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Literature Study on the Role of Nanotechnology in Grass Root Development of Green and Sustainable Energy Systems: Prospects in Africa and the World

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ABSTRACT: The exponentially growing energy demand ensuing fromimpelling anthropogenetic activities over limited energy availability andaccessibility, serves as a constraining factor towards achieving a concurrent rapidgrowth and development index to most developing nations of this age. This has promptedrational motivation behind scientific research and development (R&D) ofnovel, sustainable, cost-effective and highly efficient systemsfor energy production, conversion and storage. However, at the atomic and subatomic levels, research has shown that there is room for improvement on stale,as well as development of more efficient novel methods of energy production, conversion and storage – bothof renewable and nonrenewablesources. Competent energy systems are required which are not just efficient but necessarilyenvironmentally compatible. Thence, without compromising on environment/ecological safety and health there is a push fordevelopment of highly efficient 'green' energy systems. Successes recorded in the field of science and technology (S&T) especially in the aspectof sustainable energy (such as solar energy, biomass, geothermal, hydrogen energy, tidal energy, etc.), has presented and encourageda means towards mitigating pollution and encouraginggreen environment through inculcating nanotechnological and nanoscientific principles. On the basis of research works, this review highlightshow the emergence of nanotechnology has so far brought about some notable developments andadvancements in renewable energy systems,the general socioeconomic effect ofits incorporation, limitations, pros and cons, as well asgiving insight onprospects – presenting nanotechnology/nanosciences as a credible and practicablemeans and alternative practice towards transcending the hurdles of energy challenges in Africa and the world at large.

Keywords: Nanotechnology, Nanosciences, GHG Control, Carbon Emission, Renewable Energy, Green Energy, Africa.

I. INTRODUCTION

Nanotechnology/Nanosciences

When you think of "Giant Surface Area from Tiny Particles", think of "Nanotechnology". Nanotechnology (alternatively called Nanosciences/Nanotech) is a multidisciplinary branch of technology that involves research and development on the atomic, molecular or super-molecular levels within the nanometer scale (1-100nm) which gives a fundamental and basic understanding of phenomenon and matter composition [1]. Nanotechnology has demonstrated a great potential in solving many of the existing technological and economic challenges of the world today. It stands out as the threshold of a new era for the development of science around the world [5]. Nanotechnology has been widely and prominently embraced and employed by diverse industrial sectors such as information computer technology (ICT), energy tech, medicine and pharmacy, agriculture, textile, basic sciences and technology, etc., forimprovement and development intheir variousmethodological approaches – whether novel or stale, in model imitations (i.e. simulation), development from a laboratory stages or pilot plant to upscaled processes, etc. Withal, being a multifarious technology/science it has overtime played a key role in resolving the issues faced by man in his environment as made evident in diverse fields of its application. In 1974, Professor Norio Taniguchi of the Tokyo Science University defined the term "Nanotechnology" to mainly consist of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule". In other words, it presents an enhanced technique that involves the design, characterization and optimization of particles by deliberately manipulating and controlling their sizes and structures. The concept of nanotechnology first came into existence from a talk given on December 29, 1959 by physicist Richard Feynman titled “There’s Plenty of Room at the Bottom”, at an American Physical Society meeting held at Caltech. This shows that the concept of nanotechnology had been conceived over 60 years ago but still a frontier yet to be fully harnessed by researchers in different fields – in fact its potential seems inexhaustible as diverse fields of science and tech finds its principles applicable in systems development. Nanoparticles are motes of matter tens of thousands of times smaller than the width of a human hair [3]. Because they're so small, a large percentage of nano particles' atoms reside on their surfaces rather than in their interiors. Their intricate nature gives them larger surface area per volume than bulk materials. This means surface interactions dominate nanoparticle behavior and, for this reason, they often have different characteristics and properties than larger chunks of the same material.

According to Dr. James Tour, Professor of Chemistry, Rice University “Nanotechnology has the potential to revolutionize the way we produce and consume energy”. Some materials exhibit certain properties more efficiently and effectively with increased area of surface operation. For example, in catalyzed reactions smaller amount of catalysts may be required with increased surface area of catalysts, thereby cutting down on cost incurred in catalyst procurement and increasing efficiency. In a more progressive research, a NASA / MIT concept was designed for an advanced commercial aircraft that incorporates nanocomposites, and that could fly significantly quieter, cleaner, and with greater fuel efficiency. These are a few advantages that nanotechnology has over contemporary scientific methods. Increased surface area over bulk volume of a material gives room for better interaction with other materials in their surroundings. This is an ideal technology for processes that principally require high surface area for better operation such as batteries (Teslaleverages on nanotechnology in electric vehicle batteries by using nanoparticles to increase energy density and extend the range of its vehicles).

A lot of debates have arisen from multiple definitions of the term ‘Nanotechnology’. However, according to Lubick and Kellyn [4], summarizing that for a technology to be referred as, it should be characterized by the following:

a. Research and technological development at the atomic, molecular or macromolecular levels, within the nanoscale range;
b. Fabrication and utilization of structures, devices and systems with novel characteristics and functions because of their small to intermediate sizes; and
c. Ability to control or manipulate on the nanoscale.

By harnessing the unique properties of materials at the nanoscale, more efficient and sustainable energy systems can be created. This paper gives an overview of some of the applications of nanotechnology into R&D atdifferent levels and aspects of renewable energy precisely.

Renewable Energy: A Means to Carbon Emission Control

Renewable energy refers to energy that is sustainable or replenished in a short period of time. Renewable energy sources are alternative energy sources and unlike non-renewable sources are efficient low to zero carbon emitters. Energy – availability and accessibility – is a principal determining factor that influences the rapidity of human and economic growth and development and differs vastly across the globe. However, continuous advancements on research and development of novel and cheap techniques by inculcating new technologies (such as nanotechnology) has shown that the opportunities left untapped from the wells of energy development is vast. Energy plays a fundamental role in our everyday life and world development pathway in quality of life improvement, sustainability and affordability. Although, much of the renewable energy sources are sustainable, however a few (such as biomass) are considered unsustainable in this current rates of exploitation [5, 6].

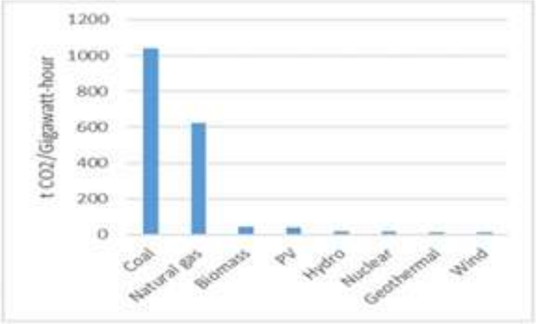

Figure 1. CO_2 emission of various energy resources for electricity generation.
(Image: [5])

After over a century of non-renewable energy (petroleum) production and heavy dependence on it, its effect on man; economically and environmentally is stale news. However, the ultimate goal is to create cleaner-burning (or green) fuels that will reduce dependence on or completely replace those of non-renewable source. Renewable energy being an alternative source has not been harnessed to an extent of cutting down or possibly replacing completely the non-renewable energy. International Energy Agency reported energy related carbon dioxide emission to have had 1.4% growth in 2017 [7]. The world's supplies of high-quality crude oil are diminishing, reserves are uncertain, new catalysts which are expensive to procure are needed to refine the remaining supplies of crude oil, which are heavier and higher in contaminants such as sulphur with rapidly growing demand and pollution rates and so on. The status quo is becoming enigmatic. Renewable energy sources make up to 26% of the world's electricity source today and according to the International Energy Agency (IEA) its share is expected to hit 30% by 2024 [7]. However, nanoporous materials are being explored to capture carbon dioxide directly from the air, while nanocatalysts can convert carbon dioxide into fuels and chemicals [8]. These innovations could help mitigate reliance on fossil fuels and mitigate the effects of climate change.

Nanotechnology and the Challenges of Renewable Energy Development in Africa

In the world today, the major sources of energy are derived from non-renewables such as coal, petroleum etc. This dependence largely on non-renewable sources of energy has left the world with three major flummoxing issues – the uncertainty of reserve and abundance; the heavy dependence on them; and the uncertainty of when this non-sustainable energy sources will be exhausted. In the context of low-carbon future, fossil fuel use is gradually becoming a thing of vulnerability and so are countries and states which have high dependence on them as a major source of international trade and economic growth. The emergence of vast and profound technologies peculiarly in the 21st century has made it clear that the world is at the verge of forgoing the technologies and systems that depend on non-renewable sources of energy. Many developed countriesnow make use of technologies that depend on renewable sources of energy; for example, technologies such as electric cars and gadgets that are solar powered, etc.

In Africa, fossil fuels represent about 40% of African exports with countries such as Algeria, Chad, Nigeria, Angola and the Sudan being highly dependent on them as a source of national revenue [9]. On the other hand, Africa is richly blessed with abundance of the sources of renewable energy but lacking in the technological advancements necessary for harnessing these sources. However, the target of renewable energy plan on solar, wind, geothermic and biomass is to replace the fossil fuel of which 70% of renewable energy will be included in Algeria energy mix in 2030 [10]. Major dependence on the non-renewable sources of energy will bring about the risk of stranded assets, in addition to the already serious effects of price volatility for internationally traded commodities. Africa is blessed with abundance of non-renewable sources of energy but by contrast, renewable energy offers African economies prospects for growth in economy, cost effective technologies to expand energy access, qualitative and major industrial development along new value-chains, with significant, considerable local job creation potential increase. Africa is a vast continent enriched with water, land and raw materials for different energy sources and resources, fast growing population and is at the brink of a major breakthrough if these energy sources are explored and harnessed. Nanotechnology will have impact on all aspects of development. However, its greatest impact is likely to be on the Sustainable Development Goals of which energy comes at number seven (7) on the list with Egypt being the top nanotechnology research country in Africa and South Africa as the African country which has filed the most patents and has established the most nanotechnology companies and institutions [11]. Generally, Africa lags behind other continents of the world in terms of nanotechnology research, inventions, standards and number of established companies and institutes operating in the region. Only few African countries have devised strategies aimed at guiding the development of the technology. However, Africa is at a risk of becoming further marginalized in S&T development and its organization.

Applications of Nanotechnology in Renewable Energy Systems: A Practical Review

Nanotechnology has become an integral science applicable in different aspects of the energy sector with the aim of comparably amplifying the efficiency of energy systems and increasing prospects. However, successes have been recorded in the field of renewable energy incorporating nanotechnology. A brief review on some applications of nanotechnology in and their outcomes on different renewable energy systems is discussed as follows:

Tidal or Ocean Energy

Energy stored in massive volumes of moving water under high pressurescan be considered a huge source of renewable energy for two principal reasons. The first is the fact that about 70 percent of the earth's surface is covered by water and the second being that the world's potential for wave energy is about 10,000 to 15,000 terawatt hours per year [12].In the field of nanotechnology, salinity gradient has been explored and harnessed from the mixing of two solutions of different salt concentrations. A membrane based technology termed reverse electrodialysis (RED) can be used to generate electricity from the controlled mixing of two water bodies with different salinities. In the investigation of Jadav and Singh [13],a novel silica-polyamide nanocomposite membrane was synthesized with enhanced properties. A polyamide nanocomposite (n-composite) film of about 400-800nm thickness coated over porous polysulfone support via interfacial polymerization using two types of silica nanoparticles of sizes about 16nm and 3nm respectively were synthesized. The two types of silica used were a commercial colloidal silica and a prepared silica from controlled hydrolysis of tetraethyl-ortho-silicate (TEOS). The main objective of the study was to synthesize a better thermo-chemically stable polyamide membrane and at same time to achieve a membrane with improved performance in terms of productivity (membrane flux) and selectivity (separation efficiency). The thermal stability of the synthesized membrane was examined using thermo-gravimetric analysis (TGA) and different scanning calorimetric (DSC) measurements, film thickness by attenuated total reflectance infrared (ATR-IR) and film surface morphology using scanning microscopy (SEM). It was observed that the nanoparticle silica loading significantly modified the polyamide network structure and subsequently pore structure and transport properties. It was also noticed that the pore size was tuneable with a radius varying from 0.34 to 0.73nm – depending on silica content unlike the fixed pore radius of about 0.34nm of neat polyamide and with further increase in silica content, the numbers of pores present in the membrane increased and were more thermally stable in comparison with only organic polyamide membrane. However, an excellent membrane performance in terms of separation efficiency and productivity flux with nanocomposite membranes containing between 1 to 2% by weight of silica was achieved. In addition, Klaysom et al.[14] proved that porosity and pore sizes play important roles as effective channels for passage of ionic species which in turn affects the properties of the ion-exchange membranes especially its permeability and transport phenomena. Klaysom et al.[14], recommended that control over the pore sizes and distribution in the membranes will further improve its ion-exchange capacity, conductivity and transport phenomena – of which nanotechnology offers such prospect. Concerning membrane performance, Serrano et al. [15] noted that the use of nanoscale hydrophilic inorganic materials in electrolytes inorganic lithium salts to improve hydrogen ion conductivity of the membrane at high temperatures (the inorganic materials present high affinity to water and the salts work in the right temperature range) as a function of nanotechnology.

Hydrogen Energy

Hydrogen energy has been explored for decades and found to be a potential substitute for many sources of energy and for a matter of fact is been seen as an ultimate solution to climate change [16, 17]. Due to high demand for cheaply sourced hydrogen, researchers have explored widely even as far as induction of water splitting by photocatalysis (a process in other words termed artificial photosynthesis). With the up rise of the hydrogen economy, the prospects looks promising [15]. However, research has shown that nanotechnology inculcation into solar energy systems have been instrumental to hydrogen production. The process is a clean, economical and eco-friendly means towards achieving "double" energy production from harnessing natural light. To achieve the process of artificial photosynthesis with solar systems a variety of semiconductors nanoparticulated catalyst systems based on Cadmium-Sulphur (CdS), Silicon-Carbon (SiC), Copper Indium diselenide ($CuInSe_2$), or Titanium dioxide (TiO_2 also known as Titania – being the most promising yet) can be utilized [18, 19, 20, 21]. Using nanoparticulate Titania as catalyst induces the production of water (H_2O) through hydrogen and oxygen recombination. However, the bandgap of Titania (reported to be approximately 3.2eV) gives allowance for only ultraviolet (UV) light in the process facilitation. Nonetheless, at current dispensation advancements in research shows prospects in achieving better results and also address the challenges related to the systems low conversion efficiency and consequent increase in associated cost.

Energy storage is very important to energy economy of which storing hydrogen is difficult and challenging due to its characteristic property i.e. having low volumetric energy density it can be easily lost into the atmosphere. Danilov et al. [22] investigating on hydrogen storage, carried out research using porous carbon nanofibres (CNF) (reported surface area: $1700 m^2/g$) synthesized and activated with potassium hydroxide (KOH). The synthesized nanofibres were able to store hydrogen efficiently, improved discharge property of the cathode and can be alternatively utilized to hybrid metals for hydrogen storage in batteries. Moreover, Kim and Park [23] modified highly porous carbon nanofibres with greater surface area ($2000 m^2/g$) using nanoparticulated nickel (Ni). This resulted in increased hydrogen storage capacity compared to previous research conducted by Danilov et al. [22]. One feature that makes energy sustainable is its storability. Serrano et al. [52] noted three important factors that affects storage of hydrogen (asmetal/alloy hydrides) in metal/alloy hybrids:

- Hydrogen storage capacity;
- Frequency at which reversible storage can be carried out; and
- Alteration of heat of hydrogen absorption and adsorption/desorption kinetics.

Metal/alloy microstructure is highly influenced by the aforementioned. However, nanointerfacial reaction pathways with faster rates are altered resulting from new surface conditions capable of chemical bonding activation [24]. These advantages of increasing surface area to bulk volume are offered by smaller particles. So, basically increasing nanostructural features of metal/alloy hydrides enhances their hydrogen storage efficiency and capacity. The investigation of Brown et al. [25] however demonstrated that a synergistic chemical combination of nitrogen and boron (NH_3BH_3)is an effective storage mechanism for hydrogen. 6-7nm widthwise channelled scaffolds were used to hold ammonia borane (NH_3BH_3) in the nanophase of mesoporous silica. It was noted that adding saturated solution of NH_3BH_3 enhanced hydrogen liberation kinetics at debased temperature after being embedded in a scaffold.

Depending on the type of electrolyte, operating principle and temperature range, hydrogen cells have been thus classified, viz.:Polymer Electrolyte Membrane Fuel Cell (PEMFC), Phosphoric Acid Fuel Cell (PAFC), Alkaline Fuel Cell (AFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cell (SOFC) [52]. However, PEMFC have traditionally attracted the attention of the automobile industry for zero carbon emission vehicles (such as tesla), and power generation industries for both home and electronic applications. In another investigation Wang et al. [26] synthesized carbon nanotubes-based electrodes for PEMFC fuel cells and discovered that multi-walled carbon nanotubes (MWCNT) can be used as catalyst support instead of carbon powder which however allows for the reduction of platinum(Pt);which can be used twice or thrice in comparison with the conventional PEMFC. Rajalakshmiet al. [27] compared both catalytic activity and membrane performance of Pt/nano-titania electrodes with traditional Pt/C electrodes. A higher performance and durability was observed for membrane electrode assemblies, while the electrodes showed higher thermal stability and higher catalytic activity. This agrees with the general knowledge of chemical reaction engineering that increased surface area of catalysts (increased active sites) promotes increase in surface activity and relatively stabilizes temperature of conductive materials.Theoretically, this can be demonstrated by the relation for heat of conduction as shown below:

$$Q = A\mu\Delta T$$

Whereμ is the heat transfer coefficient,$\Delta T$is the temperature difference,$Q$is the heat flow rate,$A$is the surface area for a regular electrode, and Q/A is the heat flux i.e. the flow rate of heat over a surface.

Considering a nanoparticulated electrode with a surface areaA_n. With the given improvement in characteristic surface area$A_n \gg A$. Hence, for two electrodes with different surface areas A_n and A given the same QandΔT, $Q/A \gg Q/A_n$ and consequently $\mu \gg \mu_n$. The heat transfer coefficient is a quantitative characteristic of convective heat transferred between a fluid medium (the electrolyte) and the wall surface (the electrodes) the fluid flows over. The heat flux is higher for regular electrodes than for nanoparticulated electrodes (made of same material)indicating that heat build-up is reduced by increased surface area of interaction.

One approach tomitigating the high cost associated with electrodes is achieved through the reduction of the quantity of platinum (Pt) catalyst used [28]. A key property of catalysts is their bonding energy. They possess an affinitive power somewhere between high and low bonding energy and so they can form weak van der Waal's forces with species in catalysed reactionsby not holding on too tightly or too loosely to chemical species.This makes the bonds easily dissociable.

The microstructural alteration through nanotechnology has the potential of increasing platinum reactivity through increased surface sites. Membrane based electrolysis is advantageous over other methods of hydrogen production for its zero carbon emissions, however using polymer electrolyte membrane (PEM) systems implies incurring high cost in sourcing catalyst and averagely durable membranes [29]. Shao et al. [30] in his review on “Novel Catalyst Support Materials for PEMFCs: Current Status and Future Prospects”, pointed out the most promising candidates for catalyst support in electrolytic cells. Electrolyte conductivity can be apprized by a factor of six when nanoparticles of aluminium oxide (Al_2O_3), zirconium ferro silicon (ZrSiFe) alloy are introduced into non-aqueous liquid electrolytes.Chien and Jeng [31] developed a family of nanocatalysts based on three-dimensional Pt and Pt-Ru nanostructures with interconnected holes. Nanocatalysts have been synthesized by growing metal networks in the voids of layers formed by self-assembly of polymer nanosphereswith improved performance of membrane fuel cells by incorporating Titania and tin oxide (SnO_2) into ordinary membranes [31, 32].In electrolytes, nanoscaled hydrophilic inorganic substances are used to increase the hydrogen ion conductivity of membranes [33]. Although Pt and Pt-Ru have been tested as anode and cathode of DMFC respectively, according to Serrano et al. [15], they have potential application on membrane fuel cells in general (i.e. both DMFC and PEMFC).

Predominantly, efforts have been geared towards and focused on improvement of solid state electrolytes(solid polymer electrolytes (SPE), polyethylene oxide-based (PEO-based)). However, SPE received most attention since PEO is safe, green and lead to flexible films. Nanocomposite polymer electrolytes could help in the fabrication of highly efficient, safe and green batteries since naturally polymers usually have low conductivity at room temperature and depending on their solid polymer electrolytes (SPE) compositions have low interfacial activity and mechanical stability. In addition, energy savings are provided by nanomaterials with high insulation ability with insulating materials produced with nanotechnology saving 30% more energy than traditional materials [34, 35, 36]. These insulation materials are used by squeezing between solid panels or as a thin film on any surface. The efficiency of fuel cells can be increased by using hydrogen sensors with nano membranes [37].

Using ceramic nanomaterials as separators in polymer electrolytes increases the electrical conductivity of these materials at room temperature from 10 to 100 times, compared with the corresponding undispersed SPE systems(Titanium dioxide (TiO_2), Aluminium oxide (Al_2O_3), Silicon oxide (SiO_2) and Sulphate-promoted superacid zirconia (S-ZrO_2)) used for this purpose, however revealing that the introduction of S-ZrO_2 led to the best performance [38].Also, nanoscaled metal alloys have been used to increase the life cycle of nanocomposites through bulk volume diminutionin alloy formation [39, 40, 41, 42]. Moreover, various catalyst supports, including carbon-based nanotubes, nanodiamonds, conductive-based oxides and carbon-based nanofibres are employed to accomplish the objective of hydrogen production [43]. Hydrogen is difficult to store, however, the inclusion of nanotechnology has made the process of storing hydrogen via enhanced physisorption [44] and chemisorption [45] mechanisms possible.

Geothermal Energy

The Earths’ crust is a reservoir of energy called geothermal energy – one of the most suitable and attractive sources of renewable energy that can be used continuously in generating heat energy, can be sourced atdepthsranging between 5 and 10 km [46, 47]. Geothermal energy is an attractive choice for future power generation due to its low carbon emission and consequential costcompared with other renewable energy sources [47] – the prospects are large.In fact, studies shows that more than 72 countries are reported to havedirect use of geothermal energy withIceland currently being the world leader with about 93% of its homes being heated geothermally, consequentiallysaving over 100 millionUSD annually in avoided oil imports and is now considered one of the cleanest countries around the world due to geothermal energy applications [48, 49]. However, experimental use of nanofluids can help augment geothermal systems [50, 51, 52]. The enhancement is dependent on several factors including the type of nanofluid, concentration and system specification. Heat transfer enhancement by employing nanofluids is mainly attributed to its higher thermal conductivity in comparison with conventional fluids [53, 54, 55].

Diglio et al. [56] investigated on the effect of using nanoparticulated fluid as heat carrier instead of conventional fluid, mixture of water and ethylene glycol, on a borehole heat exchanger. In the study, nanoparticulated graphite (C), silver (Ag), copper (CuO), copper oxide (CuO),alumina (Al_2O_3),aluminium (Al) and silica (SiO_2)were used at controlledvolumetric concentrations (ranging between 0.1 to 1%)in heat carrier fluid. It was observed that applying nanofluids resulted in noticeable reduction of borehole thermal resistance and increased thermal gradient across all nanoparticulated fluids. Since the type of nano structures influences on the thermophysical specifications [57], the results were dependent on the kind of nanofluids as shown in Figure 2.

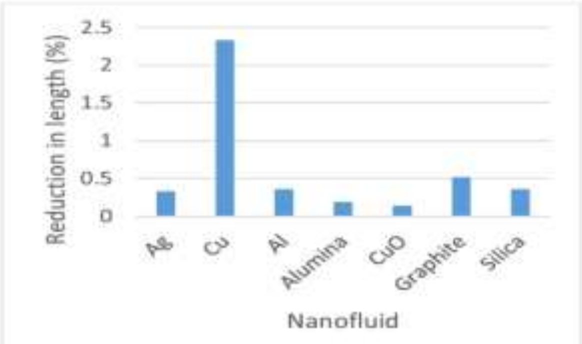

Figure 2. Borehole length reduction for various nanofluids in 1% concentration.
(Image: [56])

By considering both heat transfer and pressure drop, it was concluded that using Cu-based nanofluids led to the most reduction in the length of borehole heat exchanger implying an appreciable decrease in thermal resistance. In addition, it was observed that using Ag-based nanofluids resulted in the highest convective heat transfer and pressure drop. Although, small pressure differentia will enable laminar flow as opposed to large pressure differentia which reduces heat transfer efficiency, making Cu-based nanofluids a better option for its notable efficiency and inexpensiveness compared to Ag-based nanofluids.

Noteworthy, the amount of heat extracted from the earth by geothermal systems is a factor of the well specification, characteristics of working fluid such as its flow rate, density, thermal conductivity, etc.Al_2O_3/water nanofluid was used as a working fluid in a study conducted by Sui et al. [58] – where the thermo-physical properties (i.e. thermal conductivity, dynamic viscosity and specific heat) of the nanofluid were calculated on the basis of proposed models. Resultant effect of mass flow rate was first studied and it showed that increasing the flow rate of returning fluids led to lowering of their temperature. Lowering the mass flow rate produced insignificant effect in heat produced, however, increased mass flow rate made heat extraction sensible. Complementing the working fluid with the nanoparticulates increased temperature of returning fluid. For instance, in the case of 15 kg/m^3, the extracted heat by using water and nanofluid were 3050 kW and 3393 kW, respectively. It is safe to say nanofluids in heat exchangers of geothermal systems can be instrumental to improvement in their efficiency, however there are concerns about their use. Overtime, the sedimentation of nanoparticulates could result in deterioration of heat transfer efficiency and deter geothermal systems performance. Suggestions, have been made on how these challenges could be overcome.

Sun et al. [59] using static fluid in shut-down condition discovered that after many hours of accumulation and sedimentation NPs seemed to be extant close to boreholes bottom. Numerical simulation carried to evaluate the phenomenon showed that the velocity of fluid when relatively adjusted is capable of removing accumulated sediments and increase performance of geothermal systems. However, this issue was addressed in the work of Deneshipour et al. [60] using nanoparticulated Al_2O_3/H_2O and Cu/H_2O as circuit fluids for geothermal borehole heat exchangers. Numerical simulation was carried out applying Reynolds Averaged Navier-Stokes in analysing the effect of various factors. An extension of Menter's [1992-1993] k-ω (shear stress transport (SST) k-ω) turbulence model was employed with the volumetric concentration varied between 0 and 6% in research analysis to evaluate the impact of concentration variation. Results of the study revealed that by using CuO/water nanofluid, higher heat extraction was achievable compared with Al_2O_3/water nanofluid; the pressure loss was higher in the case of using CuO/water nanofluid. Moreover, the results indicated higher local convective heat transfer coefficient when concentration of the nanofluids was increased. Jamshidi et al. [61] numerically investigated the performance of geothermal heat exchanger and the effects of utilizing nanofluids in extracted heat. In their study, Al_2O_3 nanoparticulates were employed in volumetric concentrations between 0 and 0.5%. Data analysis and results showed that increasing the concentration of nanoparticulates improved heat flux$\left({}^{Q}/_{A}\right)$ – in a finned conical helical type heat exchanger. Conclusively, using NPs with lower dimensions improved Brownian motion and consequently, improves the heat transfer rate. Employing the nanoparticulates in 0.5% of volumetric concentration could lead to approximately 18% increase in obtained energy from the earth [61]. It is not farfetched to infer collectively that the use of nanoparticulated fluid in geothermal heat exchangers increases heat transfer rate compared to contemporary fluids and moreover effects became more significant at higher flow rates. Using nanofluids can reduce the size of heat exchangers used in geothermal-based system while increasing efficiency. The main effects of employing nanofluids is increase in convective heat transfer and decrease in pressure loss.

Biomass Energy

Bioenergy/Biomass energy is energy derived from chemical interaction of matter of organic origin such as algae, plants, etc.[62]. Vegetable oil, biofuels such as biodiesel, biogas (refer to [63, 64]) are all sourced from biomass. The abundance of biomass in the natural world coupled with their characteristic eco-friendly, carbon-free and inexpensive nature [65], makes them alternatively advantageous replacements for fossil fuels. However, nanoparticles have played a significant role in the conversion of bio-renewables to high value-added chemicals and fuels [66].By trans-esterification – a simple procedure that converts fats and oil into their corresponding esters, biodiesel is produced. Three types of catalysts are used in the trans-esterification reaction: homogeneous catalysts, heterogeneous catalysts, and biocatalysts [67], of which generally no sulphur, polycyclic aromatic hydrocarbons (PAH), or crude oil residues were reported as products. For a fact that biodiesel can be used in the operation of standard diesel engines, the cost of conventional diesel is lower than the cost of biodiesel produced from superior, refined edible oils, the actual cost of the oil is approximately four times than the stated value because feedstock costs account for around 75–80% of the operational costs of producing biodiesel [67] – an economic limitation to the use of biodiesel. The process of trans-esterification is a biochemical catalytic process. Numerous catalysts have been used by researchers in the advancement of biodiesel, such as nanocatalysts, homogeneous/heterogeneous catalytic acids, and basic uniform/heterogeneous catalyst biocatalysts [68]. The aim is to produce cheap and efficient means of biodiesel production considering the high cost implication in catalysts procurement. However, trans-esterification process using heterogeneous base catalysts has been observed to be economical in mild conditions due to its reusability, widespread availability, easier separation from the product, and longer lifespan [69, 70]. Base-catalyzed trans-esterification is more widely used in industrial output than acid-catalyzed trans-esterification due to the high yield of fatty acid methyl esters in a short reaction time [71]. Srinivasa Rao and Anand [72] showed that the presence of water and nanoparticulates (NPs) significantly affects the performance of biodiesel in compression ignition (CI) engines. They found that untreated biodiesel had lower brake thermal efficiency (BTE) and greater emission levels than 100% diesel fuel. The addition of water and NPs significantly improved the effectiveness and release quality of the test engine.

Xie and Ma [73] observed that the conversion efficiency of olive oil to biodiesel was around 94.8% after processingfor8hours at150◦Cusing Zinc oxide (ZnO) nanorodcatalysts. Inaddition, Bidir et al. [74] found that the inclusion of NPs to diesel-biodiesel ethanol mixtures significantly increased their BTE while decreasing their brake specific fuel consumption (BSFC) and consequentially increasing fuel conversion efficiency, lowering considerably the concentrations of harmful emissions such as hydrocarbon (HC), carbon monoxide (CO), and particulate matter(PM)from exhausts. However, nitrogen oxides (NO_x) emissions could rise by up to 55% considering they're of biological origin. Nevertheless, the use of NPs in diesel-biodiesel-ethanol or biodiesel-diesel blends in theoperationofcompression ignition (CI)engineswould permit engines' efficient and improved performance and effective emissions regulations.

Bidir et al. [74] investigating on the use of nanoparticles (NPs) in the biofuel industry presented the use of NPs as a means towards tackling the high cost implication of biofuel production; a useful tool in intelligent and process-efficient strategies development for the synthesis of biofuels and their products by reducing the amount of solvents and catalysts used in biofuel production. Their outstanding physiochemical characteristics makes them preferable alternatives in important applications especially catalysed processes such as production of biofuels. Nanoparticulates of titanium dioxide (TiO_2), zinc oxide (ZnO), and tin oxide (SnO_2), because of their unique properties(such as large surface area to volume fraction, smallscale immobilizing characteristics, quantum and magnetic characteristics etc.), are widely used in the production of biofuels [75, 76].Although, the use of nanoparticulated biofuels as an energy source is very advantageous over contemporary biofuels, it is however noteworthy that global biofuel production reached 127.7 billion litres in 2014 and supplied approximately 4% of the total fuel used for global transportation in 2016 which accounted for approximately 23% of global CO_2 emissions [67].

Biofuels generally account for less than 1% of global energy consumption and support approximately 3% of the transportation sector [77]. All these are setbacks that can be fixed by adding nanoparticles to fuels. The use of NPs in biofuel production enhances chemical reaction stability thereby increasing engine performance, reducing harmful exhaust discharge and cost of operation.

New catalysts are also needed for converting coal or biomass into diesel and other transportation fuels. Radhakrishnan et al. [78] found that NPs should be added before starting the trans-esterification process after using alumina NPs in the combustion process of cashew nutshell biodiesel in an unmodified diesel engine. The emissions of CO, HC, NOx, and released smoke for BD100% (biodiesel without the addition of alumina NPs) and for B100-A (biodiesel with the addition of alumina NPs) were reduced in comparison to conventional diesel fuel.

Another biofuel of commercial importance is bioethanol. Weber et al. [79] suggested Sweet potato (Ipomoea batatas) as a potential raw resource for bioethanol production. It yields more starch per unit area of land than other grains. The total sugar and moisture content in potatoes (cream peel and cream pulp) has been reported to be 26.93 ± 0.86% and 68.16 ± 0.38%, respectively. While higher distilled beverage production rates would be the most profitable, higher ethanol production scenarios are considered to be economically unfeasible based on research on the following scenarios: 80% bioethanol production, 60% bioethanol, and 20% distilled beverage production [79]. Utilizing NPs in the production process of bioethanol could enhance the efficiency of the entire system by improving handling capacity, enzymatic hydrolysis, and degree of reaction during fermentation. The reusability of catalysts is an essential concern in the ethanol production process as it directly impacts production costs [80]. Kim et al. [81] found that the use of methyl-functionalized silica NPs during the syngas fermentation process produces 166.1% bioethanol. Kimetal.[80] resulted that the use of methyl functionalized silica NPs increased the dissolved concentrations of H_2, CO_2, and CO by 156.1%, 200.2%, and 272.9%, respectively.

Fuel Cell (FC) technology has been widely recognized as a sustainable clean energy source judging from its extensive lifespan and environmental friendliness [82]. Hydrogen FCs can be used in a multitude of applications, such as in industry, transportation, electricity generation, heat generation, and so on [83]; which however, from other non-renewable alternative sources traditionallycontribute around two-thirds of the global CO_2 emissions [84]. Other advantages of using fuel cells come from characteristics such as their small size (in comparison with other energy conversion devices), the low noise levels of the process, their low environmental impact,in addition to their environmental emissions friendliness [85]. Rezk et al. [86] reported proton exchange membrane fuel cells (PEMFCs) as the most common, commercially available FC that can operate under various loads, ranging from a few hundred to several thousand kilowatts; making PEMFC technology the most advanced FC system on the market [87]. The price of the device itself and the fuel cell infrastructure necessary to operate it are significant. However,Lee et al. [88] found that the most significant obstacles to the adoption of FCs were institutional and political considerations. In addition to this, Dhimish et al. [89] noted that hydrogen PEMFCs also faced significant functionality and degradation challenges. However, PEMFCs can be replaced by biofuel cells (BFCs – traditional FC devices that use the metabolic reactions of microorganisms as they degrade organic contaminants in chemical energy transformationin organic matter into electricity). BFCs utilize catalysts at two oppositely charged electrodes to detach hydrogen atoms from their electrons before combining the remaining hydrogen ions with oxygen for water formation at the cathodic end after which free electrons are siphoned off for work performance [90]. In addition, enzymatic biofuel cells (EBFCs) are a type of FC in which enzymes act as catalysts [91].At mild operating conditions (e.g., pH 5–8 and 25–37 ◦C), BFCs are known to be advantageous. Outside conditions that promote biological enzymatic functionalities, according to Wang et al. [92] the development of implantable BFCs suffers from their limited power output, short lifespan, low efficiency, and so on, owing to drawbacks prenominal to serious enzyme leakage from electrode, low electron transfer efficiency between active centres of enzyme and electrode, low catalyst load, utilization of inappropriate catalysts, adverse effect of complex in vivo environment towards enzyme catalyst. Yahiro was the first to propose the concept of EBFCs in 1964 [88]. A key component of EBFCs is the collection of electrons produced by the bio-electro-catalytic reaction between the redox enzymes and the substrates on thesurface of the electrode [93]. Many characteristics of nanomaterials such as their considerable surface area, high catalytic activity, durability, efficient storage capacity, and high adsorption capacity can improve stability, performance, and efficiency of BFCs. The use of nanomaterials within BFCs can enhance their efficiency and facilitate the direct transmission of electrons from the enzymes to the electrodes, improving the power output of BFCs [84]. Katz et al [94] in order to tackle the challenge of poor electron transfer efficiencies of EBFCs in the development of self-powered enzyme-based biosensors, introduced CNTs in facilitating direct transfer of electrons between electrode and enzyme. The use of CNTs were instrumental to enzyme-electrode fastening via covalent bond formation, hence displacing the challenges of enzyme leakage. The EBFCs (Anodes: CNT/PQQ-glucose dehydrogenase (GDH), and Cathodes: CNT/laccase) produced an open-circuit voltage as high as approximately 0.53V in snail. As a result of outstanding conductivity of CNTs coupled with the superiority of selected enzyme activity. Katz et al. [94] reported that the use of CNTs as co-electrode material clearly contributes to electron acceleration in electron transfer has efficiently boost the practice of EBFCs implantation, however, Ryu et al. [98] reported the construction of a glucose biofuel cell using CNTs with Pt nano-islands. The study was conducted with the aim of achieving a total glucose oxidation using a constant amount of Pt. Morphology of the catalyst wasmodified and examined for the effect of catalyst morphology on glucose oxidation utilizing intense pulse light (IPL) and cyclic voltammetry respectively. The results showed an improvement of glucose oxidation with IPL irradiation on Pt-CNT electrode in comparison to unmodified Pt-CNT electrode. Corresponding to decrease in electrode bulk volume, it was observed that comparatively the power densities of biofuel cells containing the modified Pt–CNT electrode became 4.3 times higher than that of unmodified electrode.Power density increase results in large energy outputs based on mass. However, small capacitors can have the same power output as large batteries, but as a result of their smaller sizes are capable of being recharged faster. Where size, energy output and faster reversibility of cell reactions are of utmost importance nanotechnology is ideal for fuel cells systems.

Palaniappan [95] found that common nanomaterials can be used as catalytic agents to increase the rate of anaerobic reactions, enhancing the yield of the cell process by reducing the effect of the inhibitory compounds, improving selectivity and electron transport. Ruthenium (Ru) NPs have been effectively used as catalysts in the conversion of sugars. Based on this finding, Zhao et al. [96, 97] developed Ru-catalyst supported on carbon nanofibres (CNF) for the hydrogenolysis of sorbitol to ethylene glycol and propylene glycol. The wet impregnation, calcination and reduction methods were employed to prepare the Ru/CNF catalyst. The investigations were performed to assess the effect of calcination on catalyst properties. Calcination of the designed Ru/CNF catalyst were conducted at 180, 240, and 300°C for 5hours, leading to catalysts designated Ru/CNF, Ru/CNF-180°C, Ru/CNF-240°C, and Ru/CNF-300°C respectively. Results showed transmission electron microscope (TEM) images depicting 1.0 nm for designedcatalysts of Ru/CNF, Ru/CNF-180°C and Ru/CNF-240°C particles, while Ru/CNF-300°C gave a particle size of 10 nm. Treatment of the catalyst by calcination resulted in a decrease in sorbitol conversion but an increase in glycol selectivity in comparison to previous studies [98, 99].

Miu et al. [100] investigated the potential application of metallic-semiconductor (Pt-SiO_2) nanosystem as a proton exchange membrane/electro-catalyst assembled in miniaturized micro fuel cells. In this work, SiO_2 NPs and a nanostructured silicon layer were studied as two different catalyst substrates, and it was shown that the structure of the support can cause different crystalline structures to form and alter the size of the Pt NPs during the deposition process. It was shown that porous silicon nanostructures have advantages over SiO_2 NPs; advantages such as permitting the growth of Pt inside the nanostructured layer as well as on the surface of the substrate.

Similar to the findings of Katzet al. [94], Osman et al. [101] also in their study confirmed that incorporating nanomaterials within the structure of bioelectrode can solve the problem of low electron transfer efficiency between the active enzymes and the surface of the electrode – a limiting factor in the use of EBFCs. Several different nanomaterials are used in the present day, such as metallic NPs, inorganic nanomaterials, and carbon-based nanomaterials (CBNs); of wide range of CBNs can be used in BFCs and have been shown to significantly improve their performance [84]. Mishra et al. [84] noted that the use of metallic NPs dramatically increased the cost of BFCs but also significantly enhanced their power density. However, Xiao [102] showed that future efforts could be directed toward resolving the EBFC’s limited power density and lifetime by inculcating nanotechnology. Al-Bawwat et al. [67] in his work on “Availability of Biomass and Potential of Nanotechnologies for Bioenergy Production in Jordan” concluded in their findings that through Nanotechnology:

- Overall performance in biofuel production can be boosted in range of (82.3–98.0%);
- In fulfillingthenextenergyrequirements,NPsarepotentiallysignificantin improving the quality and quantity of biofuel production in the range of (11.0–166.1%); and
- NPshaveenhancedtheemissions,efficiency,andcombustioncharacteristics of internal combustion (IC) engines; BSFC (0.20–1.08 kg/kWh) and BTE (24.5–40%), CO (0.02–0.44% by volume), NO_x (257.37–1600 ppm), hydrocarbon (12–102 ppm), and smoke opacity (0.706–52%).

Finally, it is noteworthy that enzyme immobilization can be considered as the key factorfor bioenergy production. However,nanotechnology has been supportive to this feat because of the large surface-area-to-volume ratio of NPs providing more active sites for enzyme activities[103].

Solar Energy

Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation.In this 21st century solar energy hasbecome increasingly attractive as a source of renewable energy because of its inexhaustible supply and its non-polluting character, in stark contrast to the finite fossil fuels (coal, petroleum and natural gas) [104]. The total amount of solar energy incident on Earth’s surface is vastly in excess of the world’s current and anticipated energy requirements [104]. Sunlight is by far the largest energy source received by the Earth. However, its intensity at the surface of the Earth is quite low because of the enormous radial spreading of radiation from the distant Sun. About 200,000 times of the world’s net daily electric-generating capacity is received by Earth daily in the form of solar energy. The sunlight that reaches the ground consists of nearly 50% visible light, 45%infrared radiation, and smaller amounts of ultraviolet and other forms of electromagnetic radiation. The potential of solar energy systems are enormous. Although, solar energy is free, however challenges as a result of the high cost of sunlight collection and concentration, conversion and storage, unfortunately limits its exploitation in diverse regions.Inexpensive solar cells, which would utilize nanotechnology, would help tackle to a large extent some of these challenges whilepreserving the environment [105].PVtechnology has been categorized into three distinct generations, which mark step shifts in the materials and manufacturing techniques used to make the cells. They are viz.:

- ➢ The first generation of solar cells:
- Uses very high quality crystalline silicon;
- Expensive to manufacturing and;
- Have fairly low theoretical efficiency limit of ≈ 33%.
- ➢ Second generation solar PV cells:
- Uses thin film technologies in conjunction withselected semiconducting materials (SCMs);
- SCMs such as cadmium telluride (CdTe) and copper indium gallium selenide (CIGS);
- These SCMs can significantly reduce processing costs and promise much higher theoretical efficiencies than Si-based PV materials;
- ➢ Third generation solar PV:
- They represent a much broader group of technologies; all of which are emerging and still in the development phases.
- Technologies often considered part of this third generation comprise of quantum dots, nanostructured semiconductors, and amorphous silicon.

A variety of nano-based cells have been combined in the form of sheets or layers for the compact structure of solar cells. Their higher capacities inenergy restoration makes them recommendablefor home and industrial applications [106, 107]. As far as the application of nanotechnology in solar energy is concerned, it can be used to design and manufacture second generation thin film PV cells, nano-electrodes, nano-composites, nano-fluids, etc. However, nanomaterials will truly come into their own in the third generation of solar cell technologies, where novel technologies like nanowires, quantum dots and radial junctions will begin to push the upper limits of PV efficiency. A team of research engineers at the University of California, San Diego developed a new nanoparticle-based material for concentrating solar power plants designed to absorb and convert to heat more than 90% of the sunlight it captures [108]. The new material is able to withstand temperatures as high as and above 700^{o}C (1,292^{o}F), can survive harsh environmental conditions (such as atmospheric and humid) for many years outdoors. Its characteristic has the novel nanotechnology material which features a "multiscale" surface (capable of trapping and absorbing light – a feature that contributes to the material's high efficiency even at operating conditions of higher temperatures) created by using particles of many sizes ranging from 10nm to 10µm (Figure 3). The research team decided to use this material with one of the common types of Concentrating Solar Power (CSP) plant. This types of CSP systems uses more than 100,000 reflective mirrors to aim sunlight at a tower that has been spray painted with a light absorbing black paint material as shown in Figure 4 below:

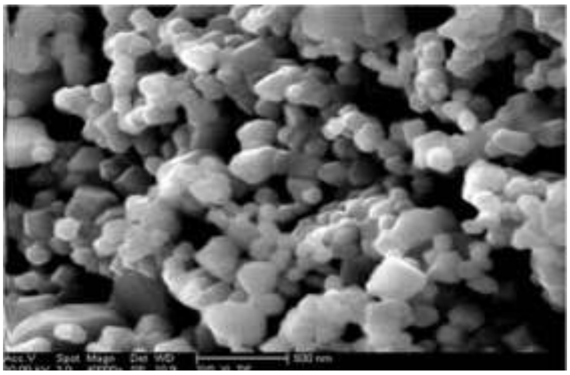

Figure 3: TEM image showing nanotechnology "multiscale" material surface with particulates sized (ranges of 10nm to 10µm), capable of trapping and absorbing light more efficiently even at higher operating temperatures (>700°C).
(Image: [108])

Figure 4: Nanoparticle-based material for more efficient concentration of solar power plants designed by a team of researchers from University of California, San Diego.
(Image: [108])

Another application of nanotechnology in solar energy enhancement is evident in the use of the semiconducting single-walled carbon nanotubes (SWNTs). SWNTs are potentially attractive materialswith many unique, electrical,micro and macro structural properties. Semiconducting SWNTs bear a wide range of direct bandgaps matching the solar spectrum, apparently exhibit strong photo-absorption and photo-response from ultraviolet to infrared, exhibits high carrier mobility with reduced carrier transport scattering. In addition, similar to semiconductor nanocrystals, SWNTs exhibit a strong coulomb interaction between electrons and holes, which suggests that SWNTs could also exhibit multiple exciton generation (MEG) – an effect that generates multiple bound charge-carrier in a dot after a single high-energy photon is absorbed; a phenomenon referable to as carrier multiplication.

Otanicar et al. [109] reported an experimental result on solar collectors based on nanofluids made from a variety of nanoparticles inclusive of carbon nanotubes and nanoparticulated graphite and silver. They demonstrated an efficiency improvement of about 5% in heat concentration in solar thermal collectors by utilizing nanofluids as an absorption mechanism. Yuhas and Yang [110] presented a novel solar cell design that combined the ideal geometry of a nanowire-based solar cell with the concept of using environmentally friendly, inexpensive and durable semiconducting PV components. Their solar cell consisted of vertically oriented n-type zinc oxide nanowires, surrounded by a film constructed from p-type cuprous oxide nanoparticles. The results showed that the use of a vertically aligned nanowire array eliminated the problem of exciton diffusion versus light absorption by allowing the light to be absorbed in the vertical direction while allowing exciton extraction in the orthogonal direction.

Liuet al. [111] highlighted some of the most exciting advances related with the preparation and characterization of nanomaterials for sustainable energy production. They mentioned that titanium dioxide (TiO_2) was still the most investigated material for solar cell and solar fuel applications. But, currently TiO_2-based cells were very inefficient with incident photon-to-current efficiencies of (10%) or less (at the band gap energy) and peak energyconversion efficiencies of (0.6%) or less over the whole solar spectrum. In their overview, they reported that the visible light photocurrent could be enhanced by coating TiO_2 nanowires with gold or silver nanoparticles. The enhancement was achieved due to optical scattering from the plasmonic nanoparticles, which increased the effective optical path of the thin film. Sethi et al. [112] explained that using nano-structured layers in thin film solar cells offered three important advantages. First, due to multiple reflections, the effective optical path for absorption was much larger than the actual film thickness. Second, light generated electrons and holes need to travel over a much shorter path and thus recombination losses were greatly reduced. As a result, the absorber layer thickness in nano-structured solar cells could be as thin as (150 nm) instead of several micrometers in the traditional thin film solar cells. Third, the energy band gap of various layers could be made to the desired design value by varying the size of nano particles. This allowed for more design flexibility in the absorber of solar cells. They concluded that solar cells efficiency could be improved by increasing the absorption efficiency of light as well as the overall radiation-to-electricity.

Mercatelli et al.[113] investigated the scattering and absorption properties of nanofluids consisting in aqueous suspensions of single wall carbon nanohorns. The characteristics of these nanofluids were evaluated in order to use them as direct sunlight absorber fluids in solar devices. The differences in optical properties induced by carbon nanoparticles compared to those of pure water led to a considerably higher sunlight absorption with respect to the pure base fluid. They concluded that the carbon nanohorns could be used efficiently for increasing the overall efficiency of the sunlight exploiting device. Nanotechnology advances leads the more valuable demand in energy production through semiconducting nanowires microscopic light sources for optical computing. These nanowires are much better over photovoltaic cells due to their shorter length considered one-dimensional structures as nanowires [114, 115, 116, 117]. The main reason for using nanoparticles appliances is the optical path for light absorption [118].

Mao and Chen [119] explained the role of nanotechnology in the development of selected renewable energy technologies. These technologies included:

- ➢ Converting the energy of sunlight directly into electricity using solar cells;
- ➢ Converting solar energy into hydrogen fuel by splitting water into its constituents;
- ➢ Storing hydrogen in solid-state forms and
- ➢ Utilizing hydrogen to generate electricity through the use of fuel cells.

The next generation of solar cells is thin film solar cells (i.e., flexible sheets of solar panels) that are easier to produce and install, use less material and are cheaper to manufacture. For example, these sheets can be incorporated into a briefcase that charges laptop, cell phone or can covered buildings windows to collect solar energy from the entire building rather than just its roof [12]. Scientists are currently implementing Carbon Nanotube (CNT) into the anode's structure – CNTs increase the capacity of solar cells by enhancing electron mobility as well as further enhancing the catalytic activity of immobilized enzymes [120]. However, perovskites and graphene (a really light nanomaterial many times stronger than steel), and various other research and industrial grade nanomaterials have been found to be able to augment the efficiency and life span of solar cells [121, 122].These will replace traditional graphite anodes and increase holding capacity of lithium ions.

Another approach is to boost efficiency by collecting wavelengths of solar energy currently wasted. The theoretical maximum efficiency of traditional single-crystal silicon solar cells is 31% for converting photons of sunlight into electrons (electric current). Current technologies are already close to that. But traditional cells don’t collect any of the sun’s long-wavelength infrared (heat) radiation or most of the short-wavelength ultraviolet radiation. Researchers are working on new nanostructures to use the entire solar spectrum from ultraviolet to visible to infrared. One class of solar cells that uses nanostructures is based on “multi-junction” layers that allow a solar cell to capture a different part of the spectrum in each layer, and a broader spectrum overall. Another is “quantum dots,” which can generate multiple electrons from a single photon, or even use energetic electrons from thermal gradients (local temperature differences). Experimental efficiencies of more than 40% have been reported with such nanostructures, and theoretical maximum efficiencies exceed 60% [123].

Inexpensive solar cells, which would utilize nanotechnology, would help preserve the environment. Coating existing roofing materials with plastic photovoltaic cells which are inexpensive enough to cover a home’s entire roof with solar cells, then enough energy could be captured to power almost the entire house. If many houses did this then the dependence on the electric grid (fossil fuels) would decrease and help to reduce pollution. Inexpensive solar cells would also help provide electricity for rural areas or third world countries. Since the electricity demand in these areas is not high, and the areas are so distantly spaced out, it is not practical to connect them to an electrical grid. However, this is an ideal situation for solar energy. Cheap solar cell could be used for lighting, hot water, medical devices, and even cooking. It would greatly improve the standard of living for millions, possibly even billions of people. Flexible, roller-processed solar cells have the potential to turn the sun's power into a clean, green, convenient source of energy even though the efficiency of Plastic photovoltaic solar cell is not very great, but covering cars with plastic photovoltaic solar cells or making solar cell windows can generate the power and save the fuels and also help to reduce the emission of carbon gases.

Natarajan and Sathish [124] investigated experimentally the role of nanofluids in solar water heater. Thermal conductivities had been measured by the transient hot-wire method. Conclusively, thermal conductivity enhancement depended on the volume fraction of the suspended particles and thermal conductivities of both particles and base fluids. The results proved that the nanofluids were effective than the conventional fluids and if were used as a heat transport medium, it increased the efficiency of the traditional solar water heater. Taylor et al. [125] performed a simplified analysis to explain how a nanofluid-based concentrating solar thermal system would compare to a conventional one. They concluded that, nanofluids had excellent potential for power tower solar thermal power plants. Efficiency improvement on the order of 5–10% was possible with a nanofluid receiver. They explained that, these enhancements could be realized with a very little change in terms of materials, system design, and initial capital investment to the entire solar thermal system.

Nanotechnology and Africa

Nanotechnology in Africa (how far?)

In recent years, the need for African governments to significantly and progressively develop renewable energy sector has become more and more evident as the environmental impact factor from dependence massively on fossil fuel is not only a national or continental but global affair. Amid the global climate crisis, Africa ranks amongst the continents with the lowest renewable energy accessibility, having high dependence on fossil fuels and facing the challenges of infrastructural development on a global scale [126, 127].The shift toward renewable energy is goaded by several essential factors. First, renewable energy is becoming more affordable; for example, the cost of unsubsidized solar PV levelized cost of electricity (LCOE) has decreased by about 90% (from $400/MWh to $41/MWh) for over a decade (between 2011 and 2022) on a global scale [128]. Secondly, rising demand for environment-friendly energy sources has been driven by calls for mitigation of CO_2 emissions through depletion of fossil fuels and its dependence. Thirdly, in Africa demand has been driven by the need for energy access with apparently around half the population of the sub-Saharan having no access to electricity while renewable sources accounts for nearly 18% of the electricity output in Africa as a whole [129, 130]. These three essential factors are closely relative to Africa at this level because of its technological and political developmental stage. In the total energy mix, fossil fuel accounts for an atomic share in many other developed regions. In Africa especially, this gap in energy accessibility drives the market for distributed solar generation installations and access expansion.The energy deficit remains large while significant renewable potential remains untapped.The big players in nanotechnology investments are the United States (US), Japan, the European Union (EU) and South Korea, along with China (recognizing Brazil, Russia and India as active players) – altogether they accounted for 72.2% of the nanotechnological patents in the United States Patent and Trademark Office (USPTO) in 2016 [131].Lateef et al. [132] revealed that Africa as a continent can enter knowledge-based economy by adopting nanotechnology,pointing out that Egypt, South Africa and Nigeria are making progress in nanotechnology research and applications. However, a lot is yet to be done for Africa to become a global player in it. The investigative analysis of Akpan et al. [133] using two scientometric indicators (i.e. number of patents and number of publications) showed that there were 1,775 publications over 23 African countries over a period of about 17years (from 1995 to 2011), approximately making up 0.628% of the world's publications in nanotechnology at the time. Further detailed analysis revealed that nanotechnology related research in Africa is concentrated mainly in six countries viz.: Egypt, South Africa, Tunisia, Algeria, Morocco, and Nigeria. Furthermore, reports by Lateef et al. [132] revealed that in a decade (between 2010 and mid 2020) extracted data showed that Algeria, Nigeria, Tunisia, South Africa, Egypt and Africa as a whole had 568, 645, 887, 2597, 5441, 10,832 respectively of the world's 414,526 total publications. As at 2014, Africa had produced approximately 0.061% (41 patents) of the world's nanotechnology related inventions, with 88% of Africa's inventive activities concentrated in South Africa and 12% in Egypt and Morocco [133]. Fast forward to 2017(from 2001), South Africa filed eighty-seven (87) and seven (7) in the United States Patent and Trademark Office (USPTO) and European Patent Office (EPO)respectively, and forty (40) patents filed by Egypt (all to the USPTO) [134]. Photovoltaic and Solar Cells (PVSC) represents one of the seven most published areas of nanotechnology in Africa with about 4% of the total publications from the period of 1995 to 2011 [133].These shows that Africa is not at the threshold in the research on nanotechnology and therefore not new to the technology with many universities in Africa inculcatingstudies and research on nanotechnology into their curriculums. Appreciably, Africa has taken advantage of the publications in nanotechnology development. However, in terms of patent contributions it is still down at the underdevelopment level.

Nonetheless, there is an ever growing push by African countries for delocalized production and industrialization. Calls to localize processes along the manufacturing value chain are increasing as events of recent past such as the COVID-19 pandemic have exposed the overreliance of African countries on global supply chains. Addition to solar energy,Africa as a continent is greatly blessed with renewable assets (such as biomass, hydroelectricity, wind power), high availability of raw materials and large reserves of inputs such as cobalt, copper, nickel, manganese, chromium, graphite, samarium, platinum, ruthenium, lithium and so on [135, 136, 137, 138, 139]; resources which are needed for the manufacture of low-carbon infrastructures (such as wind turbines, batteries, solar panels) and whichprovides an attractive option for companies looking to install renewables manufacturing facilities closer to resource supply chains.The African Union (AU) recognizes nanotechnology as a driving force that requires close attention, identifying it as one of six precedent areas in its Science, Technology and Innovation Strategy for Africa in 2024 [11].It is imperative that forAfrican countries pushing for vast and rapid economic growth theremay need to develop relationship with technologically advanced countries of which most economic researchers frequently proposed China as one of the major drivers of renewable energy development in the world. In fact,studies showed that trade between Africa and China valued at around $192Bn in 2019 and China is Africa’s leading individual trade partner, with about 14% of total trade [140].

Unfortunately, there are several headwinds to achieving this feat, such as: insufficient enabling policies in Africa discouraging investment;the complexity of Africa’s business environment; lack of legal frameworks and policies that promote renewable energy development; insufficient power and limited grid development in some countries; and so on – factors which have been noted to restrain the possibility of bringing Africa’s dream of economic breakthrough to reality. Fortunately, the bulk of these factors are man influenced and therefore flexible. Despite this, Africa’s contribution in nanotechnological advancement in all applicable aspects and particularly in energy sector is abysmally low in relation to both populace and economic size. However, the engagement of African researchers in the nanotechnological field shows that conscious efforts are being undertaken by institutions in pushing for development of the Nanotechnological field with: South Africa launching its National Nanotechnology Strategy with the aim of facilitating the establishment of characterization centres, creating research and innovation networks, strengthening, human capacity and launching flagship projects; Egypt establishing its nanotechnology centre in 2008 to support industrial research with the aim of strengthening national economy; Zimbabwe enacting a national Science, Technology and Innovation policy in 2012 with the aim of promoting the use of emerging technologies for national development of which nanotechnology is inclusive[11, 141, 142, 143, 144] and many more to mention but a few. In Nigeria, the journey so far (which was nationally initiated in 2006) has been really slow, marked by uncertainties, lack of proper coordination and poor findings [129]. Nonetheless, scientists have continued to place Nigeria on the map through research and publications. A noteworthy accomplishment is the country ranking fourth; behind Tunisia, South Africa and Egypt respectively, for research articles published on nanotechnology within a decade (from 2010 to 2020) [129].

Impact of Nanotechnology in Energy Production

Relative to energy, as world population rises so does its demand for powering homes and machines, running of businesses, industries and communities. In 2020, the United Kingdom on 10th June celebrated two months of running purely on renewable energy for the first time ever [145]. This goes a long way to show that the attainment of cleaner energy source is the new milestone set in the energy industry. However, nanotechnology provides a new means to achieving this feat. Africa’s demand for power is projected to surge over the coming decades, more than two times by 2030 and eight times by 2050 [145]. This growth will be driven primarily by industrialization as African countries push to electrify and grow their economies while decarbonizing in line with the global energy transition. Of all the renewable energy sources, in Africa solar energy is really the most accessible. Investment in energy-transition technologies creates three times as many jobs as fossil fuels per investment dollar, and up to 14 million energy transition jobs could be created in Africa by 2030 [2].

Otanicar and Golden [146] performed a comparative environmental and economic analysis of conventional and nanofluid solar hot water systems. They concluded that the nanofluid based solar collector had a slightly longer payback period, but at the end of its useful life had the same economic savings as a conventional solar collector. Also, the results showed that the nanofluid based solar collector had a lower embodied energy (about 9%) and approximately (3%) higher levels of pollution offsets than a conventional collector.This shows the advantageous application of nanotechnology in the mitigation of environmental emission.It is noteworthy, that some researchers [38, 147, 148, 149, 150, 151] have pointed out on the role of nanotechnology in achieving improvement of rechargeable lithium ion batteries. Generally, the achievements pointed out the roles nanotechnology plays in future battery applications and the consequences of its market adoption. By study, geothermal power plants can operate 24hours per day, providing base-load capacity, and the world potential capacity for geothermal power generation was estimated to be 85 gigawatts (GW) over the next 30 years [33]. But, geothermal power is accessible only in limited areas of the world, including the United States, Central America, East Africa (Kenya, Ethiopia, etc.), Iceland, Indonesia, and Philippines [12, 126]. However, the major challenge encountered in geothermal energy utilization is the requirement of deep borings which often causing tremors or earthquakes. Nanofluids can encapsulate or absorb substantially higher orders of energy compared to the normal thermal fluids. This observation opens up a range of future research prospects of using less deep borings to utilize geothermal energy as mentioned by Ganguly [152]. There is an increasing demand for energy and with the potential threat of exhausting non-renewable energy reserve in a couple of forecasted years, there is an increasing demand for renewable energy happening both on a utility scale; driven by the acceleration of large-scale investments in renewable technologies, and on the micro scale; driven by improved economics for distributed renewable energy. However, this demand has been highly amplified by aspiration of countries to shift from dependency on grid infrastructure in solving energy-access challenges. According to reports by the US Economist Intelligence Unit (EIU) on energy outlook in 2024, global energy consumption is expected to increase by 1.8% and largely driven by strong demand in Asia with still-high prices and unsolved supply chain disruptions, demand for fossil fuels reaching record levels, but with demand for renewable energy rising by 11% [153]. This report provides a comprehensive view of the challenges, opportunities and trends to watch out for in future. Nanotechnology forthrightly and indirectly offers numerous benefits (such as health improvement, environmental pollution reduction, etc.), addresses issues of energy accessibility thereby providing opportunities (such as new market and jobs creation, etc.) for the society and economy through enhancing energy efficiency.

Nanofluids are broadly utilized in various renewable energy systems such as PV/T, solar collectors and solar ponds [154, 155]. Nanoparticles for recombination layers (metal oxides): nanoparticles for recombination layers are already used today and expected to firm up their use in solar cells in 2015 [105]. Nanotechnology (“nano”) incorporation into the films shows special promise to both enhance efficiency of solar energy conservation & reduce the manufacturing cost. Although the nanotechnology is only capable of supplying low power devices with sufficient energy, its implications on society would still be tremendous. Its efficientfor increasing the absorption efficiency of light as well as the overall radiation-to-electricity which would help preserve the environment, decrease soldiers carrying loads, provide electricity for rural areas, and have a wide array of commercial applications due to its wireless capabilities,manufacturing of cars with plastic photovoltaic solar cells or making solar cell windows could be effective in generating its power and save the fuels while reducing the emission of carbon gases. Tan et al. [156] reviewed the applications and advantages of carbon nanotubes in energy conversion and storage such as in solar cells, fuel cells, hydrogen storage, lithium ion batteries, electrochemical super capacitors and in green nanocomposite design. They concluded that carbon nanotubes had the following advantages:

1) Integration of carbon nanotubes in solar and fuel cells had increased the energy conversion efficiency of these devices, which served as the future of renewable energy sources;
2) Carbon nanotubes doped with metal hydride showed high hydrogen storage capacity of around 6wt% as a potential hydrogen storage medium;
3) They showed high sensitivity toward the detection of environmental pollutants which were demonstrated by using carbon nanotubes based sensors; and
4) Carbon nanotubes could be utilized as a reinforcement material in green nanocomposites, which was advantageous in supplying the desired properties.

In addition, commercial composite materials incorporating nano-clays form the cargo beds of some sport-utility vehicles for added durability and stability. Other nanomaterials being developed include carbon nanotubes for aircraft bodies and turbine blades, graphitic nano-platelets to stiffen plastics, and lightweight carbon nanotubes as electrical conductors to replace heavy copper wiring in aircraft and satellites. One of the most promising ways to reduce overall energy use is to recover waste heat from applications such as industrial processes, car engines, and electronics, and to put this energy to use.Thermoelectric devices, which convert heat gradients directly into electricity, are ideal candidates, but so far their performance has been insufficient for large-scale use. Breakthroughs in nanotechnology may yield a solution. For example, nanowires made of silicon have a conversion efficiency that is 60 times greater than bulk silicon [123]. Making nanostructured thermoelectric devices out of silicon, which is abundant, cheap, and easily handled, could help create a new market for a wide range of devices that recover waste heat.

The power obtained from the sea waves can be used in water desalinization, hydrogen production, ocean mining, liquid and solid state synthesized fuels and ice production [153]. Very recently, Qu et al. [157] explained in their review that nanotechnology offered opportunities to develop next-generation water supply systems. They explained that nano-materials had many extraordinary properties such as high surface area, photosensitivity, catalytic and antimicrobial activity, electrochemical, optical, and magnetic properties which provided useful features for many applications such as sensors for water quality monitoring, specialty adsorbents, solar disinfection/decontamination, and high performance membranes. They concluded that the development of nanotechnology must go in parallel with environmental health and safety research to develop sustainable water management.

II. DISCUSSIONS,CONCLUSIONS AND RECOMMENDATIONS

The concept of nanoscience is fundamental on studies of matter, its components, characteristics and behavior on the atomic level. Research has shown that there is tendency of increasing the durability, strength, reactivity, conductivity, reduce the weight and increase the efficiency of systems when they are made to operate on the nanoscale level. In fact, nanoscience is an enabler and enhancer of other technologies and products; has powerfully driven most sectors including energy, information, health, security and defense, transport, etc., and many more. The question now stands at how nanotechnology can be practically and optimally used to address these challenges faced; in the world and Africa especially.

With the inclusion of nanotechnology the potential of addressing some of the world's biggest challenges such as the development of: faster, smaller and more portal electronic devices with larger memories; highly efficient, and cost effective filter production for air and water purification; medical devices and drug modeling and modulation with fewer to no side effects; stronger, highly resistant, lighter and long-lasting materials such as in the construction industries; sensors with highly efficient detectors of chemical and biological hazardous components in the environment, etc. – all without compromising on performance or safety. Nonetheless, nanotechnology has also achieved a whole lot in all facets of renewable energy not mentioned such as wind energy enhancement (by inculcating nanotechnology into their material design). The few talked about are prominent and most widely researched about.

There are clear intensions to develop renewable energy sources with tangible goals set at decarbonizing the environment through shift from fossil fuel dependence by inculcation of nanotechnology. Therefore, there is need for nanotoxicological research (research into the toxicity of nanomaterials (nanotoxicity)) as a result of their nature, size, persistence and accumulation in the environment they could be lethal (at some levels/concentrations) to living organisms. This will help to curb possible challenges and reduce environmental threats that are likely to spring up at a future time. There are many approaches to meeting the world's energy demands; by harnessing new energy sources and conserving the energy supplies already available. However, this review addresses its recommendations to Africa – which although blessed with all necessary resources for nanotechnological advancements, is yet very well aback in the world ranking of key players.

Firstly, nanotechnology is not the whole answer, but presents to a great degree a solution to national and the world rapidly growing energy needs. For example, the initiative of desert power launched in 2021 by African Development Bank (AfDB) should increase the existing capacity of African nations of the Sahel Regionif well systemically implemented.

Secondly, recognizing the promising nature of nanotechnology in its capacity for national development, countries with the capability for research and development have setup nanotechnological initiatives to spearhead research, development and innovation. These advanced nationalities have been able to capitalize on the advantages of nanotechnology in national improvement and even gone as far as inculcating nanotechnology into school curriculums – a step Africa should be willing to imitate.

Thirdly, the absence of national policies on nanotechnology and of dedicated funds also hinders research.Moreover, nanotechnology has the potential to leapfrog the African economy from its present state, by transforming the energy sector with its radically distinctive characteristics and applications.The government is therefore ladened with the task of not only investing faithfully into the development of nanoscience but also creating and implementing policies, organize, encourage and support research programs that will aid the growth of nanotech and tackle possible risks in order to mitigate the possibility of further environmental destruction. However, in order to make effective policies, policy makers must be experts in the field of nanotechnology. The collaborative efforts between scientists, policymakers, and ethicists are essential to ensure responsible development and deployment of nanotechnology.The innovative results of research can potentially make energy production safer, more sustainable, efficient, and cost-effective, offering exciting possibilities for commercialization in nearest future. Concomitantly, these addresses every aspect of research including technological, socio-economic and organizational aspects.

Lastly, energy systems can be optimized in dual mechanism systems by including greenhouse emission mitigation or converters in their engineering designs. With such dual purpose systemized mechanisms, cleaner energy generation is assured. For example, in water splitting technology, on a large scale these systems can be very advantageous.

In other to effectively confront the challenges arising from energy accessibility in Africa, technical and administrative efforts must shake hands; whensynergistically, properly and systematically planned and applied, they can serve as a very effective tool towards transcending the hurdles of energy challenges in Africa and other parts of the world according to resources availability and technique.

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