Review Article | Physics | Volume : 10 | Special Issue | August 2025 | e-ISSN : 2456-5040

NANOTECHNOLOGY AND IT'S APPLICATIONS IN AGROVOLTAICS: A REVIEW

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ABSTRACT

Nanotechnology is the technology of 21st century. When size of any material is less than 100 nm, then it is called nanomaterials. By reducing size of any material, when we reach in the nanometer regime, due to increase in surface to volume ratio and quantum confinement, physical, chemical, thermal, electrical, optical, structural and biological etc. properties of material changes rapidly. Due to changes in these properties of nanomaterials; Nanotechnology can be used as clean energy and resources for the future, especially in field of Agrovoltaics. The Present study evaluates the deployment of a grid-independent agrovoltaic system for maximizing land utilization and crop productivity. Through the utilization of solar energy, an integrated irrigation and monitoring system is incorporated to enhance crop growth. The project's feasibility is evaluated from both technical and economic perspectives. The design of the photovoltaic system and the pumping system is customized to optimize efficient utilization of solar and water resources. The findings of this research demonstrate the viability of adopting an environmentally friendly approach. The utilization of photovoltaic solar energy for electricity generation can coexist with agriculture and complement each other.

KEYWORDS: *Solar Energy Direct Sources (Photovoltaics, Artificial Photosynthesis, Solar Thermal, Nanofabrication, Dispersed Collection), Agrovoltaic System, Solar Energy, PVs*

1. INTRODUCTION

Nanoscale materials (or nanomaterials) contain nanoparticles developed using nanotechnology. Nanoparticles are commonly considered to be materials that have at least one dimension that is less than 100 nm [1]. Nanoparticles can be distinguished according to their origin. They can occur naturally (e.g., from volcanic eruptions); they can be produced incidentally during other processes (e.g., from fuel combustion); and they can be manufactured intentionally. Manufactured nanomaterials can be classified according to their methods of production. Some are produced "from the top down," as when a bulk material (e.g., gold, silicate) is reduced to a mass of nanoscale particles [2,3,4]. Because of their very small size, these nanoscale metals, metal oxides, powders, and dusts have physical, chemical, magnetic, electrical, mechanical, and other properties that differ from those of the bulk materials from which they are derived. They are found today in sunscreen products (titanium dioxide nanoparticles), solar cells (aluminum oxide nanoparticles), and several other applications in research and commerce.

The second type of manufactured nanoparticles are built "from the bottom up," atom-by atom or molecule-by-molecule. Engineered nanoparticles of this type are still relatively difficult and expensive to manufacture, but they have the potential to impact energy development and use, transportation, electronics, manufacturing and other disciplines.

2. RENEWABLE ENERGY

Nanotechnologies may also facilitate the generation of electricity directly from solar, wind, and geothermal sources. Using such energy at or near the source could enable distributed energy production of electricity, thereby minimizing transmission losses and reducing the need for ROW (right of way)-based transmission of electricity, oil, and gas. Practical energy collectors that are simple and automated may result from cheap nanofabrication. Also, more efficient electricity transmission may enable the generation of increased amounts of electricity in remote locations (e.g., nonpopulated areas with abundant renewable energy) to be sent to high-energy demand areas via nanoenhanced transmission. Solar photovoltaic technology, which at present relies on crystalline-silicon wafers that are costly to produce, is deployed economically only in limited settings. Less costly quantum dot (nanocrystal) technologies could make important contributions to improving the efficiency of solar energy systems. Examples of some of these potential nanotechnology-enabled improvements are highlighted below:

- High-performance semiconductor nanocrystals (nanodots) that are active over the entire visible spectrum and into the near-infrared have been combined with conductive polymers to create ultrahigh-performance solar cells. The solar cells have improved efficiencies because the nanocrystals harvest a greater portion of the energy spectrum. Solar roofing tiles using quantum dots that are based on metal nanoparticles are expected to be commercialized within the next several years.
- Highly ordered nanotube arrays have demonstrated remarkable properties, when used in solar cells. Researchers explained that the nanotube arrays provide excellent pathways for electron percolation, acting as "electron highways" for directing the photo-generated electrons to locations where they can do useful work. Research results

suggest that highly efficient solar cells could be made simply by increasing the length of the nanotube arrays.

- Nanoadditives, including nanoparticles and nanopowders, could be used to enhance the transfer of heat from solar collectors to storage tanks. When added to heat-transfer fluids, the solid nanoparticles conduct heat better than the fluids alone, and they stay suspended longer than larger particles

3. ENERGY STORAGE

The ability to store energy locally can reduce the amount of electricity that needs to be transmitted over power lines to meet peak demands. Energy storage could allow downsizing of baseload capacity and is a prerequisite for increasing the penetration of renewable and distributed generation technologies such as wind turbines at reasonable economic and environmental costs. Suitable energy storage is critical to the increased use of renewable energies, particularly solar and wind, because these are inconsistent resources. Nanotechnology may play an important role in distributed generation through the development of cost-effective energy storage in batteries, capacitors, and fuel cells. The next generation of storage devices may be optimized by nanoengineered advances and the use of nanoscale catalyst particles (Foster 2006). Richard Smalley has described a model for storage using nanotechnology (Foster 2006) in which he suggests that by 2050 every house, business and building would have its own local electrical storage device an uninterruptible power supply capable of handling all of the needs of the owner for 24 hours. Because such devices would be small and relatively inexpensive, they could be replaced with new models every 5 years or so as technological innovation continues. Today, such a unit, using lead-acid storage batteries and storing 100-kilowatt-hours (kWh) of electrical energy for a typical house, would occupy a small room and cost more than $10,000. Through advances in nanotechnology, it may be possible to shrink an equivalent unit to the size of a washing machine and drop the cost to less than $1,000. With these advances, the electrical grid could become exceedingly robust. Such advances could also permit some or all of the primary electrical power on the grid to come from solar and wind energy [10-11].

4. HYDROGEN GENERATION AND STORAGE

The hydrogen economy is a hypothetical future economy in which hydrogen is the primary form of stored energy for mobile applications and load balancing. It is typically discussed as an alternative to today's fossil-fuel economy. Many barriers need to be overcome for the hydrogen economy to become a reality. These include producing the hydrogen (for which adequate sources of electricity are needed), transporting it (including the possible need for additional ROWs), and storing it. Nanotechnology may play a role in helping to meet these challenges. As discussed previously, nanotechnology may help accelerate the use of solar and other renewables to generate electricity. Also, nanowires may increase the efficiency of long-distance electrical energy transmission. Nanotechnology may help address hydrogen storage problems. Because hydrogen is the smallest element, it can escape from tanks and pipes more easily than conventional fuels. There are two ways to store hydrogen in materials. One way involves absorption of the hydrogen within the material and the other is to store the hydrogen in a container. The challenge for absorption is to control the diameter of the nano tube so that the absorption energy of hydrogen on the outside and inside of the tube is high enough to provide the desired storage capacity at an acceptable pressure. If the absorption behavior of the optimized tube is acceptable, the challenge then is to develop a process capable of producing the material at a reasonable cost. Single-walled CNTs are a leading candidate for solving the storage problem for hydrogen-fueled cars and trucks. However, if this approach cannot be carried out, CNTs could still facilitate storage in a container. Small hydrogen-fueled vehicles would have a pressurized tank and large hydrogen-fueled vehicles, ships and planes would have a cryogenic liquid hydrogen tank. In this case, CNTs may be used in super-strong composites in the bodies of the vehicles to make them lighter.

5. MATERIALS

Advanced materials using nanotechnology may extend service life, reduce failure rates and limit the potential for environmental damage. Nanocoating metallic surfaces can help achieve super hardening, low friction, and enhanced corrosion protection. Stronger materials may reduce wear, corrosion and the chances of puncturing associated with third-party damage. Also, because nanomaterials can be stronger per unit volume than conventional materials, the use of pipe materials that contain or coated with nanomaterials may mean fewer disturbances to the environment during installation, maintenance and dismantlement.

1. Materials for Nanofertilizers:

Metal and metal oxide nanoparticles like silver (Ag), zinc oxide (ZnO), and iron oxide ($Fe2O3$) can act as nanofertilizers, improving nutrient uptake and stimulating plant growth. For example, ZnO nanoparticles can enhance zinc availability, which is crucial for photosynthesis and development in crops like wheat.

2. Materials for Enhancing Solar Energy Conversion:

a. Perovskites:

These materials are promising for solar cells due to their high power conversion efficiency (PCE).

b. Carbon Nanotubes (CNTs):

CNTs can be used as transparent conductive materials in solar cells, potentially replacing indium tin oxide (ITO), and they also enhance electrode erformance.

c. Other Nanomaterials:

Research is ongoing to develop other nanomaterials for advanced photovoltaic (PV) cells, including quantum dots, which can be tuned to absorb different wavelengths of light, and nanomaterials that can enhance the stability and efficiency of solar cells.

3. Materials for Materials for Enhancing Solar Energy Conversion:

Nanomaterials like polymer-based nanoparticles can be used to deliver fertilizers and pesticides in a controlled manner, reducing environmental impact and increasing the efficiency of these inputs.

4. Nanosensors

Nanosensors, or sensors made of nanomaterials, can be extremely sensitive, selective, and responsive. As such, they could be smaller and cheaper, and consume less power than conventional sensors. Sensors and controls that are small in size; work safely in the presence of electromagnetic fields, high temperatures, and high pressures; and can be changed cost-effectively may provide the ability to monitor conditions in the infrastructure and monitor for pollutants [13-14].

5. Examples of Nanomaterials in Agrovoltaics:

a. Graphene and CNTs:

These materials can be used in solar cells to improve transparency and conductivity, as well as in sensors for monitoring environmental conditions.

b. Metal and Metal Oxide Nanoparticles:

These can be used as nanofertilizers, antimicrobial agents, and in sensors for detecting pathogens.

c. Polymer-based Nanomaterials:

These can be used for controlled release of agrochemicals and for enhancing the delivery of nutrients.

6. POTENTIAL ENVIRONMENTAL, SAFETY, AND HEALTH RISKS

Due to their extremely small size and relatively large surface areas, nanomaterials may interact with the environment in ways that differ from more conventional materials. Potentially harmful effects of nanotechnology could result from the nature of the nanoparticles themselves and from products made with them. Environmental, safety and health (ES&H) risks could occur during research, development, production, use and end-of-life processes. The 21st Century Nanotechnology Research and Development Act, signed into law in December 2003, calls for addressing potential environmental and societal concerns associated with nanotechnology. About 10% of the Federal nanotechnology budget is characterized as environmental but much of this amount is for developing nanotechnologies to address existing environmental problems rather than for investigating potential ES&H effects. Some research has been conducted on the toxicology of nanomaterials, but research on the fate, transport and transformation; risk characterization, mitigation and communication; and exposure, bioaccumulation and personal protection has yet to come. All of the departments and agencies with Federal funding from the National Nanotechnology Initiative have environmental research planned or underway, but industry, nongovernmental organizations and others have questioned whether the amount of research on the potential ES&H impacts of nanotechnologies is sufficient, given the number of unknowns and the size of the potential nanotechnology market. There have been relatively few studies on the ES&H risks of engineered nanoparticles [15-20]. There are also no regulatory requirements to conduct such studies and little funding is allocated to them. The limited results to date are neither conclusive nor consistent. For example, evidence indicates that nanoparticles in the lungs may cause more severe damage than conventional toxic dusts, but few if any inhalation or exposure studies have been conducted. Nanotechnologies may speed cleanup of soil and water contamination, but in the process may harm local soil ecology. The impacts of large quantities of nanomaterials on the environment or human health have not been studied and there are no studies on accumulation or other long-term impacts.

7. BENEFITS OF AGROVOLTAIC TECHNOLOGY

Nanotechnology offers a range of potential applications across the entire agrivoltaics value chain:

7.1 Advanced solar panel coatings:

Semi-transparent PV panels: Brite Solar, a Greek company, is pioneering the use of nanotechnology coatings to create semi-transparent agrivoltaic panels that optimize light transmission for enhanced photosynthesis while maintaining high energy efficiency.

7.2 Anti-reflective and self-cleaning coatings:

Nanotechnology can be used to create coatings that reduce reflection and enhance light absorption by solar panels, while also making them self-cleaning, minimizing maintenance requirements and maximizing power generation[21].

8. ENHANCED CROP PRODUCTION AND RESILIENCE:

8.1 Nanofertilizers and nanopesticides:

Nanotechnology allows for the controlled and targeted delivery of nutrients and active ingredients, reducing losses and minimizing environmental impact. For instance, nanoencapsulated fertilizers control the release rate of nutrients.

8.2 Nanosensors for precision agriculture:

Miniaturized nanosensors can monitor soil conditions, plant health, moisture levels, and detect pathogens and contaminants in real-time, enabling farmers to optimize resource allocation and respond proactively to ssues.

8.3 Nano-enhanced seed treatments and genetic engineering:

Nanoparticle coatings can improve seed germination & growth and nanotechnology can facilitate targeted gene transfer for enhanced crop resilience and productivity.

8.4 Nanomaterials in energy storage:

Nanomaterials are being explored for use in next-generation batteries and other energy storage solutions, improving their efficiency and scalability for agrovoltaic systems.

8.5 Agrivoltaic microgrids:

Integrating agrivoltaic systems with microgrids and smart technologies can improve energy management and grid stability.

9. WATER CONSERVATION AND MANAGEMENT:

9.1 Nano-enabled water purification systems:

Nanofilters and magnetic nanoparticles can effectively remove contaminants from water, enabling safe reuse for irrigation and promoting sustainable water management.

Hydrogels, nanoclays, and nanozeolites: These nanomaterials can improve the water-holding capacity of soil, reducing water loss and increasing water use efficiency in agricultural practices.

10 USING NANOTECHNOLOGY, FOLLOWING BREAKTHROUGH MAY OCCUR IN AGROVOLTAICS:

10.1. Enhancing Solar Panel Efficiency:

1. Nanomaterials for solar cells:

Nanotechnology can be used to improve the efficiency of solar panels in agrovoltaic systems. This includes using nanomaterials like quantum dots or nanowires in solar cells to increase light absorption and conversion efficiency.[22]

2. Transparent Conductive Films (TCFs):

Nanomaterials can also be used to create TCFs for solar panels, allowing more sunlight to reach the crops underneath while still generating electricity.

10.2. Improving Crop Growth and Protection:

1. Nano-fertilizers:

Nanoparticles can be used to deliver nutrients to plants more efficiently, reducing the amount of fertilizer needed and minimizing environmental impact. [23]

2. Nano-pesticides:

Nanoparticles can be used to encapsulate pesticides, releasing them slowly and targeting specific pests, reducing the overall amount of pesticide needed and minimizing harm to beneficial insects and the environment.

3. Nanobiosensors:

Nanosensors can be used to detect diseases and nutrient deficiencies in crops early, allowing for targeted interventions and preventing widespread outbreaks or deficiencies.

11. PRECISION FARMING AND ENVIRONMENTAL MONITORING:

1. Nanosensors for Soil and Plant Health:

Nanosensors can be used to monitor soil conditions, such as nutrient levels and moisture content, as well as plant health, providing real-time data for informed decision-making in agrovoltaic systems.[24]

2. Water Management:

Nanomaterials can be used to improve water retention in soil and enhance water use efficiency in crops, which is particularly important in agrovoltaic systems where water resources may be limited.

3. Environmental Monitoring:

Nanosensors can be used to monitor air and water quality in agrovoltaic systems, ensuring that the systems are operating sustainably and minimizing environmental impact.

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