the scope of solar cell applications. Transparent solar cells are constructed up of a translucent substrate (glass or plastic) and Nano layers of materials with specified optical properties and thickness's, which are responsible for absorption beyond the visible light spectrum. Transparent cells produce visible light, which is then consumed by ultraviolet and infrared-producing cells. The translucent nature of solar cells allows for a wide range of uses in buildings and automobiles. The volume of visible light in various types of cells varies between 50% and 80%. Researchers believe that using nanotechnology, they will be able to achieve a 12 percent performance without affecting cell movement qualities [11,12].

1. Use of Nano catalyst in solar cell helps in increasing the efficiency

Solar panels make use of photocatalysts. Photocatalysts have a wider range of applications due to their high absorption capacity and susceptibility to visible and ultraviolet light. In this case, a variety of nano-photocatalysts were used, including titanium dioxide, zinc oxide, cadmium sulphide, and others. The accumulation of tiny wavelengths of sunlight is the largest problem for photocatalysts. To get around this problem, two types of catalyst are employed at the same time. The location of the titanium oxide photocatalyst in the absorption of wavelengths, for example, is the application of silver nanoparticles to titanium oxide. Most nano-photocatalysts have self-cleaning, anti-steam, and anti-dirt qualities, thus using them outside and in the bodies of solar cells creates an environment free of air pollution and light obstructions, which increases sunlight absorption and cell efficiency. Another aspect of nanophotocatalysts in solar cells, similar to elevating the spectrum of absorption and guiding it to visible light, is that they improve and increase the passage of electrons to the electrodes, hence increasing cell resistance [12].

2. Application of nanotechnology in power storage system.

As we know that one of the major drawbacks with solar power is with the availability of sunlight is limited and specific to a particular location and continuous and consistent output is not feasible. Therefore we are required to store the excess energy produced. Ordinary batteries are expensive to use because of their heavy weight, capacity, and poor performance. Nanotechnology is frequently employed to solve these issues in this industry. The use of an organic solvent as an electrolyte solution rather than gas is the most fundamental difference between classical cells and lithium batteries. In this situation, lithium batteries establish an electrical connection between the two electrodes, allowing electrons to be transferred through charging. Nanomaterials are employed to improve the electrolyte's efficiency. Adding powders, especially nanoparticles, from compounds like aluminium oxide, silicone oxide, and zirconium oxide to non-aqueous electrolytes can boost conductivity by up to 6-fold, allowing us to improve the efficiency of the batteries we use to store the power [10,12].

4. HYDROGEN ENEGRY

After solar energy comes the hydrogen energy which is proving to be a sustainable fuel resource. Hydrogen energy is the use of hydrogen and/or hydrogen-containing molecules to create energy for all practical purposes with great energy efficiency, significant environmental and social advantages, and competitive economics. Hydrogen energy is now being tested in all areas, including energy generation, storage, and distribution; power, heat, and cooling for buildings and families; manufacturing; transportation; and feedstock manufacture. Energy efficiency and sustainability are two important factors driving the transition from today's fossil-fuel-based economy to a circular economy, i.e., a renewable circular sustainable fuel utilisation cycle that will define the highly efficient engineering and energy technological choices of the twenty-first century [11].

4.1 Types of Fuel Cell

There are different type of fuel cells, some of which are discussed below:-

1. Hydrogen fuel cell (HFC): The figure below represents HFC which is utilized in automotive industry as a possible replacement for fossil fuels in public transportation and vehicles. This cell utilizes the free electrons from hydrogen when passed through a membrane as the source of energy and the by-product which we get over here is water.

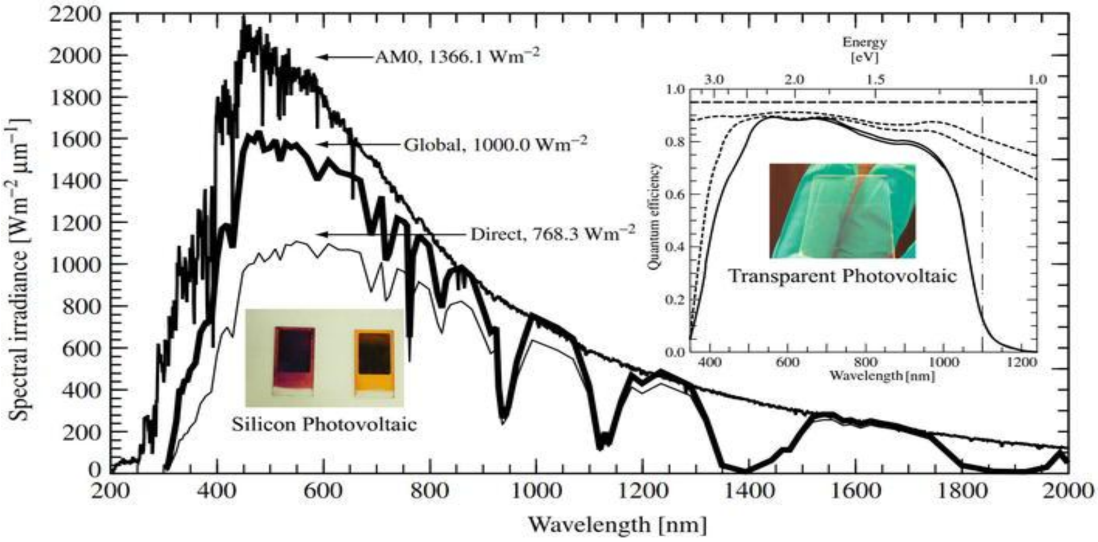

Fig. 3. Spectrum of light energy absorbed by transparent and silicon based cell

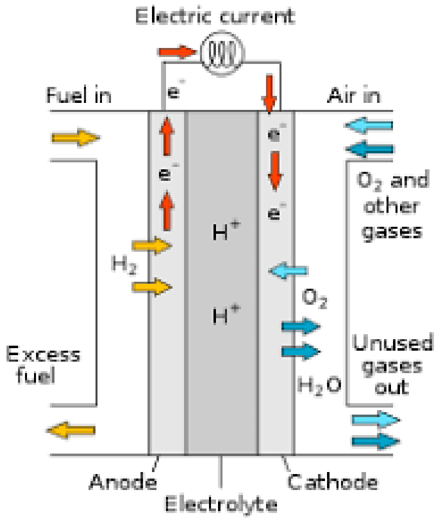

Fig. 4. Hydrogen fuel cell

The net reaction of this type can be written as:

H_2 +0.5 O2 ⟶ H2O (4)

2. Direct menthol fuel cell: Direct-methanol fuel cells or DMFCs are a subcategory of proton-exchange fuel cells in which methanol is used as the fuel. This type is used to power portable small electronic device like laptops and phones. Few of its characteristics which are very advantageous are low working temperature, high energy conversion efficiency and low emission of pollutants.

The chemical reactions of this type can be written as:

Anode - CH_3OH + H_2 ⟶ CO2+6H+ $6e^-$

Cathode - $1.5O_2$ + 6H + 6e ⟶ $3H_2O$

Net reaction - CH_3OH+$1.5O_2$ ⟶ CO_2 + $2H_2O$ [2]

4.2 Role of Nanotechnology in Fuel Cell

Fuel cells have an amazing potential to be an incredible efficient power source. Theoretically they have a wide range of operations, this technology can be scaled on operating fuel cells potable laptops up to huge stationary installations to power data centers.

However, when we put this notion into practise, there are a number of issues that limit the utilisation of fuel cells. The electrode catalysts require expensive materials such as platinum. Other fuels can induce electrode fouling, while hydrogen is both expensive to generate and difficult to store. The most efficient forms of fuel cells work at extremely high temperatures, which shortens their lifespan owing to fuel cell component corrosion.

Many of these issues may be alleviated through nanotechnology. A number of interesting nanomaterials have emerged as a result of recent nanotechnology research, which could make fuel cells cheaper, lighter, and more efficient [13].

1. Nanotechnology as fuel cell catalyst/ carbon nanotube catalyst

Platinum, which is an expensive metal, is more commonly utilised as a catalyst in fuel cells. As an alternative, it is well known that using platinum nanoparticles rather than solid platinum surfaces improves efficiency and allows for the use of less metal. Supporting platinum nanoparticles on a porous surface, such as activated carbon, or nanostructures like carbon nanotubes or nano-walls, is another advancement in modern technology. This improves the accessibility of platinum surfaces,[14] lowering the amount of the costly metal required to form a functional catalytic electrode.

Modified carbon nanotubes may be able to completely replace platinum in fuel cells. Carbon nanotube fabrication technology is fast improving, and the low cost and abundant raw material means that they can be produced quickly. As platinum presently bills for a minimum 25% of the price of commercial fuel cells, adoption of those catalysts will get rid of a major barrier to many applications of fuel cells.To further increase the efficiency of the carbon nanotubes by altering its electrical properties, it can be doped with nitrogen or coating them in an electron-withdrawing polymer.The nanotube electrodes also prove to be more robust. Their catalytic activity is not damaged by carbon monoxide or the crossover effect when using methanol as the fuel, unlike platinum, which improves the lifetime of the cell [15].

2. PEMFCs – Proton Exchange Membrane Fuel Cells

Apart from catalysts, nanotechnology has also aided in the improvement of the fuel cell membrane, such as a proton exchange membrane (PEM) created by University of Illinois researchers. A layer of porous silica with a diameter of 5 nanometers is included in the proton exchange membrane they designed. The goal is for water to reside in the nanopores of the silica layer and react with acid molecules. The water in the silica nanopores forms an acidic solution that enables hydrogen ions move through the membrane. In comparison to traditional fuel cells, this boosts the operation of the fuel cell by tenfold even in low humidity climates.

3. Storage of hydrogen fuel

While hydrogen fuel meets all of the other criteria for a perfect substitute for conventional fuel, storage issues have stymied its adoption. Extremely high pressures are required to store hydrogen as a compressed gas or liquid, resulting in costly tanks and the risk of leaks or explosions. The only approach that appears viable is to lock hydrogen into solid metals, in which the hydride producing substance absorbs hydrogen and stores it securely at a high density, although even this process cannot store a significant amount of hydrogen. In 2011, scientists at Lawrence Berkley National Laboratory developed a composite material made up of magnesium nanoparticles placed in a flexible organic polymer matrix to solve this challenge. The material is capable of selectively absorbing hydrogen gas, storing it safely at high densities as magnesium hydride, and releasing it rapidly when required [15,13].

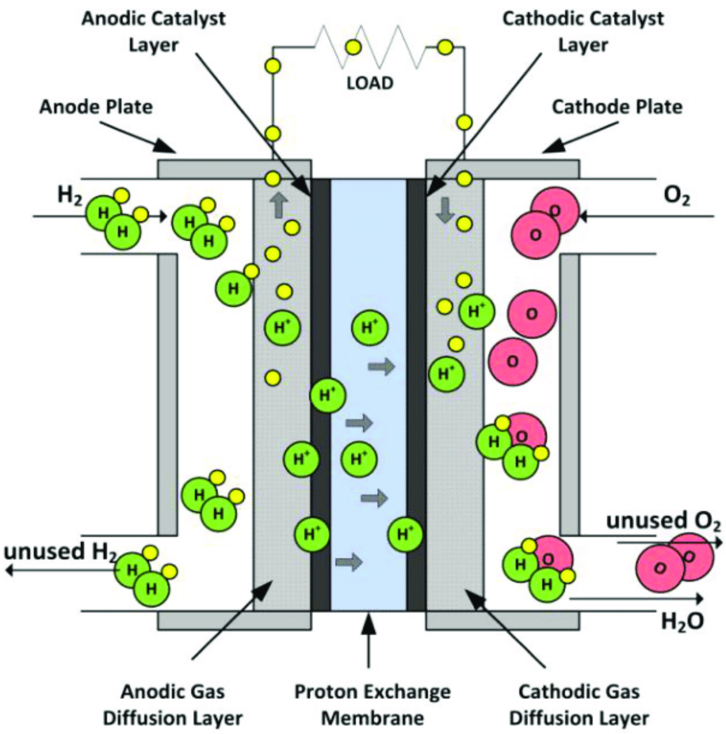

Fig. 5. Proton exchange membrane fuel cell

5. CONCLUSION

With a growing population and technological advancements, our reliance on renewable energy sources will expand day by day, and nanotechnology will bridge the gap between energy generation and consumption. Nanotechnology has revolutionised the scale and design of renewable energy devices for energy conversion and storage, as well as environmental monitoring and green engineering of environmentally acceptable materials. Nanomaterials have been proved to have a substantial impact on human existence by supplying inexpensive and clean energy, which has now become a worldwide business. Nanotechnology plays a critical role in all aspects of energy capture, storage, and transfer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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