Chapter 1
Application of Nanomaterials for Renewable Energy Production

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Abstract The ever-increasing demand for energy due to the rapidly increasing industrialization and urbanization compels the research community to devise ways to transition from non-renewable sources of energy to renewable energy sources. The burning of fossil fuels is the primary source of energy that we are utilizing today. Apart from the fact that it is not sustainable and is likely to diminish by 2050 (if we continue using it at the same rate), it also poses severe adverse threats to the environment due to harmful greenhouse gases (GHGs). Thus, we must look for ways to utilize renewable energy in ways so that it can fulfill our energy demands without causing harm to the environment. The efficiency of production and storage of renewable energy needs to be enhanced. Nanotechnology is one such field that is being explored and studied extensively lately due to its practical applications in renewable energy. This chapter discusses the primary classification of nanomaterials and their applications in various renewable energy generation and storage, such as solar energy, hydrogen energy.

Keywords Non-renewable energy · Renewable energy · Fossil fuels · Nanotechnology · Solar energy · Wind energy · Hydrogen energy · Hydrogen economy

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M. Srivastava, P. K. Mishra (eds.), *NanoBioenergy: Application and Sustainability Assessment*, Clean Energy Production Technologies,
https://doi.org/10.1007/978-981-19-6234-9_1

1.1 Introduction

Energy is very crucial for the holistic progress of any country (Stern 2011; Barnes et al. 2011). The energy demand increases exponentially due to the rapid increase in industrialization and urbanization (Graham 2009; Mazur 1994). The significant portion of energy that we are utilizing today comes from the burning of fossil fuels. But the burning of fossil fuels has many deleterious effects on the environment attributed to the release of harmful greenhouse gases (GHGs). It also adversely impacts human health (Kataki et al. 2017). It is cited as the primary contributor to the increasing global warming. As stated by the US Energy Information Administration, the all-consuming of fossil fuels in 2016 caused a substantial 76% of the US greenhouse gas emissions. Also, fossil fuels are representatives of non-renewable sources of energy; that is, they cannot be utilized sustainably. If we continue using fossil fuels at the same pace for our energy needs, it is reported that we will fall short of this energy source by 2050 (Satyanarayana et al. 2011; Demirbas 2009). Thus, it is very imperative that we look for other sources of energy having some of the essential attributes of sustainability and minimal harmful effect on the environment. Renewable sources of energy are the potential alternatives having the characteristics above. Renewable energy is any energy source that can fulfill the existing energy demands without compromising the energy needs of the future as well. In other words, they are a form of a sustainable source of energy. Renewable energy sources such as solar energy, hydrogen energy, wind energy, geothermal energy, and biomass energy have the potential to generate electricity, heat, and light, which can be utilized for various purposes without having deleterious impacts on the environment. Nowadays, much interest and research have been attentive on the practice of Nanotechnology in the renewable energy field. Nanotechnology is basically the science of materials in the nanoscale (diameter having less than 100 nm mostly). Nanomaterials, owing to their very small size, confer many technological and engineering advantages for the parts or equipment associated with renewable energy generation. Various beneficial aspects of nanomaterials have been explored in renewable energy generation, such as wind energy, solar energy, hydrogen energy, etc., and efforts are being made to transition the use of nanotechnology for renewable energy production to a commercial scale. Let us know more about the use of nanotechnology in renewable energy generation.

1.2 Classification of Nanomaterials

Nanomaterials can be classified according to various parameters. Broadly, they can be classified into (Mageswari et al. 2016): (1) Nanoparticles, (2) Nanoclays, and (3) Nanoemulsions.

1.2.1 Nanoparticles

Nanostructures and composites are the two forms in which nanoparticles can exist. Their size range from 1 to 100 nm (Hasan 2015). They can be of various shapes, sizes and can be composed of different types of materials. Based on the materials they are composed of, nanoparticles can be (Mageswari et al. 2016; Jeevanandam et al. 2018; Ealia and Saravanakumar 2017)

1.2.1.1 Organicnanoparticles

These nanoparticles are favorable choices for drug delivery. Some of the characteristics which make them a favorable candidate for this purpose are: (1) They are biodegradable; (2) They are not toxic by nature; (3) Some of them form a hollow core and are called nanocapsules. They are believed to be sensitive towards light and heat (Tiwari et al. 2008), such as liposomes and micelles; (4) Suitable for targeted drug delivery. Besides their general characteristics such as morphology, size, etc., their field of application is also determined by their drug-carrying capacity, drug delivery system (whether encapsulated or adsorbed) as well as stability. Some examples are liposomes, ferritin, micelles, and dendrimers.

1.2.1.2 Inorganic Nanoparticles

They do not contain carbon. They comprise metal and its oxides-based nanoparticles.

1.2.1.3 Carbonnanoparticles

It consists of carbon entirely. Examples: Fullerenes, carbon nanofibers, carbon nanotubes (CNT), etc.

1.2.2 Dimension-Based Nanomaterials Classification

The nanomaterials classification based on dimension is achieved by considering the pattern of the electron trail alongside the various dimensions in the nanomaterials. Pokropivny and Skorokhod proposed this system of classification in 2007 (Pokropivny and Skorokhod 2007). Based on the dimension, nanoparticles can be of different types (Jeevanandam et al. 2018; Mageswari et al. 2016):

1.2.2.1 0D

In these types of nanomaterials, the electrons movement is enmeshed in all three dimensions, or they are confined within the dimensionless space. Examples are fullerenes, molecules, metal carbides, etc.

1.2.2.2 1D

The electrons movement in this type is restricted in one dimension, in the X-direction. Examples include nanotubes, filaments, fibers, etc.

1.2.2.3 2D

The movement of electrons is confined in the X-Y plane. Examples- Layers.

1.2.2.4 3D

The movement of electrons can occur along the X, Y, and Z directions (Siegel 1993).

1.2.3 Classification Based on the Origin of Nanomaterials

1.2.3.1 Natural

They are naturally present in the Earth's sphere, i.e., atmosphere comprising of hydrosphere, lithosphere, troposphere, and even the biosphere. It is noteworthy to mention here that the biosphere includes all the microorganisms and the higher organisms, which include humans (Sharma et al. 2015; Hochella et al. 2015). Either natural processes or some sort of anthropogenic activity serves to produce these nanomaterials.

1.2.3.2 Synthetic

They are fabricated or engineered and are generated by processes that may be physical, biological, chemical, or hybrid methods such as mechanical grinding, etc. One of the significant challenges with these nanomaterials is difficulty in assessing whether the current knowledge is sufficient in forecasting their behavior or if they exhibit any environment-related activity that is distinct from the nanomaterials occurring naturally (Wagner et al. 2014).

1.2.4 Nanoclays

They are the other types of nanomaterials, the preparation of which exploits the hydrophilic or charged characteristics of clay molecules. The charged groups can be ammonium, aryl/alkyl, phosphonium, or imidazolium, either in the aqueous or solid-state. X-ray diffraction, gravimetric analysis, Fourier transform infrared (FTIR) spectroscopy, and inductively coupled plasma can be used for chemical characterization.

1.2.5 Nano-Emulsion

These types of nanomaterials are in the form of soft materials and are generated by dispersing the solid materials, droplets, and polymers in the viscous liquid. It is generally synthesized by using either of the two methods:

1. High-energy emulsification includes microfluidizer, ultrasonication, and high-pressure homogenization.
2. Low energy emulsification includes techniques like phase inversion temperature, solvent displacement, and phase inversion composition.

The given figure (Fig. 1.1) shows the general classification of nanomaterials.

1.3 Synthesis of Nanomaterials

The route for the synthesis of nanomaterials can be physical, chemical, or biological (Mageswari et al. 2016).

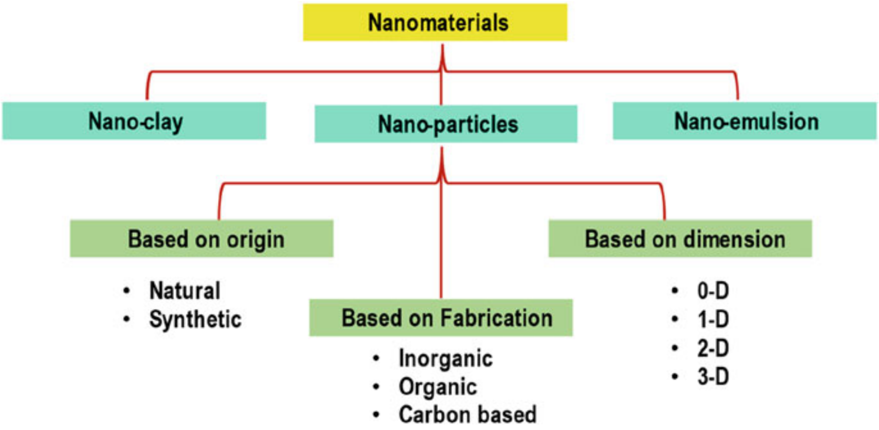

Fig. 1.1 Types of nanomaterials

1.3.1 Physical Methods

These include physical techniques to synthesize nanomaterials. One of the main advantages of physical methods over chemical methods is that nanomaterials have a uniform distribution as they are devoid of solvents. Some of the techniques include:

1.3.1.1 Laser

It uses Transmission Electron Microscopy to emit high-energy electron beams and irradiate surfaces to synthesize nanomaterials of various forms. Examples are carbon nanocapsules, nanotubes, etc.

1.3.1.2 Arc-Discharge

Two methods, including higher frequency plasma and direct current arc plasma, can be applied for this technique. This is mainly used to synthesize fullerenes.

1.3.1.3 Combustion

In this technique, the activation energy barrier is overcome by the heat generated during the exothermic reaction. It is fast and has the potential to form a wide range of ceramic oxides.

1.3.1.4 Evaporation–Condensation

In this technique, first, the metals, ceramics, or alloys are allowed to evaporate and react with each other using gases. Later, they are subjected to condensation, leading to the formation of nanomaterials.

1.3.1.5 Laser Ablation Method

This is an advanced technique that allows for the controlled synthesis of nanomaterials with respect to the composition and size of particles. In this, the target is subjected to vaporization followed by controlled condensation with well-defined pressure and temperature parameters. It can be used to synthesize various nitrides, carbides, and metal oxides at the nanoscale.

1.3.2 Chemical Methods

These methods allow for the extensive quantity synthesis of nanomaterials in a controlled manner (Hyeon 2003). There are many methods for synthesizing nanomaterials by chemical means (Chaki et al. 2015; Umer et al. 2012; Anbarasu et al. 2015; Yu et al. 2009).

1.3.2.1 Chemical Reduction

It is the most applied technique for the synthesis of nanomaterials in the form of colloids. It involves the chemical reduction of inorganic as well as organic reducing agents.

1.3.2.2 Oxidation

The process of oxidation can be used to form nanomaterials of alloys, metals, or oxides, either in water or some other organic solutions.

1.3.2.3 Microemulsion

It involves the separation between two immiscible phases in space, that is, between reducing agent and metal in two-phase aqueous organic systems. Quaternary ammonium salts are used to mediate the interface between two phases. Stabilization of the clusters of the metal is achieved as the stabilizer molecules are capped in the non-polar aqueous medium, which is then transferred to the organic phase.

1.3.2.4 Sol-Gel Process

In this method, the first formation of sol is achieved by dispensing precursors in suitable solvents, which upon drying, are put in solid (gels) to form a polymeric network. When the gel is subsequently dried to be subjected to operations such as sintering and calcination, ceramic products are formed. Other chemical synthesis methods include polymerization, microwave-assisted synthesis, UV-initiated photoreduction, irradiation, etc.

Some drawbacks of physical and chemical methods of nanomaterial synthesis (Mageswari et al. 2016; Hebbalalu et al. 2013):

1. Complex protocols.
2. High operational costs.
3. The presence of minor toxic components makes their biological use questionable.

Table 1.1 Synthesis of nanomaterials using various biological agents

Biological agent	Examples	Types of nanoparticles
Plants	*Azadirachta indica,* Lemon grass, *Garcinia mangostana,* etc.	Gold, Silver, Copper, Aluminium oxide, etc.
Bacteria	*E.coli,* sulfate-reducing bacteria, *Bacillus subtilis,*etc.	Cadmium sulfide, Magnetite, Titanium oxide, etc.
Fungi	*Aspergillus flavus, F.oxysporum, Agaricus bisporus,*etc.	Silver, Lead sulfide, Zinc sulfide, Silver, etc.
Yeast	*Saccharomyces cerevisiae,* Extremophilic yeast, *Yarrowia lipolytica*, etc.	Titanium oxide, Manganese oxide, Gold, Silver, etc.
Actinomycetes	*Rhodococcus* sp., *Nocardiopsis* sp., *S. albidoflavus,* etc.	Gold, Silver, etc.

1.3.3 Biological Synthesis

Biological production of nanomaterials is more environment-friendly and thus preferred more over physical and chemical modes (Hebbalalu et al. 2013; Sastry et al. 2003; Kruis et al. 2000; Ahmad et al. 2003).

The given table (Table 1.1) enlists some of the biological agents with examples for the synthesis of nanoparticles.

1.4 Nanomaterials: Applications in Renewable Energy

The advancements in nanotechnology, together with the fact that nanomaterials hold several benefits to be applied for renewable energy, have in all opened a new domain of research. Some of the attributes of nanomaterials that make them a preferred choice for various renewable energy applications are (Hussein 2015):

1. They provide greater capacity for energy storage and efficiency for lighting and heating.
2. The energy so generated with the use of nanotechnology can help curtail pollution.

The nanomaterials, having their one or more dimensions at the nanoscale, tend to disobey conventional rules of physics and thus express remarkable properties compared to their larger entities. Some of the advantageous features and potential benefits they show at the nanoscale are their strength, electrical conduction capacity, and reactivity increase.

1.4.1 Solar Energy

Solar energy is one of the primary sources which can be harnessed to produce renewable energy. The sunlight that is reflected on the Earth's surface annually surpasses the total resources that we use. It is noteworthy to mention here that the sunlight of 1 h equates to more than the total energy consumed annually (Vayssieres 2009). Thus, it is of utmost relevance to utilize this most excellent energy source to meet the energy requirements efficiently and inexpensively. There are two ways by which we can use solar energy (Ghasemzadeh and Shayan 2020; Esmaeili Shayan et al. 2020):

1. To directly produce electricity utilizing sunlight.
2. Solar thermal energy can be used in high-temperature power plants to generate electricity. Or for ventilation in houses and processing of hot water when used in low-temperature power plants.

Nanotechnology can be used to improve heat and electricity generation. Nanotechnology can be exploited to increase the efficiency of solar cells in many ways (Sarbu et al. 2017):

1. Nanotechnology can be used to enhance the storage of solar power.
2. The efficiency of solar cells can be boosted using nanowires.
3. Sunlight absorption and retention can be enhanced.

1.4.1.1 Improved Absorption and Capture of Solar Energy

Nanomaterials having the capacity to emit and capture light such as Silver, gold, or quantum dots, and fluorescent nanofibers may be employed to advance the functioning of solar cells (Esmaeili Shayan and Najafi 2019). Based on their dimensions, these nanoparticles can absorb different wavelengths and become excited. After this these nanoparticles emit the absorbed energy in the form of radiation with a different wavelength or from the earliest one. Owing to their photoelectric properties, which help in the conversion of solar light to electricity, however, they tend to absorb wavelengths that are beyond the visible spectrum. A fascinating improvement of 64% in the performance of solar energy is observed when projected simulating the quantum-based cell theory. Quantum dots of silver sulfide and silver selenide tend to immensely enhance the response of the solar cell to light. It has been observed that almost a 4% increase in the production of electrical energy is seen with these quantum dots when compared to routine pigment-sensitive cells. Hence, such quantum dots are very relevant to increase the efficiency of solar cells.

1.4.1.2 Nanofluids

Nanofluids, owing to their high heat transfer coefficient in heat exchangers or engines, serve to rise the economy and performance. Many businesses and academic institutes are adopting solar batteries and heaters.

1.4.1.3 Photocatalysts

These are stable semiconductors generating an electron-hole pair as they collect photons, thus interfering with the molecules at the surface level. Some of the advantages of nano-photocatalysts with respect to solar cells are:

1. The performance of the solar cells can be enhanced dramatically as the absorption of light can be improved attributed to their property of absorbing specific light spectra.
2. The absorption of sunlight and the performance of the solar cells also get improved as they render a clean atmosphere free from air pollutants and obstacles to light. This is due to their anti-dust, self-cleaning, and anti-steam properties.
3. They also help in improving the energy-transfer capacities.

1.4.1.4 Nanotechnology in the Storage of Power

Nanotechnology is also being increasingly used for the storage of power. Many factors such as environmental conditions, including temperature, hours, photoperiod, and atmospheric patterns, tend to impact solar power generation systems production, rendering the consistent supply of output not feasible in such cases (Achkari and El Fadar 2020). Owing to the fact that the ordinary or conventional batteries have certain loopholes such as inefficient capacity, heavyweight and poor performance and therefore, Lithium batteries are in trend nowadays (Walker 2013). Lithium-ion batteries utilize organic solvents for the purpose of electrolytes instead of gas used in conventional batteries. But liquid electrolytes have strong electrical resistance, and nanomaterials are being utilized to increase the electrolyte's efficiency. Nanotechnology aims to boost the conductivity by sixfolds by adding powers in the form of nanoparticles (silicon oxide, zirconium oxide, etc.) to non-aqueous electrolytes.

The given figure (Fig. 1.2) displays some of the general approaches in which nanotechnology can be applied in solar energy sector.

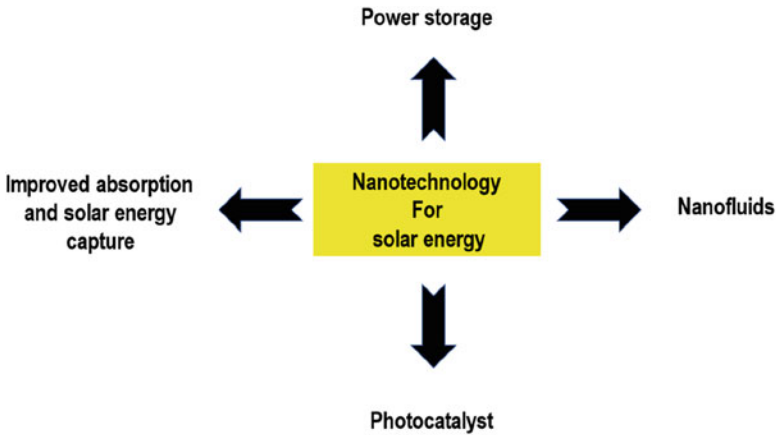

Fig. 1.2 Approaches for nanotechnology applications in solar energy

1.4.2 Renewable Hydrogen Energy and Use of Nanotechnology

Hydrogen energy is also being explored as a clean source of renewable energy for it only produces water upon consumption in fuel cells. Solar water splitting has been considered as one of the most efficient ways of producing hydrogen energy. The hydrogen so produced can then be utilized by fuel cells for the generation of electricity, with water being the only emission. This also paves the way for the effective utilization of solar energy and its conversion (Mao et al. 2012). For the purpose of ensuring efficient and optimum utilization of solar energy for hydrogen energy production, the efficacy of solar water splitting systems must be increased. Also, the storage capacity and performance of fuel cells should be enhanced to make hydrogen energy the primary contributor to the prospective renewable energy-based economy.

The given figure (Fig. 1.3) shows the general framework for production of hydrogen energy using solar water splitting-

1.4.2.1 Nanomaterials-Based Electrodes for Photo-Electrochemical Water Splitting

Water splitting by photo-electrochemical (PEC) means been the fascinating way of hydrogen energy production amongst other techniques. Fujishima and Honda first pioneered Solar energy-induced splitting of water in PECs, wherein they used TiO_2 anode and Pt cathode to generate oxygen and hydrogen, respectively (Fujishima and Honda 1972). In this system, once the anodes are irradiated by sunlight, and if the irradiated energy has energy larger than its bandgap, then electrons are generated in

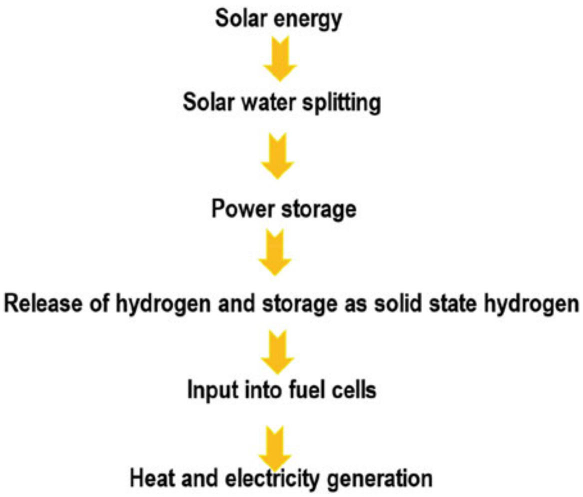

Fig. 1.3 A general framework for hydrogen energy production using solar water splitting

the conduction band, and holes are generated in the valence band respectively (Chen et al. 2010). As a result of this, water gets oxidized at the TiO$_2$ anode liberating oxygen, and the photogenerated electrons are transferred to the Pt cathode to produce hydrogen. However, oxygen production at the photoanode is kinetically limited for splitting of water in the PEC process, and so, nanostructured photoanodes were designed for PEC water splitting leading to the production of oxygen.TiO$_2$, which is the most widely used semiconductor for PEC-based water splitting, has a very large bandgap of almost 3.2 eV (Chen and Mao 2007; Ni et al. 2007). This renders the TiO$_2$ anode inefficient and incapable of absorption of light in the visible and infrared range. Thus, photoanodes were designed to introduce either a donor or acceptor level in the forbidden gap to narrow the bandgap of TiO$_2$. This makes the photoanode TiO$_2$ sensible to visible light (Chen et al. 2010; Chen and Mao 2007). For instance, a TiO$_2$ doped nanocrystalline film showed a more excellent efficient water splitting phenomenon with 11% accounting for total energy conversion and 8.35% of photoconversion efficiency, attributed to the enhanced capability to absorb visible light (Khan et al. 2002). The morphology of TiO$_2$ is also of considerable importance since the morphology impacts the capability of transfer of charge. TiO$_2$ nanotube arrays were designed and examined by Grimes and co-workers for water splitting by PEC, and it was found that they render more efficient charge separation owing to their architecture (Rani et al. 2010; Mor et al. 2005, 2007). The photoelectric conversion efficiency of almost 16.5% could be obtained under UV illumination when nanotubes of 24 μm in length were fabricated electrochemically in an ethylene glycol-based electrolyte (Mao et al. 2012).

1.4.2.2 Nano-Photocatalysts and Hydrogen Production

Bard in 1979 designed a photocatalytic water splitting system based on the concept of photoelectrical splitting of water. He utilized particles or powders of semiconductors as photocatalysts (Bard 1979). Electrons and holes photogenerated at the conduction and valence bands, respectively, are transferred to photocatalysts, where they participate in a redox reaction leading to oxygen and hydrogen production.

Some of the fundamental characteristics to be considered for photocatalysts are (Mao et al. 2012):

1. Relevant band gaps and structures to ensure optimum absorption of sunlight are needed to drive oxygen and hydrogen production.
2. Efficient transferability of holes and electrons.
3. High catalytic reactivity of surface for half-reactions.

Extensive research and efforts have been put in the past decades to meet the specific requirements and ensure efficient generation of hydrogen from water (Chen et al. 2010; Shen et al. 2011; Osterloh 2008; Shen and Mao 2012; Maeda and Domen 2010).

1. **Surface Layer Disorders**

   As mentioned earlier, TiO_2 is the most widely studied photocatalyst, but it has a wide band gap, limiting its absorption efficiency. To narrow its bandgap, doping with ions is done, but this also has a drawback. The energy levels created by doping can then act as recombination centers for photoinduced charges and deleteriously impact the photocatalytic activity of doped TiO_2 (Chen and Mao 2007). To circumvent this issue, a new approach of surface layer disorder was envisioned for the enhanced absorption of solar energy by TiO_2 nanocrystals (Chen et al. 2011). Surface disordered black TiO_2 nanocrystals obtained by hydrogenation of anatase TiO_2 nanocrystals at 200 °C for a duration of 5 days in 20.0- bar H_2 atmosphere, produced hydrogen at a constant rate. The hydrogen production rate so observed (10 mmol h^{-1} g^{-1} of photocatalysts) and efficiency as close to 24% of solar energy conversion is almost two times greater than most semiconductor photocatalysts' yield (Chen et al. 2010). This observation is attributed to the efficient energy harvesting from UV to near infrared by the surface disordered black TiO_2 and the retardation in recombination of charge (Mao et al. 2012).
2. **Cocatalysts**

   Loading of cocatalysts onto photocatalysts is considered as an efficient strategy for optimal water splitting due to increased photocatalytic activity for the formation of hydrogen or oxygen. Different materials have been developed as proficient cocatalysts in the past few decades, such as sulfides and oxides of metal, transition metals, etc.

1.4.2.3 Solid-State Nanomaterials (Hydrogen Storage)

Storage of hydrogen is very crucial to realize the full potential of hydrogen energy economy or renewable energy economy. It can be stored in various ways—as a cryogenic liquid, pressurized gas, or inappropriate solid-state materials such as carbon materials, metal organics, or metal hydrides. Of all these ways, solid-state hydrogen storage is the most efficient and technically feasible approach. Material specified surface interactions determine the capacity of storage and kinetics in case of solid-state storage, either through strong chemisorption or weaker dispersed physisorption (Liu et al. 2012; Abbasi and Abbasi 2011; Froudakis 2011; Dagdougui 2012; Ding and Yakobson 2011). Metal hydrides (reversible chemisorption), particularly MgH_2, are essential representatives of the candidates for solid-state hydrogen storage attributed to their high capacity of hydrogen storage and comparatively high weight percentage (7.6%) of hydrogen in MgH_2 besides the fact that magnesium is also available abundantly (Mao et al. 2012; Sakintuna et al. 2007).

However, there are certain limitations with these metal hydrides:

1. Poor reaction kinetics
2. High thermodynamic stability
3. High enthalpy of formation of bulk MgH_2 rendering it incapable of producing hydrogen at temperatures below 300 °C

And so, it is needed to reduce the enthalpy to make MgH_2 a potent candidate for storage systems. Alloying Mg with metals such as Al or Ni can help in circumventing this enthalpy issue. However, they tend to substantially decrease hydrogen weight percentage (Bouaricha et al. 2000; Hirata et al. 1983). A better option is the sandwiched Mg nanoparticle layer as Pd/Mg/Pd thin films deposited by the PLD approach. This nanoparticle film proves beneficial in the reduction of enthalpy of formation, and so, the thermodynamic barrier to the formation of hydride can be catered (Barcelo et al. 2010).

1.4.3 PEMFCs and Nano-Electrocatalyst

Polymer Electrolyte Membrane (or Proton Exchange Membrane) Fuel Cells are very potent in the conversion of clean energy for they can generate electricity without pollution and combustion at an astounding conversion efficiency of 70% by harnessing hydrogen's chemical energy. This renders them as a highly eligible candidate to replace combustion engines both for stationary and mobile purposes (Yuan et al. 2012). In this system, ionization of hydrogen occurs at the anode liberating protons and electrons, which subsequently recombine at the cathode and reduce oxygen to water. Electrocatalysts are needed to improve the kinetics of reduction of oxygen at cathode, which otherwise, because of slow kinetics, can significantly cause voltage loss in PEMFCs. Pt is regarded as a good electrocatalyst for this purpose; however, owing to its scarcity and very high cost, efforts have been made in the past few decades to devise low-Pt alloys for the reduction in the use of Pt in fuel cells (Chrzanowski and Wieckowski 1998). Some of the non-Pt electrocatalysts include metal carbides, metal chalcogenides, metal oxides, metal nitrides, and macrocycles. Attributed to the high resistance against corrosion and wear, non-Pt chromium nitrides electrocatalysts such as CrN (highly crystalline CrN nanoparticles) and Cr_2N are the prospective electrocatalysts (Volz et al. 1998; Lackner et al. 2006).

1.4.4 Nanotechnology and Wind Energy

Wind energy is also a type of renewable energy in which wind turbines are used to convert the wind's kinetic energy into another form such as electrical or mechanical energy, which can then be utilized for various functional applications. Wind energy is believed to be less detrimental to the environment when compared to other energy sources, for wind turbines do not burn the fuels for the generation of electricity. For the optimum utilization of wind power plants, wind speed should be a minimum of 13–15 m/s and 10 m/s for the smaller ones. However, the wind speed is always not uniform and optimum, which limits the efficiency of these plants up to 30–60% (Hussein 2015). It is noteworthy to mention here that the square of the length of the wind turbine and the energy production are proportionally related (Dalili et al. 2009; Sherif et al. 2005). This is where nanotechnology steps in. Nano-composites enable the fabrication of a longer blade with greatly enhanced strength. This can be attributed to their superb and efficient stiffness and strength-to-weight ratios. Nanotechnology via low-friction coatings and nano-lubricants also serves to reduce the loss of energy due to various tribological problems such as scuffing, wear, etc. (Hussein 2015).

1.4.5 Nanotechnology in Other Renewable Energy Sources

1.4.5.1 Biofuels

- It may successfully lead to the generation of biofuels from solid wastes (Mahmood and Hussain 2009). Nanotechnology also serves to increase the yield of biodiesel production. It has been observed that KF/CaO nanocatalyst led to biodiesel production with a yield of 96.8%. It has also been stated that it could also be used for the conversion of oil with high acid value into biodiesel efficaciously (Wen et al. 2010). It has also been stated that a more "greener" production of biodiesel could be obtained with the use of nanocatalyst (Konwar et al. 2014). Sajith et al. (2010) concluded that the emission of nitrogen oxides compounds and hydrocarbons could substantially be reduced with the addition of particles of cerium oxide in the nano range on biodiesel (Sajith et al. 2010). Hipólito et al. (2014) stated that they could obtain a biodiesel yield of 97–100% using STNT following a chemical reaction of 8 h duration (Hipólito et al. 2014).

1.4.5.2 Geothermal Energy

Nanofluids can prove to be crucial in cooling the pipes exposed to very high temperatures during the extraction of geothermal energy from the crust of the Earth. They can also be utilized for cooling purposes in components such as electronics and sensors in drilling machines (Hussein 2015).

1.5 Conclusion and Future Perspectives

It can evidently be stated that nanotechnology is playing a significant part in producing various renewable energies. Nanomaterials greatly influence the absorption capacities of various devices involved in the conversion and utilization of renewable energy. Various aspects of nanotechnology are being explored and exploited lately. As the need for clean energy generation increases due to multifarious problems associated with conventional energy sources, i.e., burning fossil fuels, the demand for renewable energy production is also increasing exponentially. Nanotechnology finds its wide applications in almost all renewable energy sources—solar energy, hydrogen energy, biofuels, geothermal energy, wind energy, etc. Nanomaterials can be efficiently used for the storage of renewable energies, such as solar energy and hydrogen energy. They also boost the efficiency of renewable energy-producing devices; for example, nano-composites can be used to fabricate longer blades with enhanced strength, which will ultimately increase wind energy generation efficiency.

1. Nanotechnology is one of the critical factors for the complete realization of the "Hydrogen Economy."
2. It is mandatory to study, research, and explore more about nanotechnology so that its shortcomings can be managed and its transition to commercial status can be accomplished entirely soon.

Acknowledgments Authors are grateful to the Patna University, IIT (BHU), Rajendra Memorial Research Institute, Patna, and S S College Shahjahanpur for providing necessary facilities for this work.

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