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29 February 2024

Nanotechnology: Bridging Solar Energy for Sustainable Solutions in Singapore

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More than fifty years have passed since Richard Feynman laid the groundwork for a frontier of innovation capable of shaping the future of science into a realm no one envisioned before: the ability to manipulate matter at the size of atoms into specific structures to achieve desired properties (Michigan State University). Feynman's speech "There's Plenty of Room at the Bottom" captured scientists around the globe to start researching and developing this concept of 'miniaturisation' on a large scale, eventually evolving into an emerging field officially recognized as nanotechnology, entailing "the process of separation, consolidation, and deformation of materials by one atom or one molecule." (qtd. in Abdin et al. 838). The size of these materials are of the nanoscale– referring to sizes between 1 and 100 nanometres, comparable to around a billionth to multiple tens of billionths of metre in size. The potential that derives from the unique characteristics that distinguishes nanoscale materials from its bulk counterparts creates distinctive functionalities exploitable to create novel technology, even simulating natural processes that were originally impossible to replicate using synthetic materials, thus creating the thought of prospective application to enhance the production, storage and use of energy, particularly to grant Singapore energy independence. Through the integration of nanotechnology illustrated by quantum dots and 1-D nanomaterials, the potential for renewable energy sources in the form of solar energy in Singapore, can experience transformative advancements, enhancing efficiency and sustainability.

Preface and Relevancy

As the world pioneers into an age of urbanization and industrialization in order to achieve numerous economic and civil goals to develop a greater quality of life for humanity, its consequences of releasing uncontrolled amounts of pollutants is leading to a detrimental pace of global warming (Shafi et al. 1). With the rate of global warming increasing three times as fast since 1982, increasing by 0.20° C per decade, climate change has been a major global concern (Lindsey and Dahlman). For Singapore, the best strategy for responding to this situation and drawing a path for future environmental sustainability is by reducing carbon emissions and achieving carbon neutrality through transitioning non-renewable sources of energy to renewable sources (Bai et al. 67).

Proclaimed as a global economic powerhouse (“An Economic”) owing to its export-oriented economy with crude oil refinery as its primary industry (Bai et al. 67), Singapore’s booming economy has faced a crucial disadvantage in terms of limited geographical area and natural resources, as Singapore naturally lacks various sources of extensive renewable energy including geothermal, hydroelectricity, wind, tidal and wave (Quek et al.). Alternatives to establish a greener pathway could be to import energy; however, imported energy dependency is unsuitable for Singapore as it causes a substantial susceptibility to geopolitical and economic alterations in the global energy market, compromising energy supply stability (Martin). Such vulnerability might have substantial repercussions for a country with a relatively dense population (qtd. in Quek et al.) as supply disruptions might cause major consequences for sustaining economic operations, infrastructure development, transportation and so on (Martin). As a consequence, this demonstrates the need for Singapore to create renewable energy domestically in an efficient manner, due to the challenges of both climate change and imported energy dependency.

A Path of Solar Energy

Considering that Singapore possesses zero hydro and geothermal resources and average wind speeds being an average 2 m/s (excluding coastal areas), solar energy –specifically solar photovoltaics (PVs)–is the most accessible renewable energy source (Bai et al. 67-68). To illustrate the scope and effects of solar energy implementation, if a distributed solar grid were to fulfil merely 1% of the global electricity needs, it could prevent the emission of around 40 million tons of carbon dioxide annually (Hussein and Ahmed 463).

Solar photovoltaics are surfaces consisting of a conducting oxide layer alongside with a catalytic platinum layer that directly converts sunlight into electrical and heat energy, while the device that converts photons from solar light into electricity using electrons is called a photovoltaic solar cell (463). Due to Singapore's abundant daylight supply throughout the year, photovoltaic cells will consistently absorb sunlight to generate energy. When combined with the flexibility of photovoltaic cell implementation in Singapore– its availability to be installed on rooftops, building surfaces, land-based, floating and infrastructure– solar energy becomes a very practical solution and theoretically probable implementation in the quest to procure greater environmental sustainability (Bai et al. 67). As electrical generation accounts for more than a quarter of the energy used in proportion to the total energy used in Singapore, the greater implementation and conversion of photovoltaics to supply electricity would exponentially decrease the amount of carbon emissions, as reducing the 95.2% of natural gas used for energy production would aid in reducing the rate of global warming (Quek et al.)

With the most exploitable of these forms of photovoltaic to be rooftop and building surface photovoltaic to also be the most expensive (76), this raises an issue of whether solar cells can be a suitable renewable energy source until its manufacturing costs decreases to an affordable level relative to other energy sources, and are capable of meeting Singapore's energy demand (Abdin et al. 838). The simplest method to cut energy production costs and fulfil Singapore's energy demand from photovoltaics would be to crucially enhance the efficiency of energy production, leading to a decrease in the overall manufacturing costs per unit of energy produced and creating a reliable high-energy-density resource. Nevertheless, there are a multitude of complications that impede the maximisation of solar photovoltaic efficiency.

The primary liabilities of photovoltaic cells include its limited absorption capabilities of conventional fluids (Hussein and Ahmed 463), along with absorbed solar radiation causing excessive heating over a certain period of time (Abdin et al. 843), affecting their energy production performance and resulting in a decreased efficiency of these devices. With first and second generation solar cells only reaching 27% and 14% efficiency respectively, this begs the development of a third generation solar cell hoping to surpass the efficiency percentage of both the first and second generation, aiming to be both economically-viable and cost-effective by integrating nanotechnology into its development (838).

The leading mechanisms in nanotechnology that show enormous potential for integration into the creation of the third generation solar cells are quantum dots and 1-D nanomaterials.

Employing the Potential of Quantum Dots

Quantum dots are tiny crystal particles offering notable advantages for integration into solar cell technology as they have the ability to augment light absorption through multiple energy levels and can extend its absorption capabilities into the infrared spectrum, a feat conventional solar cells can't achieve (847). In 2011, the National Renewable Energy

Laboratory of the U.S.A pioneered a new form of quantum dots composed of lead selenide. Remarkably, the lead selenide quantum dots exhibited a quantum efficiency surpassing 100%, indicating that when integrated into a photovoltaic cell, it generates more electricity than the amount of sunlight it received. This breakthrough was attributed to the unique properties of lead selenide, a material that triggers more electrons to be released upon interactions with photons, thus enhancing energy generation (Hussein and Ahmed 463). Furthermore, quantum dots exhibit the ability to absorb diverse wavelengths of sunlight due to their inherent variations in volume and size (Abdin et al. 848). By leveraging these distinct sizes, they are able to absorb a broader spectrum of sunlight (solar spectrum), enabling a greater harvest of solar energy within the cell and consequently yielding higher energy output.

Using quantum dots, this research evidence suggests employing quantum dots holds the potential to successfully create the desired prospects of the third generation solar cell that is both cost-effective but yields significant energy output, with theoretical modeling of quantum dot solar cells suggesting a potential efficiency increase of approximately 64% (847).

Leveraging 1-D Nanomaterials

One-dimensional nanomaterials including nanotubes, nanowires, and nanorods, offer significant opportunities to enhance the efficiency of solar cells by facilitating photon absorption, electron transport and collection (Yu and Chen 1). Due to being regarded as the most miniscule dimension for harnessing, converting, and storing solar energy, nanowires have gained considerable recognition for its potential in enhancing photovoltaic cells. (Abdin et al. 849). Their unique morphology allows for low optical reflection, enhancing light absorption and retention, alongside its capability to exhibit efficient generation, transportation and separation of electric charges, rendering them an ideal device to facilitate solar energy conversion. An prototype solar cell design that integrates the optimal structure of a nanowire-based solar cell with the utilization of a cost-effective, and durable semiconductor photovoltaic components, revealed that employing a vertically aligned array of nanowires addressed the challenge of where light energy gets lost before it can be turned into electricity (qtd. in Hussein and Ahmed 464). Through meticulous material selection, shape optimization, and surface treatment, nanowires can be further enhanced for heightened efficiency in converting solar energy into electricity.

Moreover, the mobility of electrons in one-dimensional nanomaterial tends to be numerous levels of magnitude greater than that of semiconductor films, as well as the inherent large surface area from the geometry of nanomaterials allowing for greater light collection, ultimately increasing the energy conversion efficiency of photovoltaic cells (qtd. in Hussein and Ahmed 463,464).

The Limitations of Nanotechnology

While extensive applications of nanotechnology have led to bright results that may lead the future of humanity into a greener world, it is essential to weigh and acknowledge all of the challenges and limitations that arise from nanotechnology. Ranging from the absence of similarity between experimental outcomes from different groups; inadequate theoretical comprehension of critical energy transfer systems; lack of conclusive experimental studies on convective heat transport in nanofluids; the deficiency of green technology for large-scale nanofluid manufacturing, to difficulties arising from the characteristics of nano-materials and nanoparticle production, including long-term stability of nanoparticle dispersion; thermal performance of nanofluids in turbulent and fully developed regions; raised pressure and so on, creating a vital hindrance to the pace of creating a more environmentally sustainable future (Abdin et al. 849).

The impediment of nanoparticle production ensues due to the tendency of larger particles to aggregate, hence limiting the benefits of possessing a high surface area. This issue can be retaliated by the addition of additives; however, the combination of additives and nanofluids can alter the surface properties of the particles and introduce absurd quantities of impurities (849, 850).

Evaluation

With the context of Singapore, this paper addresses specific renewable energy applications in order to address the concern of climate change, while integrating different forms of nanotechnology into renewable energy technologies to determine a cost-effective and efficient renewable energy resource in Singapore. It doubles as a literature review on the recent developments of nanotechnologies structures that could be utilized in solar photovoltaic cells to domestically procure renewable energy.

Although nanotechnology holds immense promise for advancing renewable energy technologies, particularly in solar photovoltaic energy production, it is crucial to confront its limitations to ensure a fruitful application and maximise its benefits in creating a more environmentally sustainable world. Moving into the future, it is clear that advancements in nanotechnology hold the key to unlocking greater capabilities in solar energy technologies, implying a greater need for investment in research and development of nanotechnology for sustainable solutions; this could be done through interdisciplinary wide-scale theoretical and practical research.

While Singapore possesses favourable expectations and dependency on the innovation of solar energy technology domestically as a renewable energy source, on a global scale, solar energy would also be the most feasible due to the availability of sunlight on Earth, and the volume required in order to significantly substitute the energy quantities currently derived from hydrocarbons, remarkably reducing the pace of global warming and ultimately delaying climate change in the long-run.

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